APPENDIX C

Ecosystem Considerations for 2004

Reviewed by
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of the Bering Sea, Aleutian Islands, and Gulf of Alaska

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INDICATOR SUMMARY

The following table (Table 1) is a summary of most of the indicators contained in this document. Eventually, the document will contain a more complete set of indicators. Bycatch information needs to be updated and broken down by region (EBS, AI, GOA). Also, lower trophic level status and trend information is presently lacking in these regions and systematic sampling needs to be initiated to obtain this type of information.

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 chapter will be used in an ecosystem assessment chapter which accompanies the single-species assessment chapters comprising the SAFE. This new chapter will assess aggregate effects of groundfish fisheries on ecosystem and habitat and could result in advice regarding changes in aggregate catch levels (OY cap), species mix of the catch, discard amounts, and systems of closed areas.

Table 1. Indicator summary of most indicators in the Ecosystem Considerations chapter.

INDICATOR	OBSERVATION	INTERPRETATION
Physical Oceanography		
Arctic Oscillation Index	Currently positive, values are near-normal	When positive it supports a weak Aleutian Low and helps drive a negative PDO pattern. It is likely not important in recent climate fluctuations in the Pacific.
Pacific Decadal Oscillation	Cool coastal waters in GOA from 1998 to fall of 2002. August 2002 to July 2003 cool interior and warm coastal waters in GOA.	Indicates that PDO shifted to positive in August 2002 ; enhanced production in AK, and inhibited production in WA-OR
SST Anomalies	Winter 2003, warm water along the west coast of North America extending from the equator to the GOA and into the BS	Indicates El Nino
EBS summer temperature	The 2003 average bottom temperature was well above the 1982-2003 average, and the average sea surface temperature was also higher than average.	Pollock distribution shifted to middle shelf.
EBS sea ice extent	In 2003 ice at Mooring 2 in mid-March and stayed for 2 weeks; weak winter winds	Low ice and wind year, resulted in 2-layer thermal structure in February, warmer waters on shelf, may result in northward shift of shelf ecosystems
AI summer bottom temperature	2002 not as cold as 2000, but second coldest year	Colder than average year
GOA summer temperature	2003 temperatures were the warmest yet recorded in depths less than 150 m	Temperature at depths 50-150 m generally tracked the PDO trend.
PAPA Trajectory Index	Surface water circulation in the eastern Gulf of Alaska showed a beginning of a southward shift in 2003.	
Seasonal rainfall at Kodiak	Winter and spring (except May) 2003 experienced average or greater rainfall	Survival potential of age-0 walleye pollock increased, because it promotes eddies in the ACC, which may benefit the pollock
Wind mixing south of Shelikof Strait	January-June of 1998-2002 have been below average	Weaker than average mixing after spawning (Feb-Mar) favors pollock survival
Ocean transport in WGOA	ACC was more organized and stronger in 2003 than in 2001 or 2002	Complex flow as seen in 2003, creates eddies which are favorable to pollock survival
Eddies in the GOA	Spring/Summer of 2003, an eddy with high chlorophyll concentrations was found in the GOA	Eddies may be areas of high productivity
Habitat		
Area closed to trawling BSAI and GOA	same closures as 2002	Less trawling than prior to 1999 on bottom in certain areas though may concentrate trawling in other areas

INDICATOR	OBSERVATION	INTERPRETATION
Groundfish bottom trawling effort in GOA	Bottom trawl time in 2002 was similar to 1998-01 and lower than 1990-96	Less trawling on bottom
Scallop tows in GOA	Number of tows decreased in 2001/02 in EGOA but increased in Kodiak relative to 2000/01	Generally decreasing number of scallop tows by area since 1997/98
Longline effort in GOA	Effort levels were about the same in 2000 and 2001	Generally stable or decreasing levels of longline effort in 1990's to 2001
Total exploitation rate in GOA	Rates have remained relatively constant since the mid-1980's	Generally stable exploitation rates
HAPC biota bycatch in GOA groundfish fisheries	Estimated at 46t for GOA in 2002, ranged from 27 to 46 t from 1997 to 2002.	About constant in GOA 1997-2001, with an increase in 2002.
HAPC biota biomass indices from GOA bottom trawl survey	Possible increase or stable anemones observed in central and western GOA in 2001.	Survey may provide biomass index for anemones and sponges; more research is needed to understand and interpret trends
Groundfish bottom trawling effort in EBS	Bottom trawl time in 2002 was similar to 2001 and lower than 1991-97	Less trawling on bottom relative to 1991-97
Groundfish bottom trawling effort in AI	About the same in 2002 compared to 2001 generally decreasing trend since 1990	Less trawling on bottom
Scallop tows in EBS/AI	Number of tows decreased in 2001/02 in western AK	Generally decreasing number of scallop tows since 1997/98
Longline effort in BSAI	Higher in 2001 relative to 2000	Generally increasing levels of longline effort in 1990's to present
Total exploitation rate in BS	Rates have remained relatively constant since the mid-1980's	Generally stable exploitation rates
HAPC biota bycatch in EBS/AI groundfish fisheries	Estimated at 2191 t for BSAI in 2002; ranged from 923 to 2548 t since 1997.	Similar to 2001 catches.
HAPC biota biomass indices in EBS bottom trawl survey	Survey may provide biomass index for seapens, anemones, and sponges. These groups have been better identified in the survey in the 1990's to present	More research needed to understand trends
HAPC biota biomass indices in the AI bottom trawl survey	Survey may provide biomass index for seapens, anemones, and sponges.	More research needed to understand trends
Target Groundfish		
Groundfish fleet	Total number of vessels actually fishing in 2002 was less than 2001, at 1006.	Relatively stable number of vessels participating
Groundfish discards	Slightly increased level in 2002 compared to 2001	Fairly stable rates of discarding since 1998

INDICATOR	**OBSERVATION**	**INTERPRETATION**
Total groundfish catch EBS	Total catch in 2001 as in 1990's, pollock dominant	Catch biomass about the same from 1984-2001
Total groundfish catch AI	Total catch in 2001 shows decline since about 1996, Atka mackerel dominant	Total catch returning to lower levels
Total biomass EBS/AI	Total about the same in 2002 as in 2001, slight decreasing trend, pollock dominant	Relatively high total biomass since about 1981
EBS recruit per spawner	Some above average recruitment in the early 1990's, most below average	Groundfish recruitment is low in mid- to late- 1990's
BSAI groundfish stock status	In 2002, 0 overfished, 12 not overfished, 8 unknown (of major stocks), 71 unknown (of minor stocks)	Many major stocks are not overfished
Total groundfish catch GOA	Total catch lower in 2002 than 2001	Total catch similar from 1985 through present
Total biomass GOA	Biomass declined 1982-01, slight increase in 2002 to about same level as 1996, arrowtooth dominant	Relatively low biomass compared to peak in 1982
GOA recruit per spawner	Recruit per spawner below average in the 1990's for most age-structured stocks	Groundfish recruitment is low in the 1990's
GOA groundfish stock status	In 2002, 0 overfished, 9 not overfished, 11 unknown (major stocks), 80 unknown (minor stocks)	Many major stocks are not overfished
Forage		
Forage bycatch EBS	24 t in 2002, 32-83 t in 1997-2001, mostly smelts	Lower smelt catch rates in 2002
Larvae and age-0 walleye pollock and Pacific cod in EBS	distribution related to bathymetry, depressions in abundance noted in 1997-99	El Nino of 1997-98 in EBS may have disrupted distribution patterns
Larval fish in GOA	1-3 year cycle in larval pollock abundance, elevated larval abundance in late 1980-90's, depressed abundance in 1993 and 1997-2000.	There is a similar response across many species to oceanographic conditions in the GOA
Forage biomass indices from EBS bottom trawl survey	Survey may provide biomass index for some species	More research needed to interpret trends
Forage biomass indices from AI bottom trawl survey	Survey may not sample these well enough to provide biomass indices	
Forage bycatch GOA	Ranged from 27-125 t in 1997-2000, over 500 t in 2001, and 158 t in 2002; mostly smelts	Lower smelt catch rates in 2002 compared to 2001, but still above average.
Forage biomass indices from GOA bottom trawl survey	Survey may provide biomass index for sandfish and eulachon, eulachon index increased in 2001 in central and western GOA	More research needed to interpret trends

INDICATOR	OBSERVATION	INTERPRETATION
Forage biomass indices from ADFG inshore small mesh survey in GOA	Osmerid biomass index increased in 2002	Increase due primarily to increase in eulachon abundance
Miscellaneous and other managed species		
EBS Jellyfish	Large decreases in 2001 - 2003 relative to 2000	Possible return to 1980's low levels of jellyfish biomass
NMFS bottom trawl survey - EBS	Trends indicate poachers and echinoderms higher in 1990's, eelpouts lower in 1990's	More research on life history characteristics of species needed to interpret trends
NMFS bottom trawl survey - AI	2002 trends are unclear	More research needed to interpret trends
Crab stock status - BSAI	4 stocks overfished (BS Tanner, St. Matt. and Pribilof Is. blue king, EBS Snow crab), 2 stocks not overfished, 14 stocks unknown	Mixed crab stock status
Scallop stock status	1 stock- not overfished	
SEAK Herring stock status	SEAK herring spawning biomass decreased slightly in 2002, but was still above the 22-year median	Slight increasing biomass trend at 7 of 9 locations
Togiak Herring stock status	2002 abundance and age 4 recruits decreased slightly from 2001	Abundance is still below 1978-02 average; population is considered stable
Salmon stock status	0 stocks overfished, 5 stocks not overfished, 0 stocks unknown	Generally, Alaskan salmon stocks have been at high levels of abundance in the last 20 years
Spiny dogfish	Observer bycatch rates in 2002 were generally lower than previous years in the GOA; highest catches recorded in area 640 in 1998; catches higher in GOA than BS	Both increasing and decreasing catch rates observed over time by area
Spiny dogfish	IPHC bycatch rates 1997 to 2002 show peaks in 1998 and 2001	Possible distribution changes caused peaks in 1998 and 2001
Sleeper shark	Mixed trends by area (Observer, IPHC, ADF&G); large increase in one area of BSAI in 2001 and 2002	Mixed trends
Salmon shark	Highest bycatch rates in Kodiak region	Similar catch rates in recent years
ADF&G large mesh inshore-GOA	2003 catch rates of Tanner crab and arrowtooth flounder are increasing, flathead sole, and pollock are higher than prior to the 1977/78 regime shift	Increasing Tanner crab, other species slightly increasing last 4-5 years
ADF&G small mesh inshore survey-GOA	Pandalid shrimp increased in 2002	Possible increase in Kodiak area pandalid shrimp
NMFS bottom trawl survey-GOA	2001 trends indicate possible increase in eelpouts, and starfish in 1990's, unclear trends for jellyfish	More research needed to interpret trends

INDICATOR	OBSERVATION	INTERPRETATION
Prohibited species bycatch	2002 bycatch rates show a decrease in halibut, herring, other tanner crabs, and chinook salmon, increases in other salmon, red king crab, and other king crabs, and little change in bairdi bycatch rates relative to 2001	Prohibited species bycatch rates are mixed
Non-specified species bycatch	Non-specified species bycatch was the lowest in 2001 (11,122 t), compared to other years (13,368 to 24,634 t). Bycatch in 2002 was 13,368 t.	Dominant species in non-specified bycatch were jellyfish, grenadier and starfish
Marine Mammals		
Alaskan sea lion western stock pup counts	Composite 2001/2002 count showed continuing decline (WGOA only area with an increase)	Kenai to Kiska areas annual decrease averaging about 4%/yr since 1994
Alaskan sea lion western stock non-pup counts	2002 non-pup counts increased by 5.5% from 2000	First region-wide increase in 2 decades. Average long-term trend 1991-2002 shows decline of 4.2%/yr. Western Aleutians still showing strong decline
Alaskan eastern stock sea lion counts	Overall increase from 1991-2002 was 15.4%	Stable or slightly increasing at average of about 2%/yr
Northern fur seal pup counts	Annual rate of decline on both islands combined during 1998-2002 was 5.2% per year	Pup production at low levels not seen since 1921 (St. Paul) and 1916 (St. George)
Seabirds		
Seabird breeding chronology	Overall seabird breeding chronology was earlier than average or unchanged in 2001	Earlier hatching times are associated with higher breeding success
Seabird productivity	Overall, productivity of plankton feeding seabirds was average or below average in 2001; whereas, productivity of piscivorous seabirds was average or above average in 2001.	Variable chick production
Population trends	Mixed: 27 increased, 24 showed no change, 33 decreased	Variable depending on species and site
Seabird bycatch	2002 BSAI longline bycatch is lower than 2001, N. fulmars dominate the catch (GOA longline bycatch is small and relatively constant) Trawl bycatch rates are variable and perhaps increasing	Unclear relationship between bycatch and colony population trends

INDICATOR	OBSERVATION	INTERPRETATION
Aggregate Indicators		
Regime shift scores	No consistent evidence for regime shift after 1998, 1999-2001 cooling of the NE Pacific has reversed, conditions in the past year were like those of the 1977-97 warm regime	More time and biological series needed to see if trend continues
Trophic level catch EBS and AI	Constant, relatively high trophic level of catch since 1960's	Not fishing down the food web
Trophic level catch GOA	Constant, relatively high trophic level of catch since 1970's	Not fishing down the food web
Groundfish biodiversity EBS	Significant change in flatfish and roundfish species richness and evenness in late 1980's; stable to the present	An event in the 1970's sparked ecosystem changes that were perpetuated into the late 1980's and early 1990's; an event in the late 1980's countered the 1970's event
EBS groundfish community size spectrum	The bottom trawl fish community appears to have fewer small individuals and more large individuals through time.	This may be a reflection of climate driven declines in recruitment in the 1990’s
EBS groundfish community composition	There were no differences in k-dominance curves between year groups.	There appear to be no major changes in community composition over time.
Groundfish species richness and diversity - BS	Species richness and diversity was high in the 1990's and decreased in 2001	
Groundfish species richness and diversity - GOA	Species richness and diversity increased from 1990-99 and decreased in 2001	
Combined standardized indices of recruitment	Positive values 1976/77 - 1989, negative values in early 1970's and most of 1990's in GOA and BSAI	Above-average recruitments from 1976/77 - 1989, below average recruitments in early 1970's and most of 1990's.
Combined standardized indices of survival	Varying patterns	Relatively low survival of demersal stocks in 1990's
Total catch EBS (excludes salmon)	Total catch about the same in 2001 as in 1990's, pollock dominant	Catch biomass about the same from 1984-2001
Total catch AI (excludes salmon)	Total catch in 2002 shows decline since about 1996, Atka mackerel dominant	Total catch returning to lower levels
Total catch GOA (excludes salmon)	Total catch lower in 2002 than 2001	Total catch similar from 1985-present
Total CPUE BS	Peaked in 1993, was near 20-year average in 2000	
Total CPUE GOA	Peaked in 1993, decreased until 1999, increased slightly in 2001	

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 a previous Ecosystem Considerations Chapter, 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, and
4) Provide a stronger link between ecosystem research and fishery management

The 2000 and 2001 Ecosystem Considerations sections included some new contributions in this regard and will be built upon in future years. **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 is the addition of the Ecosystem Assessment section. The primary intent of the assessment is to summarize historical climate and fishing effects on the shelf and slope regions of the eastern Bering Sea/Aleutian Islands and Gulf of Alaska from an ecosystem perspective and to provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function. This is the first year that this assessment strategy is being used and not all of the modeling tools are ready for use in projections. Future development of modeling tools will enable scientists to provide advice on management strategies that are robust to a wide range of future ecosystem states.

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 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

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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 1 provides a complete listing of the elements in the 100 time series matrix, and Figure 1 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 2. 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 3). This limited number of observations for 2000 and 2001 mean that the 2000 PC scores plotted in Figure 2 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 4). 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.

Reference:

Hare, S.R., and N.J. Mantua, 2000: Empirical evidence for North Pacific regime shifts in 1977 and 1989 . Progress in Oceanography. 47:103-145.

Table 1. The 100 time series used in the analysis. The time series are plotted geographically in Figure 1. 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 1. 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

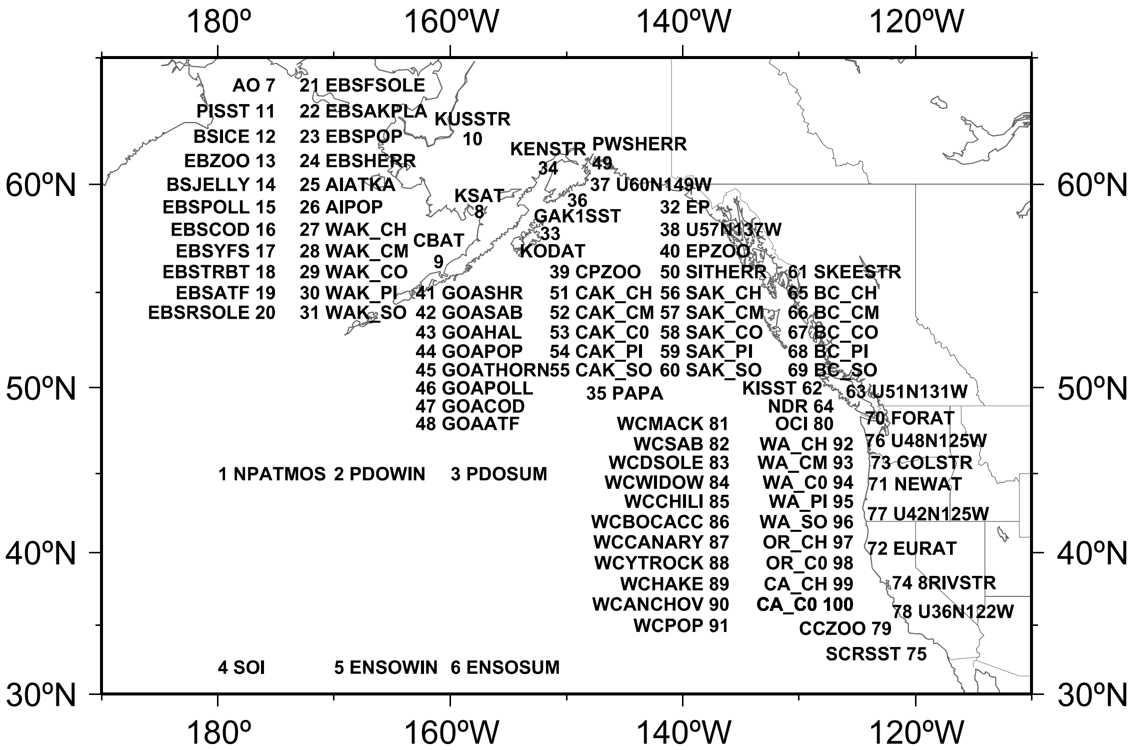

Figure 1. Numeric and alphabetic abbreviations for the 100 time series (reproduced from HM2000). Geographical arrangement gives a general indication of where each variable is measured or has influence. See Table 1 for a definition of each abbreviation.

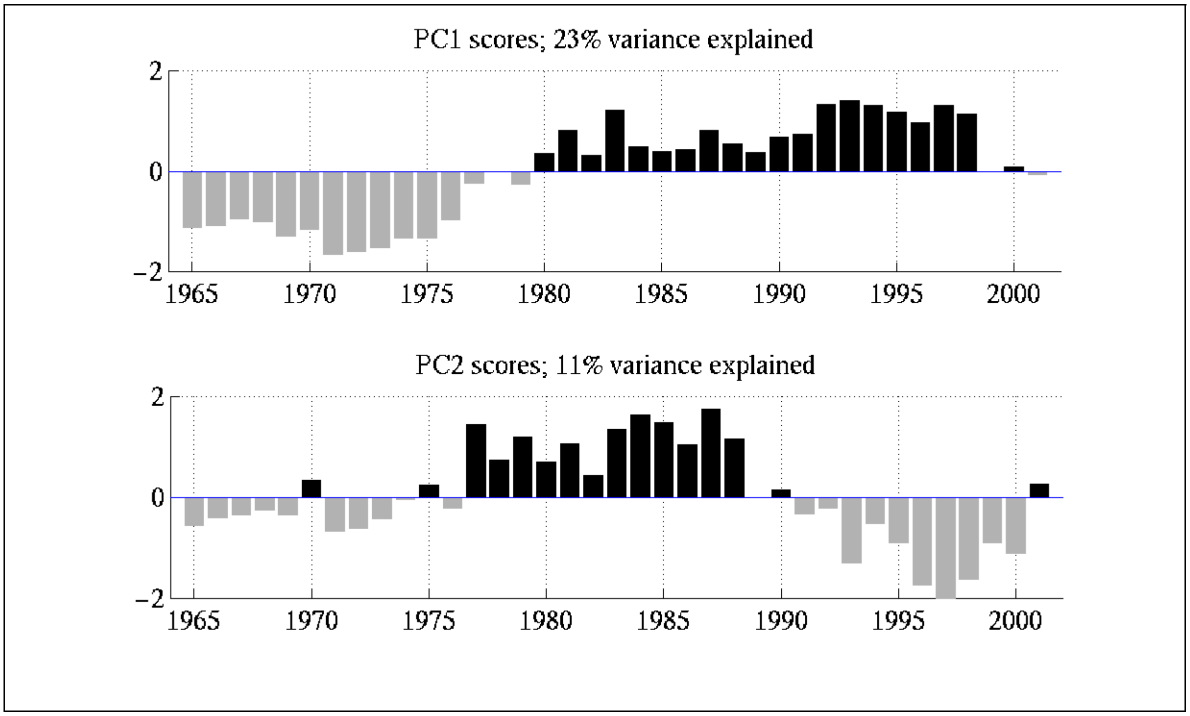

Figure 2. The first two principal component scores from a principal component analysis of the 100 environmental time series for 1965-2001, updated from HM2000.

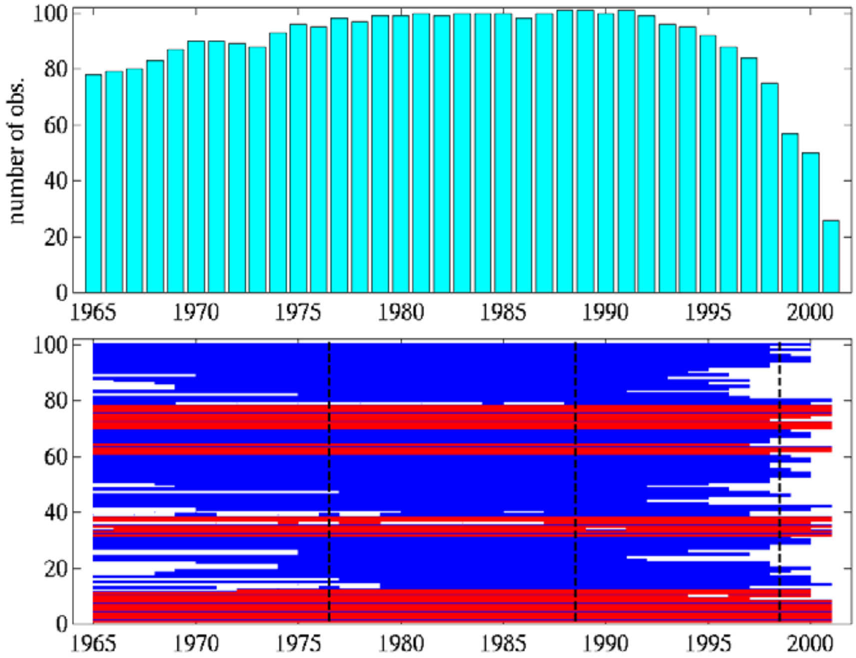

Figure 3: Data coverage for each of the 100 time series. The top panel shows the number of observations for each year, while shading in the bottom panel indicates years with observations (white areas have no observations). The blue (dark) shading indicates a biotic time series observation, the red (light)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

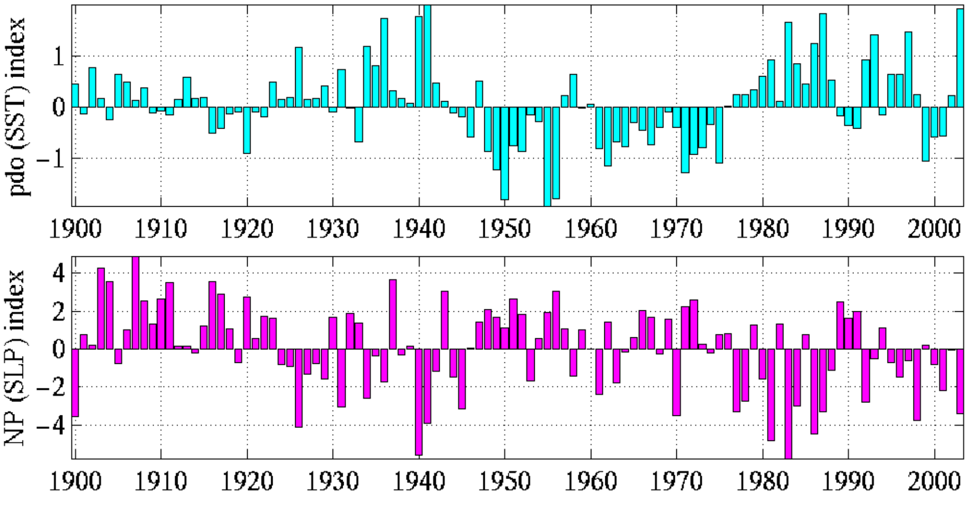

Figure 4: Annual PDO index (top) and Nov-Mar NP index, a measure of the intensity of the Aleutian Low. Both indices are plotted as anomalies from the 1900-2003 means. The 2003 value for the PDO index is based on data for January-June only.

GULF OF ALASKA

Ecosystem Indicators and Trends Used by FOCI – 2003

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 (2003) conditions. New additions for this year are availability of the BeringClimate website (see EASTERN BERING SEA: Temperature and Ice Cover in this report); a time series of eddy kinetic energy for the Gulf of Alaska (WESTERN GULF OF ALASKA: Eddies in the Gulf of Alaska); and improved, numerically modeled drfit trajectories for the southeastern Bering Sea (EASTERN BERING SEA: Bering Sea Drift Trajectories).

Climate Overview – FOCI

Contributed by S. Rodionov, J. Overland, and N. Bond, NOAA/PMEL

The winter of 2003 was influenced by an El Niño event in the equatorial Pacific (Figure 1). This event was most pronounced in the central part of the equatorial zone (Nino 3.4 region in Figure 2), whereas near the coast of South America (Nino 1+2 region), it was barely noticeable in terms of sea-surface temperature (SST) anomalies in this region. During the spring of 2003 negative SST anomalies developed in this region, but as of July 2003, the equatorial Pacific is in near-neutral state.

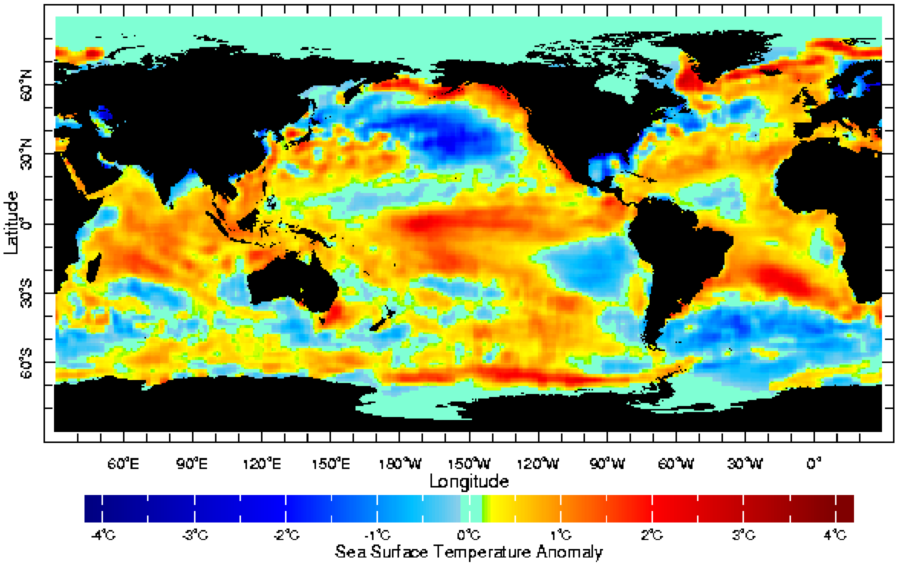

Figure 1. SST anomalies in January 2003.

The distribution of SST anomalies in the North Pacific during the winter of 2003 was typical for an El Niño event, with a strip of anomalously warm water along the west coast of North America extending from the equator to the Gulf of Alaska and farther into the Bering Sea (Figure 1). The central part of the North Pacific was occupied by an extensive pool of anomalously cold waters. Overall, the distribution of SST anomalies resembled the positive Pacific Decadal Oscillation

(PDO) pattern, which is reflected in strongly positive values of the PDO index (Figure 3). The mean winter (DJF) value of the PDO index during this winter was the second highest (after 1941) for this season since the record began in 1901. The spring (MAM) value of the PDO index was also strongly positive exceeding the mean value for the post-1977 regime (1978-2003).

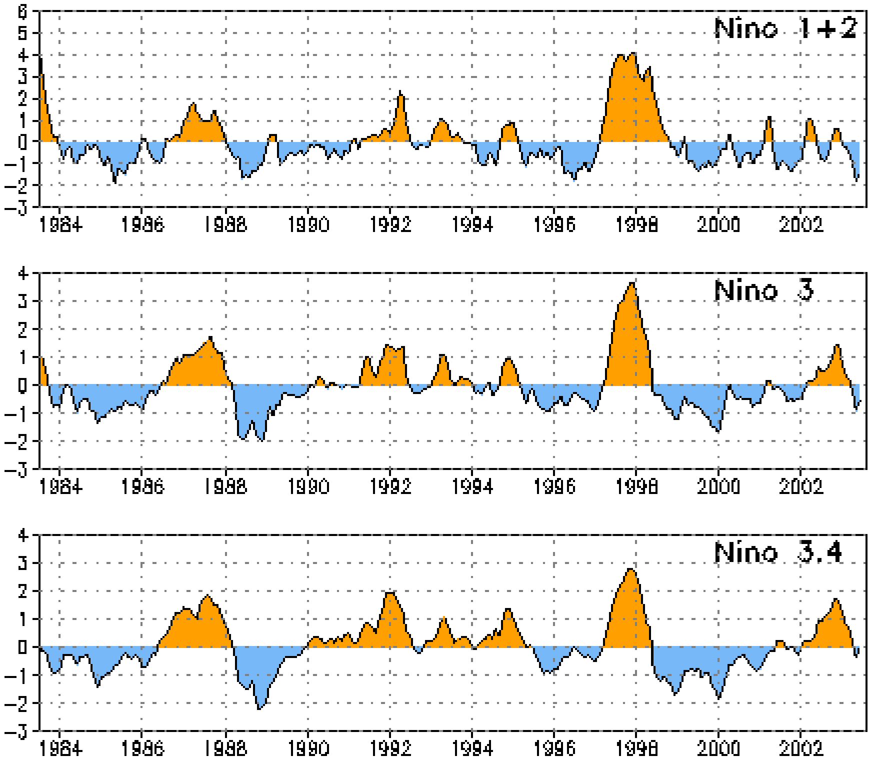

Figure 2. SST anomalies (deg. C) along the west coast of South America (Nino 1+2 region) and central parts of the equatorial belt (Nino 3 and 3.4 regions).

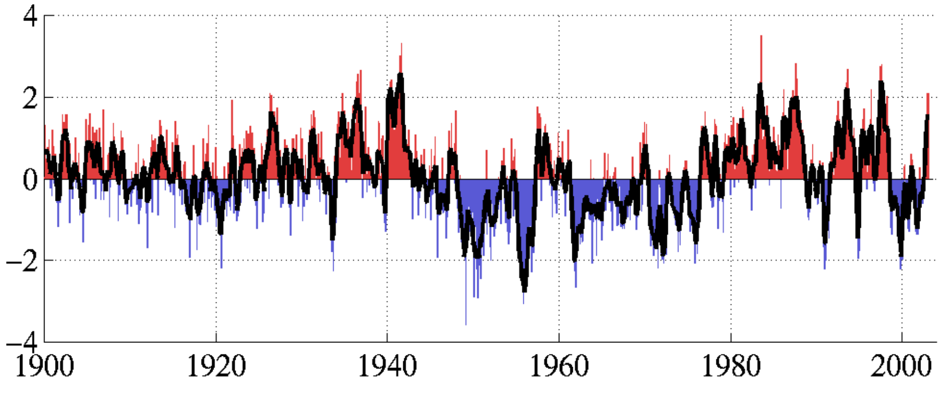

Figure 3. Monthly values of the PDO index, January 1900 – February 2003 (Mantua *et al.* 1997).

The atmospheric circulation during the winter of 2003 was characterized by a deep Aleutian low centered south of the Alaska Peninsula. This is typical for both El Niño and positive PDO winters. The North Pacific Index (NPI), which measures sea level pressure (SLP) over the region 30˚N-65˚N, 160˚E-140˚W was strongly negative (Figure 4). Note that, unlike the PDO index (Figure 3), the NPI shows no sign of reversal around 1999. But was there really a reversal in the PDO *spatial* pattern?

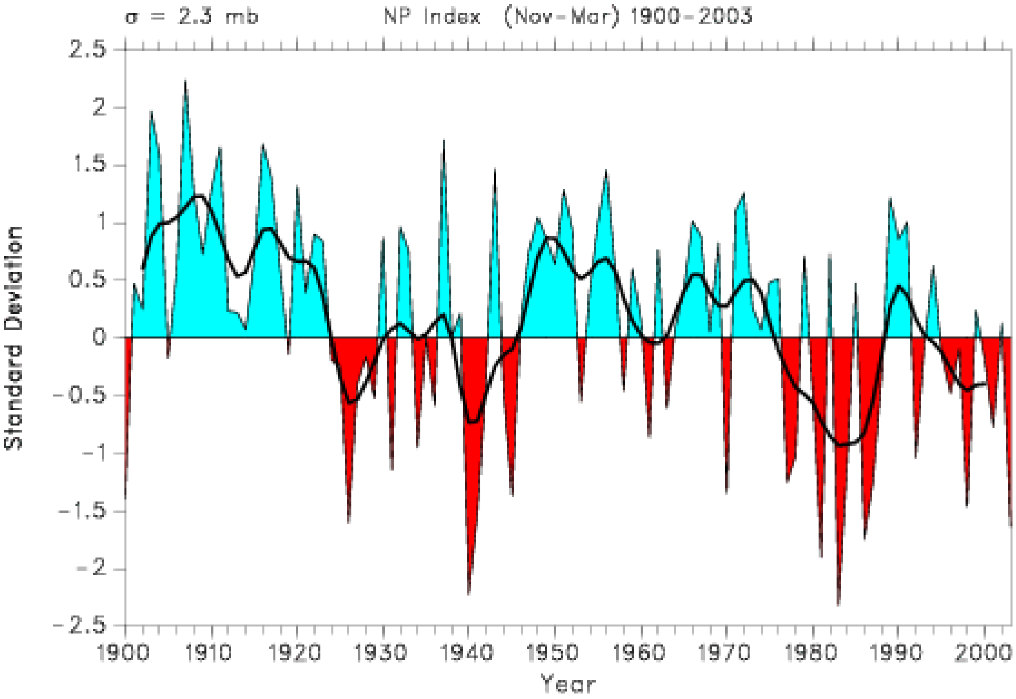

Figure 4. The North Pacific Index, 1900-2003 (Trenberth and Hurrell 1994).

Figure 5 shows the distribution of mean winter SLP (left column) and SST (right column) for two 5-yr periods, 1972-1976 (top panel) and 1999-2003 (bottom panel). The first set is typical for a negative PDO phase; it features an anomalously high pressure cell over the east-central north Pacific and the Bering Sea (Figure 5a). The corresponding SST pattern (Figure 5b) consists of a pull of warm water in the east-central Pacific and cold water along the west coast of North America.

In contrast, the distribution of SLP during 1999-2003 represents a dipole, with the positive center over the eastern subtropical Pacific and the negative center over the Bering Sea and eastern Alaska. The latter center is a reflection of an enhanced cyclonic activity in the higher latitudes (particularly since February 2000) that resulted in an advection of warm Pacific air into the eastern Bering Sea and cold Siberian air into the Sea of Okhotsk. These are the two areas where the difference in SST between 1999-2003 and 1972-1976 are particularly striking.

The SLP pattern in Figure 5c resembles the so-called North Pacific Oscillation (NPO). In the early 1930s this pattern was discovered by Sir Gilbert Walker who first noticed an opposition between SLP variations over Hawaii and Alaska. Apparently, climate variations other than those strictly associated with the PDO characterize the recent state of the North Pacific.

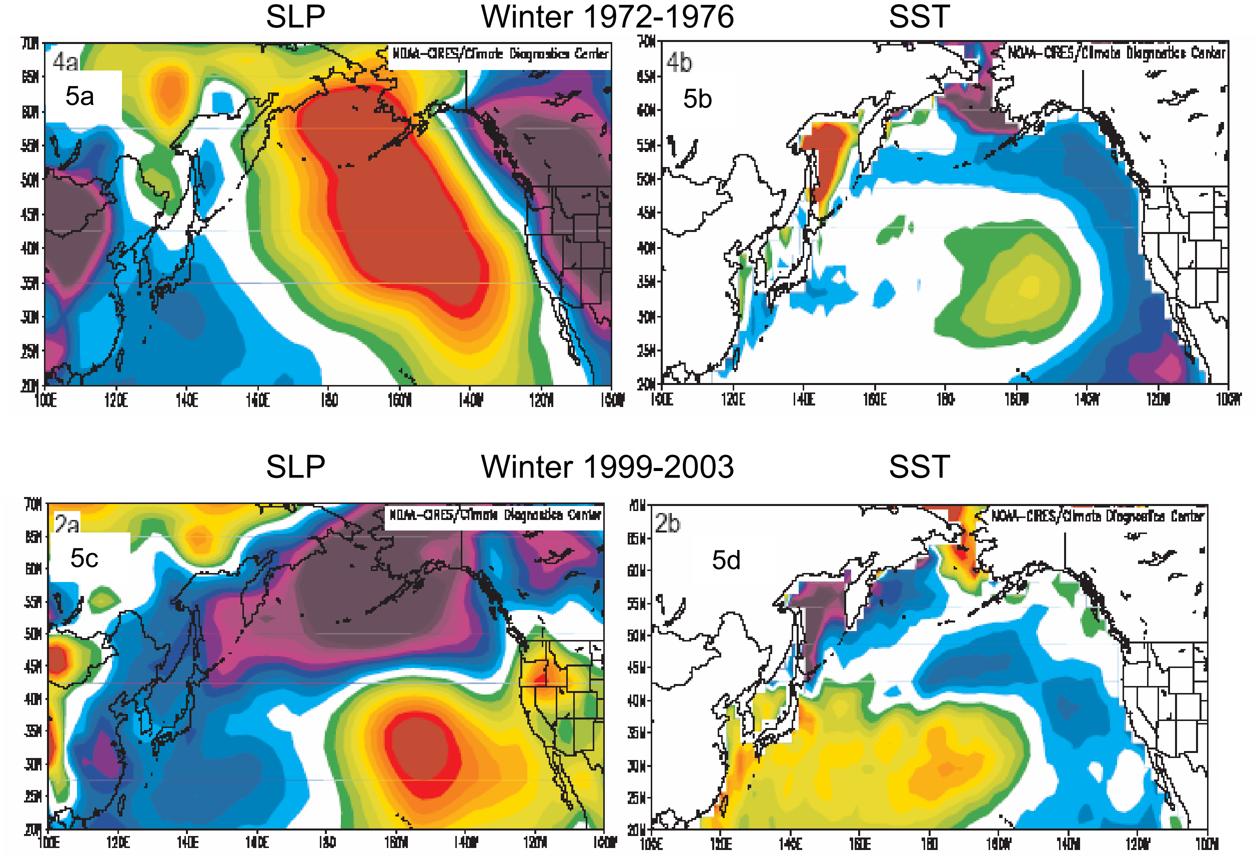

Figure 5. SLP and SST anomalies for the winters of 1972-76 and 1999-2003.

One of the major modes of atmospheric circulation not related to the PDO is the Arctic Oscillation (AO). The AO experienced an abrupt shift in 1989 (Figure 6) and was among the best candidates for explaining a concurrent shift in some biological indices. Since then, however, the magnitude of the AO index slowly decreased to near-normal values, and it is unlikely that this mode played an important role in recent climatic fluctuations in the Pacific sector.

A major question about the state of the Pacific climate is whether or not it experienced a shift toward a new climatic region around 1999. The negative phase of the PDO during 1999-2001 coincided with a prolonged La Niña event, whereas the switch back to the positive PDO phase in 2003 was accompanied by an El Niño event. Therefore, it all may be just short-term climatic fluctuations rather than a shift to a new multi-decadal regime. An analysis of various climatic indices sends a mixed signal. While some of them (e.g., the Pacific-North American index, Aleutian low pressure index, and zonal wind index) show no sign of reversal, other indices point to important changes since 1999. Among the latter are the winter West Pacific index, spring-to-summer East Pacific and North Pacific indices, and summer PDO (data until 2002) index.

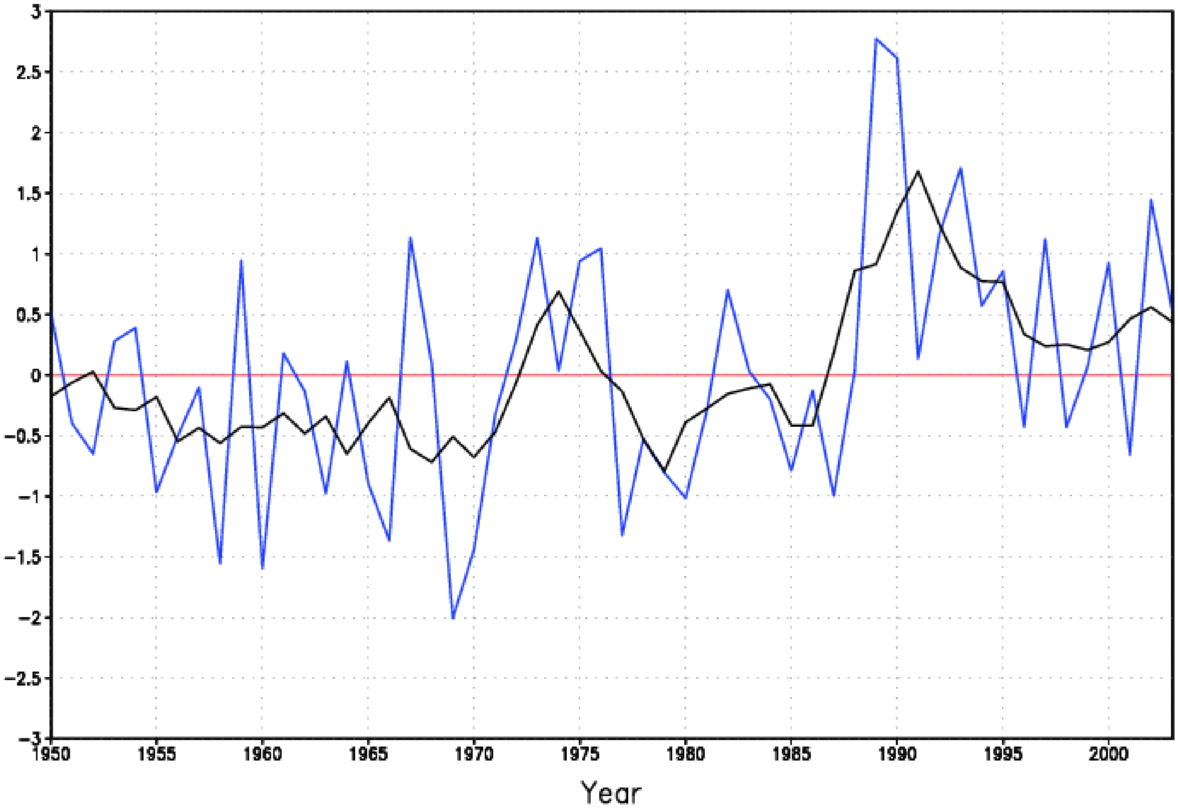

Figure 6. Mean winter (JFM) Arctic Oscillation index (blue line), 1950-2003. The black line denotes a five-year running mean of the index. The index is normalized using 1950-2000 base period statistics.

In summary, climatic events during the winter and spring of 2003 significantly reduced our confidence in a regime shift in the North Pacific climate. The winter of 2003 resembled in many respects those winters that were observed during the first part of the post-1977 regime. Nevertheless, the last 5-year period, 1999-2003, as a whole, showed significant deviations from a typical positive PDO pattern. Those deviations, however, do not indicate a return to the pre-1977 climate.

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Trenberth, K.E., and J.W. Hurrell. 1994. Decadal atmospheric-ocean variations in the Pacific. Climate Dynamics 9:303-319.

WESTERN GULF OF ALASKA

Seasonal rainfall at Kodiak –FOCI

Contributed by S. A. Macklin, NOAA/PMEL

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). Monthly rainfall amounts drive a simple model that produces an index for survival for age-0 walleye pollock that may benefit from spending their earliest stages in eddies. The model assumes that greater than average late winter (January, February, March) precipitation produces a greater snow pack for spring and summer freshwater discharge into the ACC. Similarly, greater than average spring and early summer rainfall, with their nearly immediate run-off, also favor increased baroclinity after spawning. Conversely, decreased rainfall is likely detrimental to pollock survival. The time series of FOCI's pollock survival index based on precipitation is shown in Figure 1. 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 because all winter and spring months, except May, experienced average or greater rainfall. 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 precipation 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. 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.

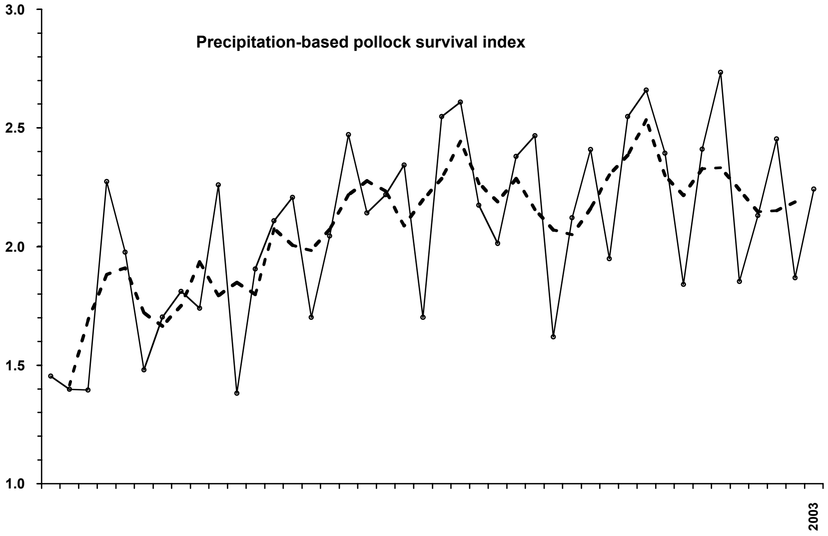

Figure 1. Index of pollock survival potential based on measured precipitation at Kodiak from 1962 through 2003. The solid line shows annual values of the index; the dashed line is the 3-year running mean.

Literature Cited

Megrey, B.A., A.B. Hollowed, S.R. Hare, S.A. Macklin, and P.J. Stabeno. 1996. Contributions of FOCI reserach to forecasts of year-calss strenght of walleye pollock in Shelikof Strait, Alaska. Fisheries Oceanography *5*(1):189-203.

Ocean transport in the western Gulf of Alaska –FOCI

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 1), 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.

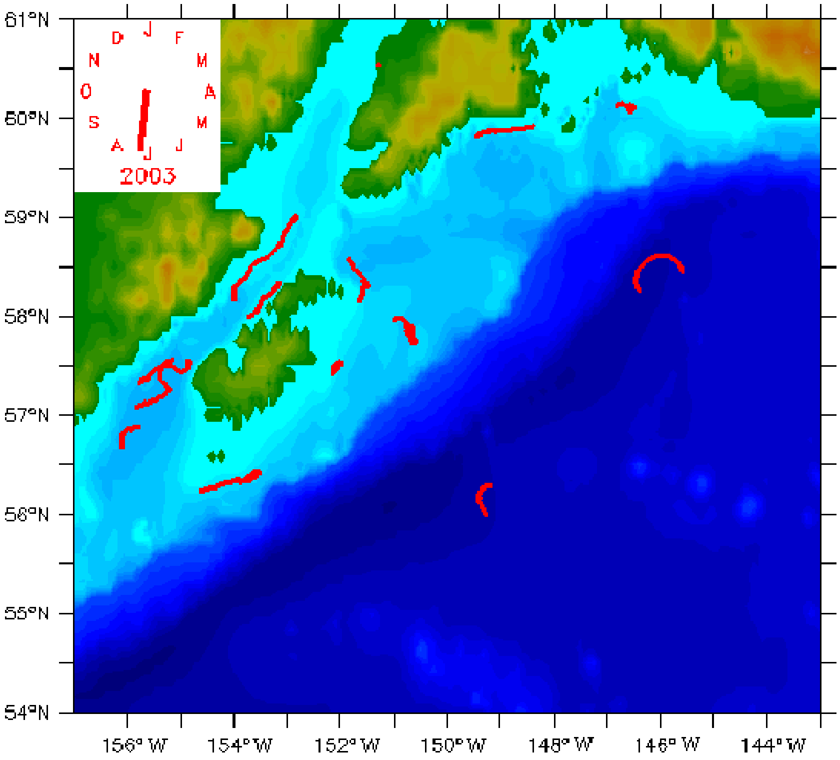

Figure 1. Tracks of satellite-tracked drifters for the period October 14-18, 2001, show sluggish flow on the shelf, except for within Shelikof Strait.

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.*, *in press*). The influence of eddies on biological processes has been confirmed with data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) (Figure 1) showing elevated chlorophyll associated with eddies.

Eddies propagating along the slope in the northern and western Gulf of Alaska are generally formed near Yakutat, Alaska 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 2003, an eddy was located around 146ºW, 58.5ºN (Figure 1). In late April, a chlorophyll maximum was observed at the center of the eddy surrounded by a ring of low chlorophyll surface waters. The outer edge of the eddy contained higher chlorophyll concentrations and appeared to be pulling coastal water with relatively high chlorophyll off the shelf.

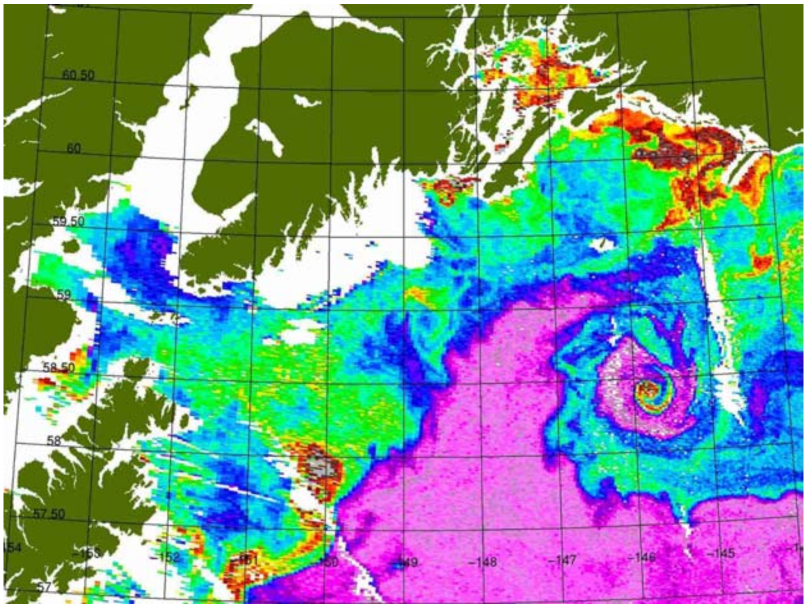

Figure 1. Chlorophyll from SeaWiFS satellite (April 27, 2003). Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE; courtesy of Mike Schmidt (SIAC/GODDARD), the Goddard Space Flight Center.

Since 1992, the Topex/Poseidon satellite altimetry system has been monitoring sea surface height (SSH). Near-real-time maps of mesoscale SSH anomalies (Leben *et al.*, 2002) obtained from the Colorado Center for Astrodynamics Research (CCAR; http://www-ccar.colorado.edu/~realtime/global-real-time_ssh/) allow analysis of the current number and location of eddies in the Gulf of Alaska. In addition, we intend to use these altimetry data to analyze time series of the number, timing and strength of eddies in previous years.

Gridded altimetry data (merged TOPEX/Poseidon, ERS-1 and ERS-2 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 2 is a time series of eddy kinetic energy (EKE) in the region where eddies often impinge on the shelf in the northern Gulf of Alaska. Prior to 1997, EKE was generally lower (with the exception of 1995) than the ~10 year climatological average. After 1997, EKE in the region increased, particularly in the spring and summer. In addition, the amplitude of the seasonal cycle also appears to have increased later in the record. Research is ongoing on the causes and implications of this pattern. (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.jason.oceanobs.com/html/donnees/welcome_uk.html).

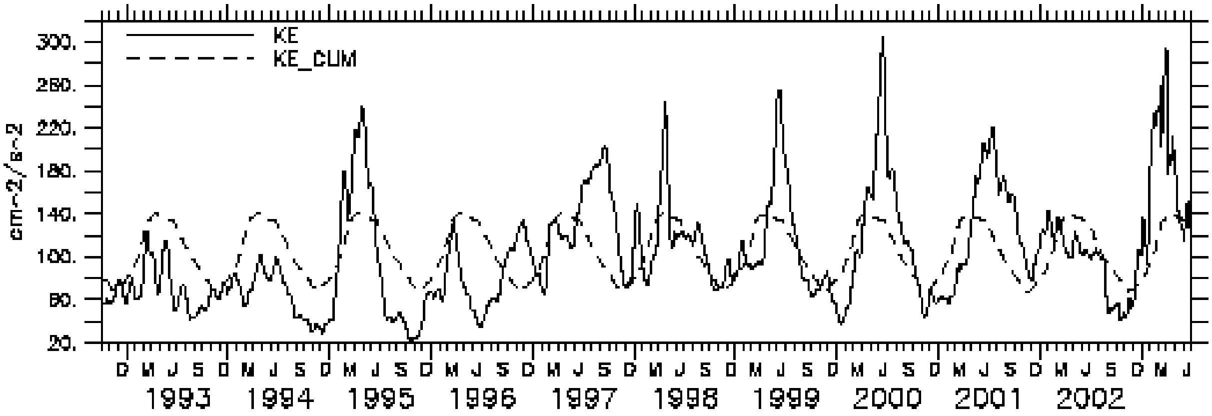

Figure 2. Eddy kinetic energy averaged over the region 57-59ºN, 147-140ºW calculated from TOPEX/Poseidon, ERS-1 and ERS-2 merged altimetry.

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Ocean Surface Currents – Papa Trajectory Index

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

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., 1999) 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 in special projects by contacting jim.ingraham@noaa.gov or 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) home page, http://www.afsc.noaa.gov/refm/docs/oscurs/default.htm **,** and clicking on "OSCURS".

See the information article, Getting to Know OSCURS, for a summary of such experiments that have already been run on the webpage:
http://www.afsc.noaa.gov/refm/docs/oscurs/default.htm
or go directly to the NOAA-NMFS-PFEL site at
http://www.pfeg.noaa.gov/products/las/OSCURS.html
for model calculations.

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 2001 (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.1) 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 37 years and continuing (1964-2001). 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 overdue in the 2001 report (at least the longest oscillation this century). The time-series has been updated with winter 2003 calculations and shows the beginning of the possible shift. The 5-year running mean has fallen to the mean value, the possible start of a zero crossing. Once the 5-year running mean crosses the zero line it usually stays there for several years, but this last cycle it has touched the mean four other times. 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.

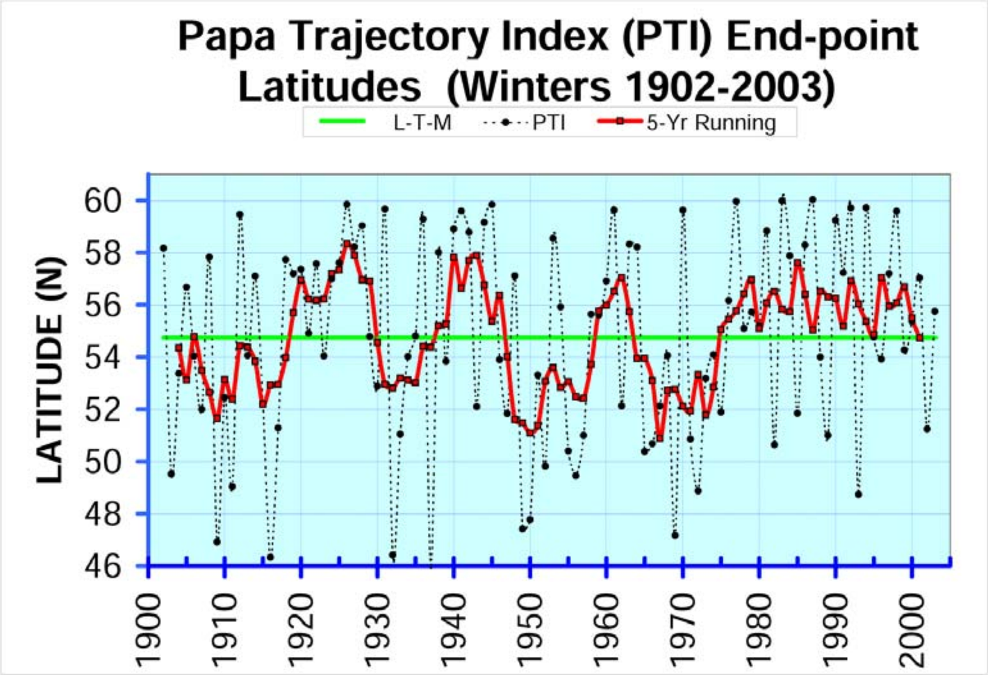

Figure 1. Annual, long-term mean, and 5-year running mean values of the PAPA Trajectory Index (PTI) time-series from winter 1902-2003. Large black dots are annual values of latitude of the end points of 90-day trajectories started at Ocean Weather Station PAPA (50º N, 145º W) each December 1, 1901-2002. 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.

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Gulf of Alaska Survey Bottom Temperature Analysis

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 1). 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.

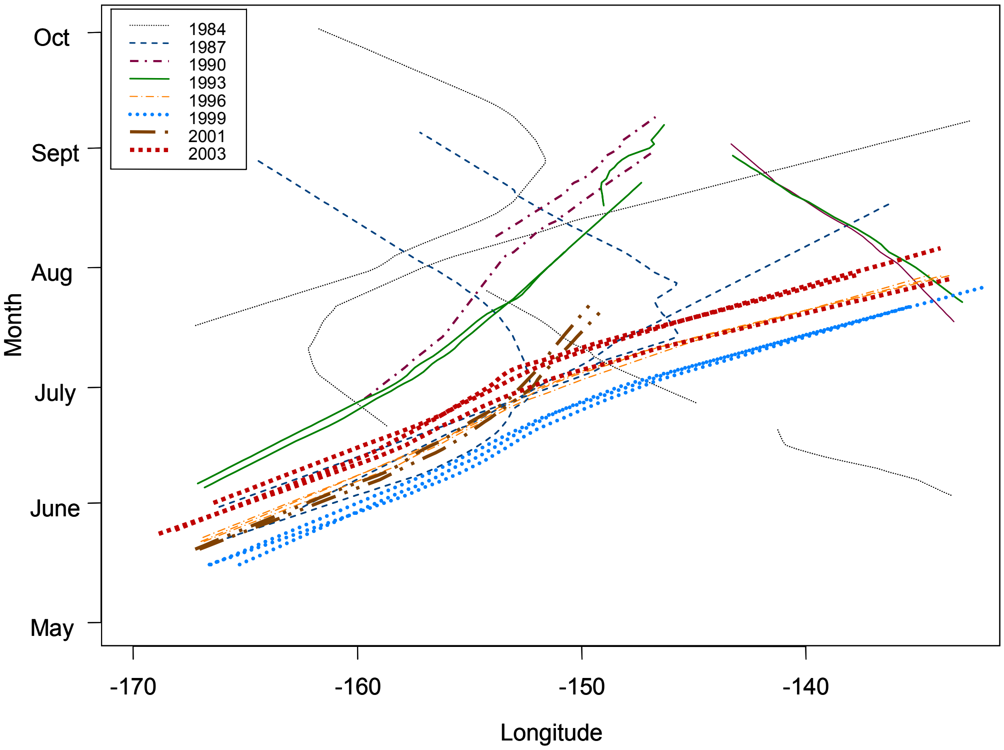

Figure 1. GOA survey temperature data collection by date and longitude.

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 2 and 3. Figure 2 shows the results plotted by depth with year on the x-axis, while Figure 3 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 2). The data also suggest a general warming pattern in depths less than 50 meters over the entire time series (Figure 2).

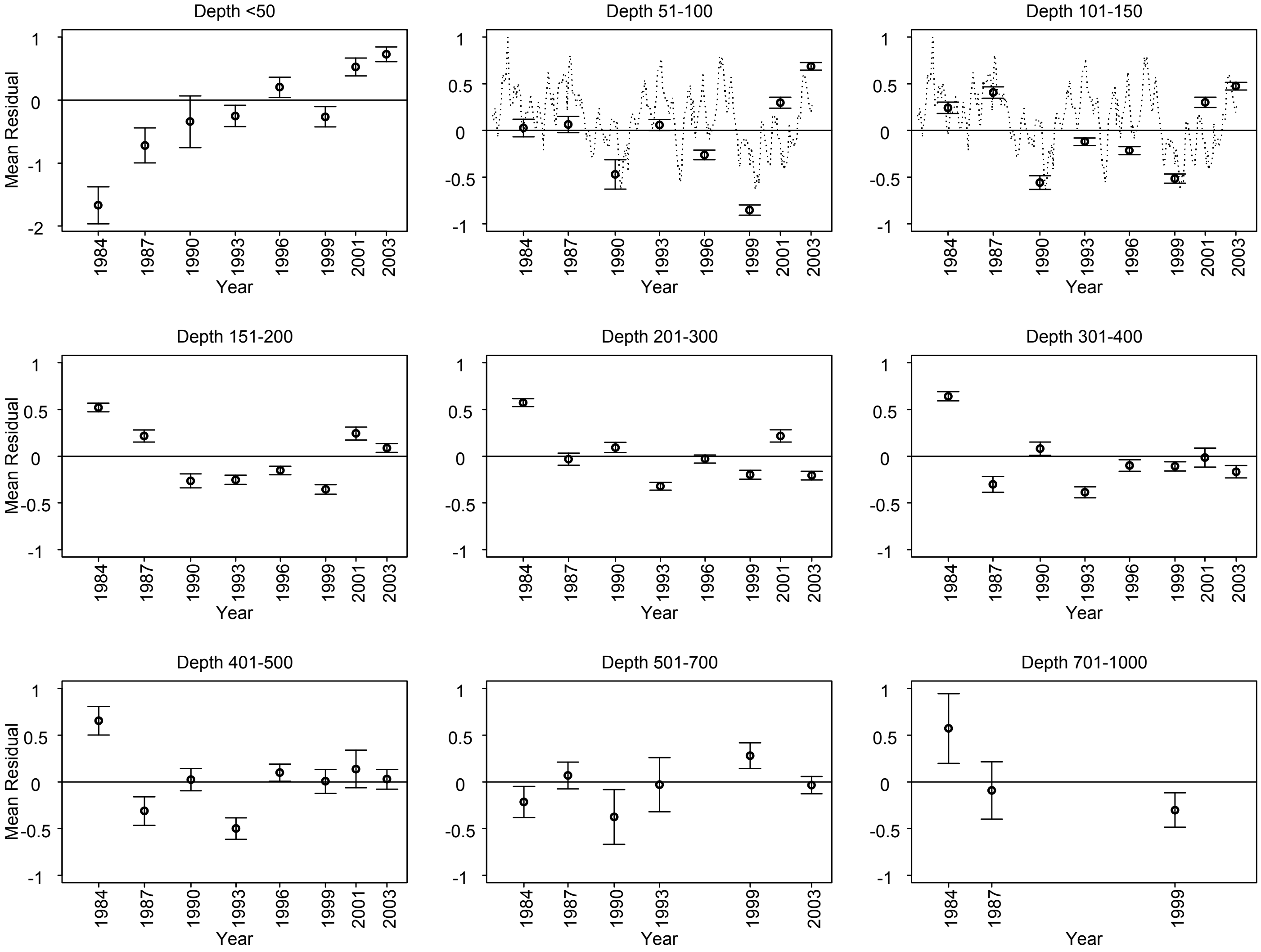

Figure 2. Mean temperature anomalies plotted by year within each depth stratum. Dotted line represents Pacific Decadal Oscillation index. Note expanded scale in < 50 m plot.

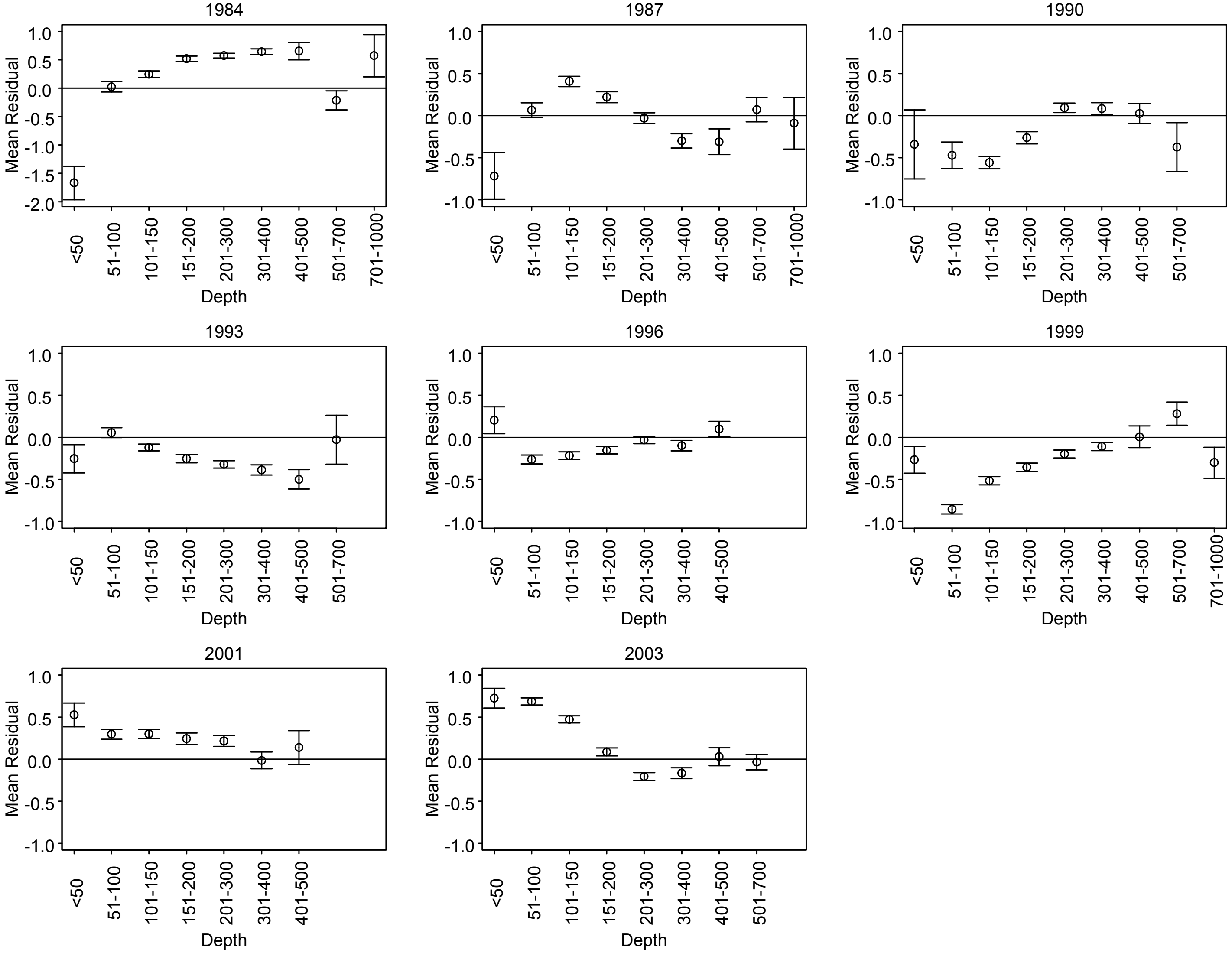

Figure 3. Mean temperature anomalies plotted by depth stratum within each year. Note expanded scale in 1984 plot.

Mixed Layer Depth at GAK 1 in the North Gulf of Alaska

Contributed by Nandita Sarkar and Tom Royer, Old Dominion University

The GAK 1 station is located in the mouth of Resurrection Bay in the North Gulf of Alaska. Temperature and salinity have been collected at various times throughout the year at this location since 1973. Mixed layer depths (MLD) were estimated using the Freeland et al (1997) algorithm. This algorithm performs well at estimating the winter MLDs, but overestimates the summer and spring MLDs. Currently we are investigating the use of another algorithm for estimating MLD.

Using the Freeland et al (1997) algorithm, MLD at GAK 1 was deeper in the winter (days 1-59 and 335-365) of a given year than other times of the year (Figure 1). The depth of the MLD in the winter has ranged from 3 to 201 m, with a median of 122 m and an average of 123 m.

The deepest winter mixed layer depth from 1974 to 2001 shows a deepening trend, but this trend is not statistically significant. Even though the non-significance of the trend maybe due to the short length of the time series, nevertheless the only conclusion is that during 1974-2001, there have been no significant changes in the deepest winter mixed layer at station GAK 1 in the northern Gulf of Alaska. This is in contrast to the studies by Freeland et al (1997) who report a significant shoaling trend at Ocean Station P at the center of the Alaskan Gyre. This dissimilarity in trends at the center and edge of the gyre may indicate that the gyre is spinning up.

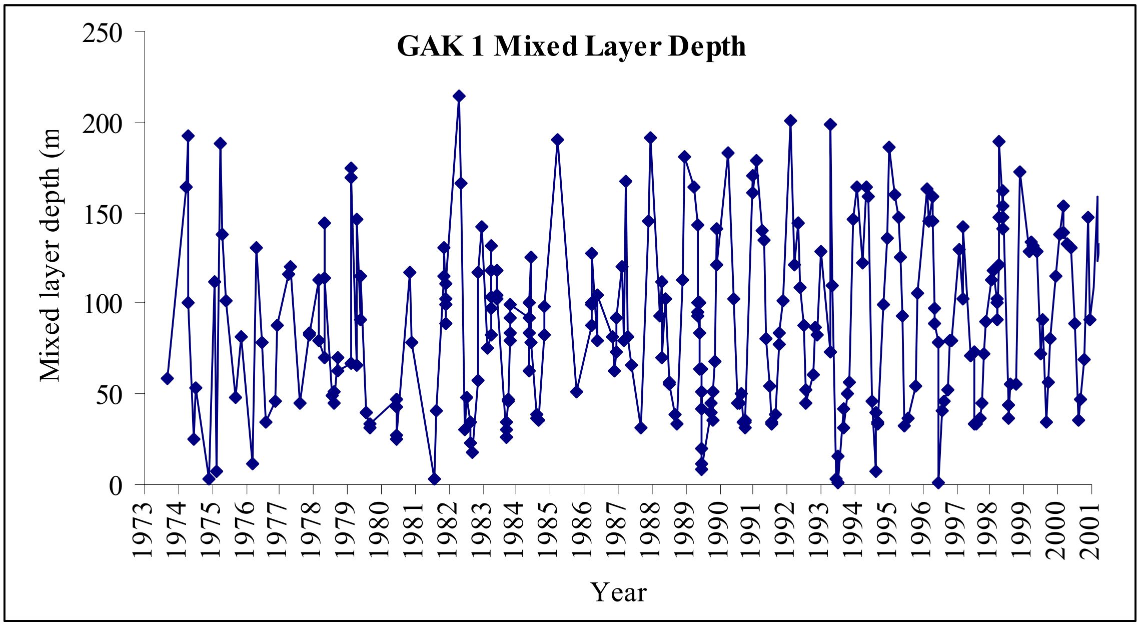

Figure 1. Mixed layer depth at GAK 1, 1973-2001 using the Freeland et al. (1997) algorithm.

EASTERN BERING SEA

Temperature and Ice Cover -FOCI

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

The winter of 2003 was very mild in the Bering Sea. Mean winter (DJFM) surface air temperature (SAT) in St. Paul was 2.1˚C (or more than one standard deviation) above normal (Figure 1a). This mild weather was associated with an intensified Aleutian low that pumped warm Pacific air into the eastern Bering Sea. Although an intensification of the Aleutian low is characteristic of El Niño winters, after the 1977 climate shift, the center of the depression was often positioned too far east of its normal position near the dateline, causing an advection of cold air from Alaska into the Bering Sea. This year's reaction of winter temperature to an El Niño event is more typical of the pre-1977 period.

The recent decades saw an increase in the interannual variability of winter temperatures in the Bering Sea, as opposed to more persistent cold and warm states before and after the regime shift, respectively (Figure 1a). The magnitude of positive SAT anomalies, however, still remains higher than the negative ones. Another emerging pattern in temperature variability is that winters tend to start on the cold side, and these early negative temperature anomalies can cause significant ice cover, as illustrated by the Ice Cover Index (Figure 1b). However, due to strong positive SAT anomalies during late winter, spring and summer, mean annual temperature anomalies remain positive. Some cases in point are 1998, 2000, and 2002.

This pattern appears to be associated with a shift in the peak of cyclonic activity in the Bering Sea. Normally, the maximum storm activity is observed in November as the storm track moves south through the Bering Sea in its annual cycle. In winter, the storm track is located south of the Aleutian Islands. During 1998, 2000, and 2002, unusual cyclonic activity developed in the Bering Sea either in February or March; the temperature increased substantially and the ice retreated.

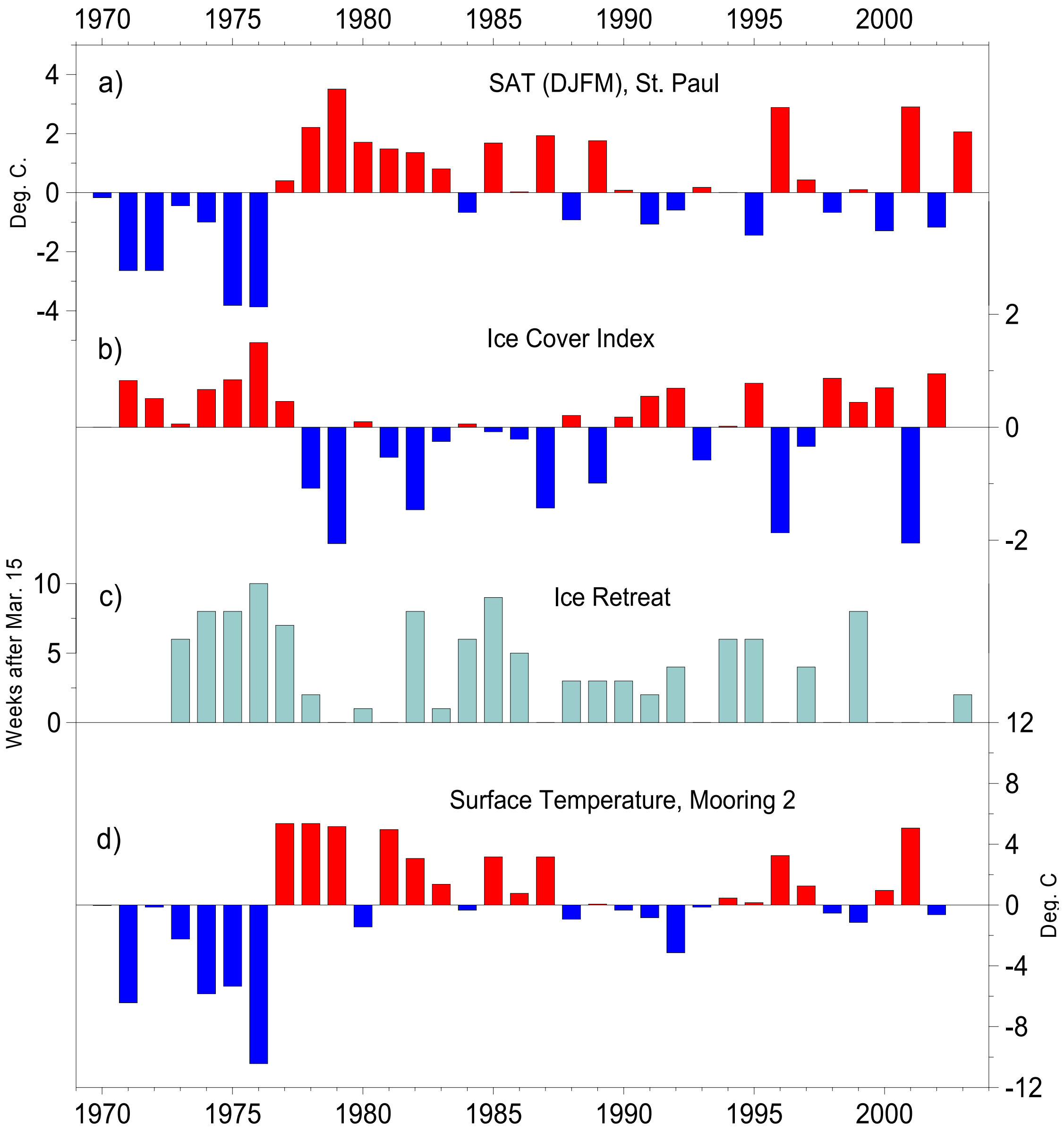

Figure 1. a) Mean winter (DJFM) surface air temperature anomalies in St. Paul, Pribilofs Islands, 1970-2003, b) Ice Cover Index, 1970-2002, c) number of weeks with ice cover after March 15 in the area 56-58°N, 163-165°W, 1972-2003, and d) Surface temperature anomalies (Jan-Apr) at Mooring 2 (NCEP/NCAR Reanalysis data), 1970-2002.

All this leads to an increased variability in the timing of maximum ice cover, which itself has little relation with the total area or extent of ice cover. Typically, the heavier the ice cover in a given winter the later it retreats in the spring, but, as Figure 2 illustrates, this was not the case in recent years. Particularly striking was the winter of 2000, when ice cover had its maximum in January, reaching farther south then in any other winter during 1997-2002, but then quickly retreating in February.

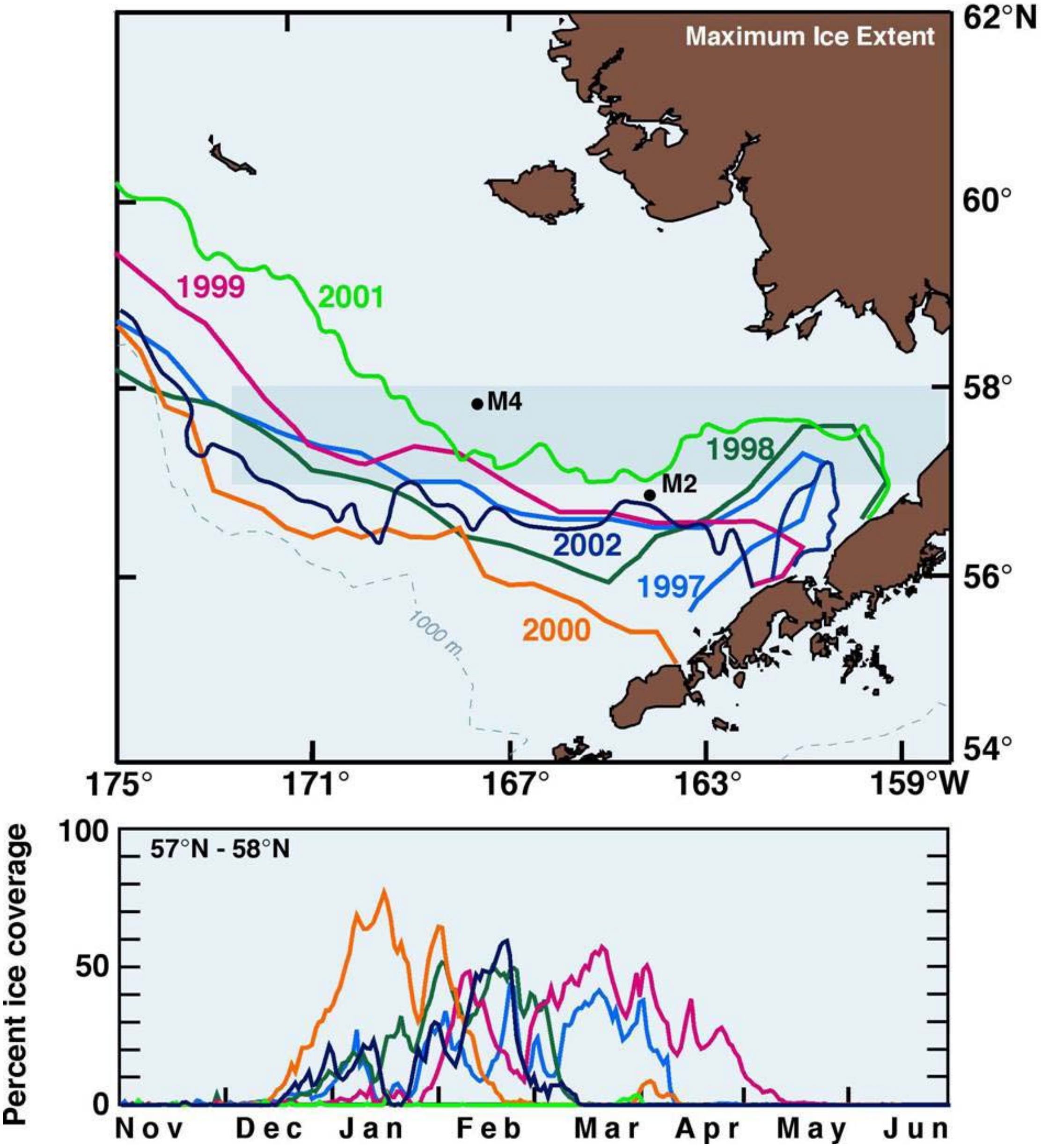

Figure 2. Top: Maximum ice extent during the period 1997-2002. Bottom: Weekly percent ice cover of the area indicated by the shaded box in the top figure (57° N – 58°N) for the same 6-year period.

Atmospheric circulation during spring and early summer is characterized by a tendency toward positive sea level pressure anomalies. This suggests lighter winds, less cloud cover, more insolation, and hence, faster warming of the sea. As a result, the transition from winter to spring occurs earlier and faster.

Sea ice plays an important role in determining the timing of the spring phytoplankton bloom. If there is ice after mid March, there is an associated ice-edge phytoplankton bloom. If there is no ice after that date, then the spring phytoplankton bloom occurs later in May or even June, when the water column becomes thermally stratified. The timing of the spring bloom is critical to supplying food to zooplankton. A phytoplankton bloom during March or April when the water is cold favors the benthic community since the zooplankton is unable to fully consume it. Alternately, a bloom in May is cropped by zooplankton ultimately favoring pelagic production.

There is an obvious negative trend in the timing of ice retreat calculated for the 2˚ x 2˚ rectangle (area 56-58°N, 163-165°W) that includes Mooring 2 (Figure 1c). During the 3-year period of 2000-2002, no ice was observed in this area after mid March. Over the record extending back to 1972, there had not been even two years in a row lacking ice at Mooring 2 prior to 2000. Interestingly, in 2003, ice first showed up in this area only in mid March during a period of brief cooling; this ice remained for two weeks.

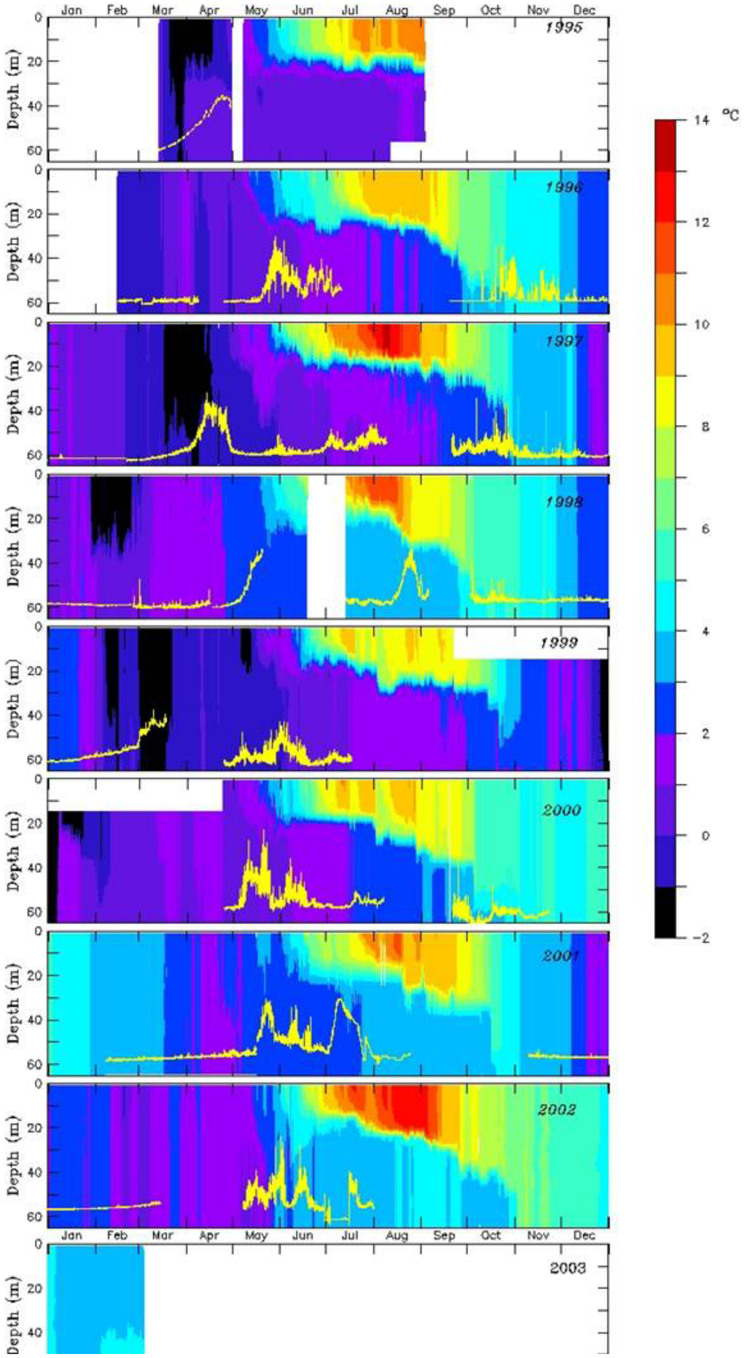

Figure 3. Time series of ocean temperatures and fluorescence from Mooring 2. The thin yellow line in each panel is fluorescence at 11 m. Temperatures of less than -1˚C indicate the presence of ice over the mooring. Note that during 1996, ice was present during the winter when there was no mooring in the water at this site.

Figure 1d illustrates historical changes in the mean January through March ocean surface temperatures at Mooring 2 from the NCEP/NCAR Reanalysis data, and Figure 3 shows observed temperature at this location for each year since 1995. Note unseasonably high temperatures during the first 1-2 months of the last three years (2001-2003), with no presence of ice. In addition, winds during 2003 were very weak, resulting in a two-layer thermal structure in February. It has been hypothesized that warmer temperatures over the shelf would result in northward shift of shelf ecosystems. Because most of the variability on the Bering Sea is interannual, it can be difficult to pick out trends in climate patterns. These data from the mooring site, however, indicate that a warming is liable to be occurring on the shelf. Whether this is short term or even decadal in nature is unknown, but changes in temperature on the shelf would likely impact its ecosystems.

For more information on the Bering Sea climate and recent trends in the atmospheric and oceanic indices visit www.BeringClimate.noaa.gov. The data section of this web site currently contains 44 indices broken into five categories: climate indices, atmosphere, ocean, fishery, and biology. The metadata for each index describes: 1) the source where it was obtained, or the raw data used for its calculation, 2) its relevance to the ecosystem, and 3) recent trends in its fluctuations. The site also provides capabilities to draw single or stacked plots, calculate correlation coefficients, and download data.

Bering Sea Drift Trajectories -FOCI

Contributed by D. Righi, NOAA/PMEL

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 and larvae trajectories and hindcast survival rates. FOCI attempts 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 1997-2001. The simulated drifters are initialized in the Bering Sea just north of Unimak Island and to the northeast of Unimak Pass. This area is known to be an area of strong spawning for walleye pollock (Hinckley, 1987). The initial drifter positions fill out a seven by seven grid with horizontal separations of about 10 kilometers (Figure 1). Vertically, there are 15 drifters initialized at each grid point with maximum depths just over 40 meters. 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.

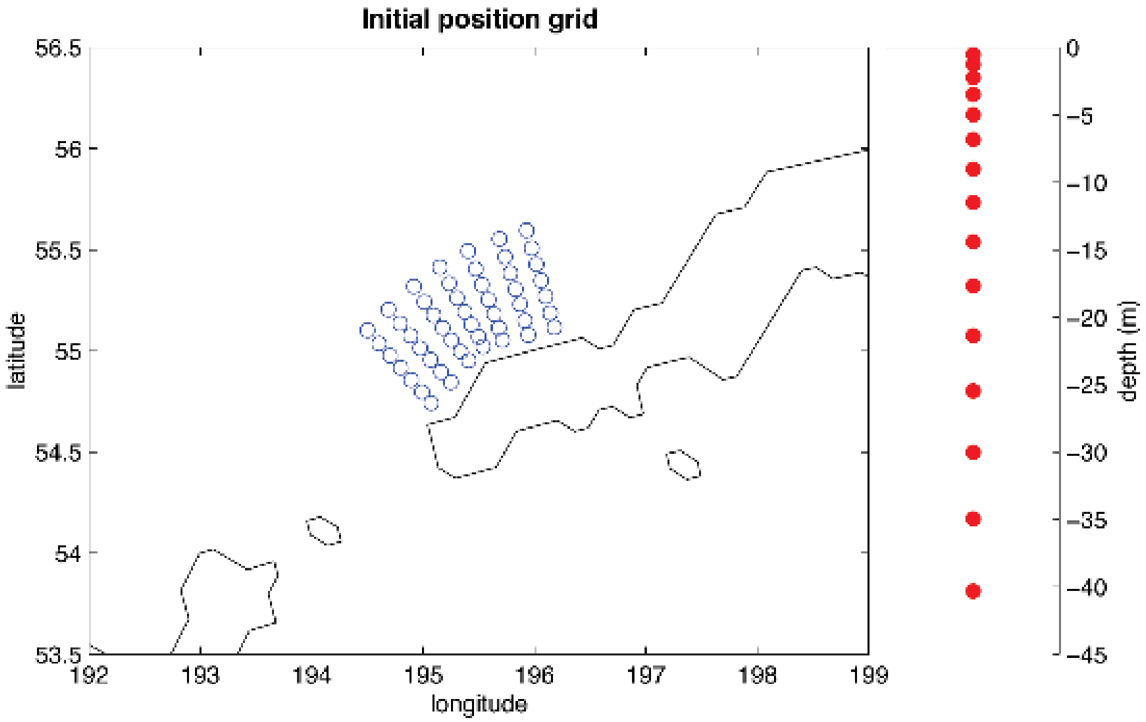

Figure 1. Simulated drifter initial horizontal (left) and vertical (right) positions.

Endpoints after 90 days for drifter trajectories from the 1997-2001 runs are shown in Figure 2 (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-meter isobath. The split between these two paths is seen clearly in the 1998, 1999 and 2001 drifter endpoints. In 1997 the full trajectory plots (not presented here) show that a subset of the drifters begin following the standard 100-meter isobath path, but then currents change and drive them up the shelf to the northeast. The endpoints in 2000 are the result of a strong turning to the northwest of trajectories that had been moving up the Alaskan peninsula. Further study of possible forcing mechanisms is needed to understand what leads to these years departing from the archetypal two-limbed flow.

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 meters 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 3 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.

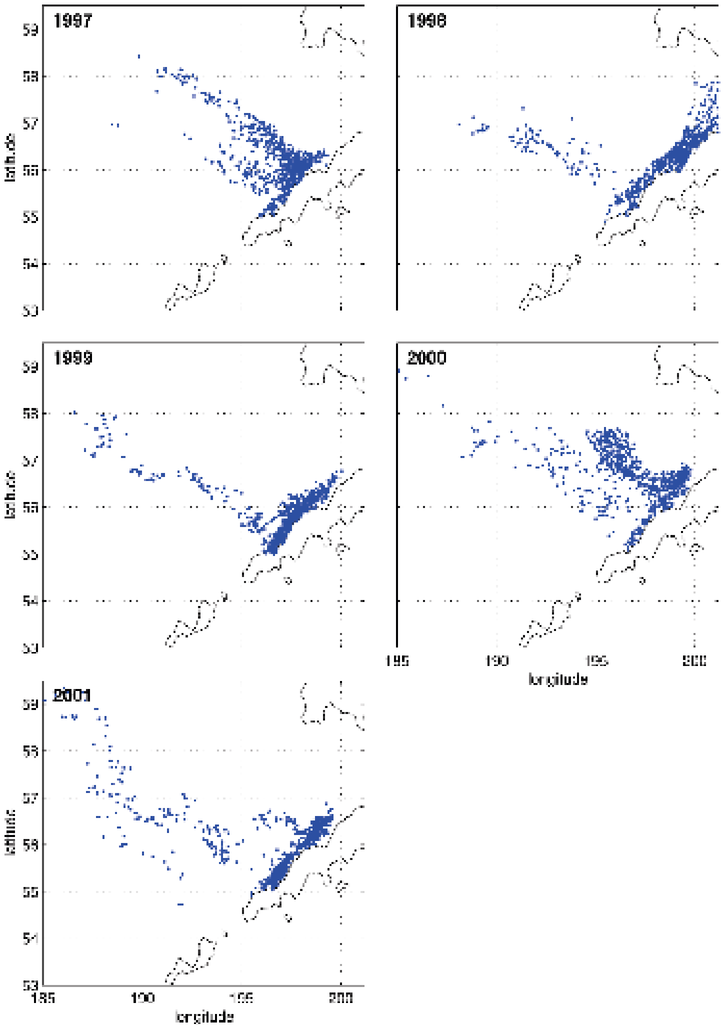

Figure 2. Endpoints for 90-day drifter trajectories for 1997-2001.

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 five meters of the water column (upper right panel of Figure 3). But with deeper release points comes a stronger divergence of the trajectory fates. In the 5-20 meter and 20-40 meter release bins there are significant numbers of drifters that join the 100-meter isobath flow to the northwest, with some even moving through Unimak Pass before turning back. The OSCURS model, which only models surface currents, would completely miss this variation in particle fates.

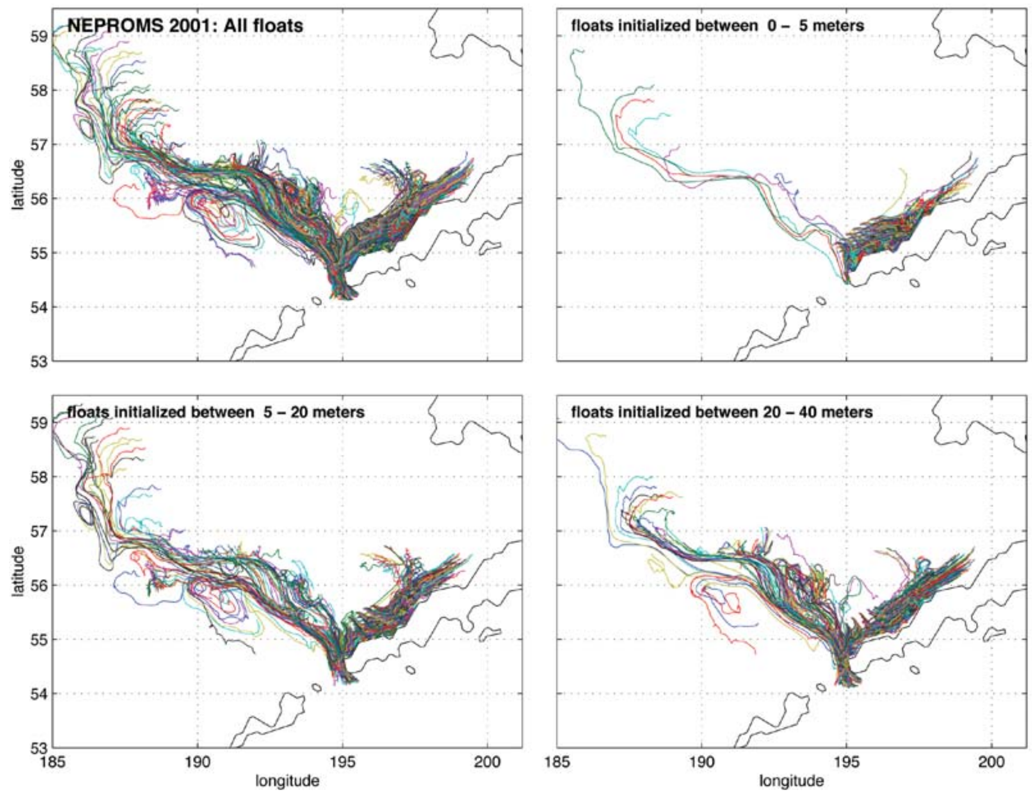

Figure 3. Full trajectories for the 2001 90-day simulated drifters. Upper left panel shows all drifters, while the upper left and bottom panels show drifters divided as a function of initial release depth.

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Summer bottom and surface temperatures – Eastern Bering Sea

Contributed by Gary Walters, Alaska Fisheries Science Center

The annual AFSC bottom trawl survey for 2003 was started on June 2 and finished on July 22. In general, temperatures continued to climb from the 1999 record low reflecting the lack of winter ice cover for another year. The average bottom temperature was 3.81 ^{o}C, well above the 1982-2002 mean of 2.46 ^{o}C (Figure 1). The average surface temperature was also higher at 7.79 ^{o}C (long term mean 6.60 ^{o}C). Increases in bottom temperature were evident in all major areas of the standard survey (Figure 2). Bottom temperature anomalies from the long term station means were positive over virtually the entire shelf (Figure 3). Maximum anomalies occurred in the middle domain with several stations over +2 degrees Celsius. The ‘Cold Pool’, usually defined as an area with temperatures less than 2 degrees Celsius, barely surrounded St. Matthew Island. This was again reflected in the distribution of walleye pollock in the bottom trawl survey. When middle domain bottom temperatures are warmer, pollock distributions shift into the area. When the cold pool is dominant, pollock distributions seem to shift to the outer domain.

Surface temperature anomalies also reflected increases. Of 356 stations, 187 had temperatures over 1 degree Celsius above station long term means (Figure 4). Unlike the bottom trawl results, the largest increases were inside Bristol Bay.

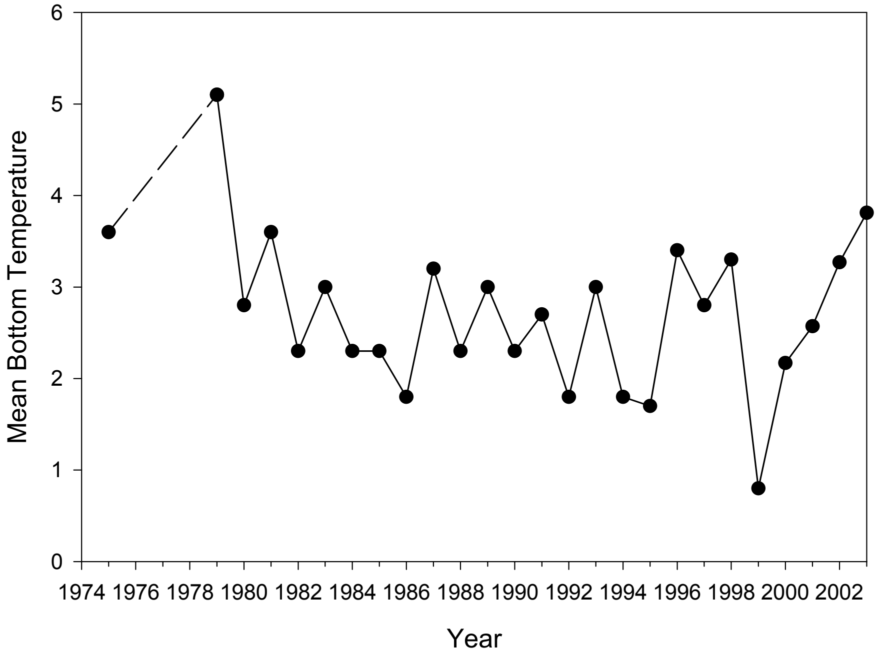


Figure 1. Mean summer bottom temperature (degrees C) in the standard bottom trawl survey area of the eastern Bering Sea Shelf, 1975-2003.

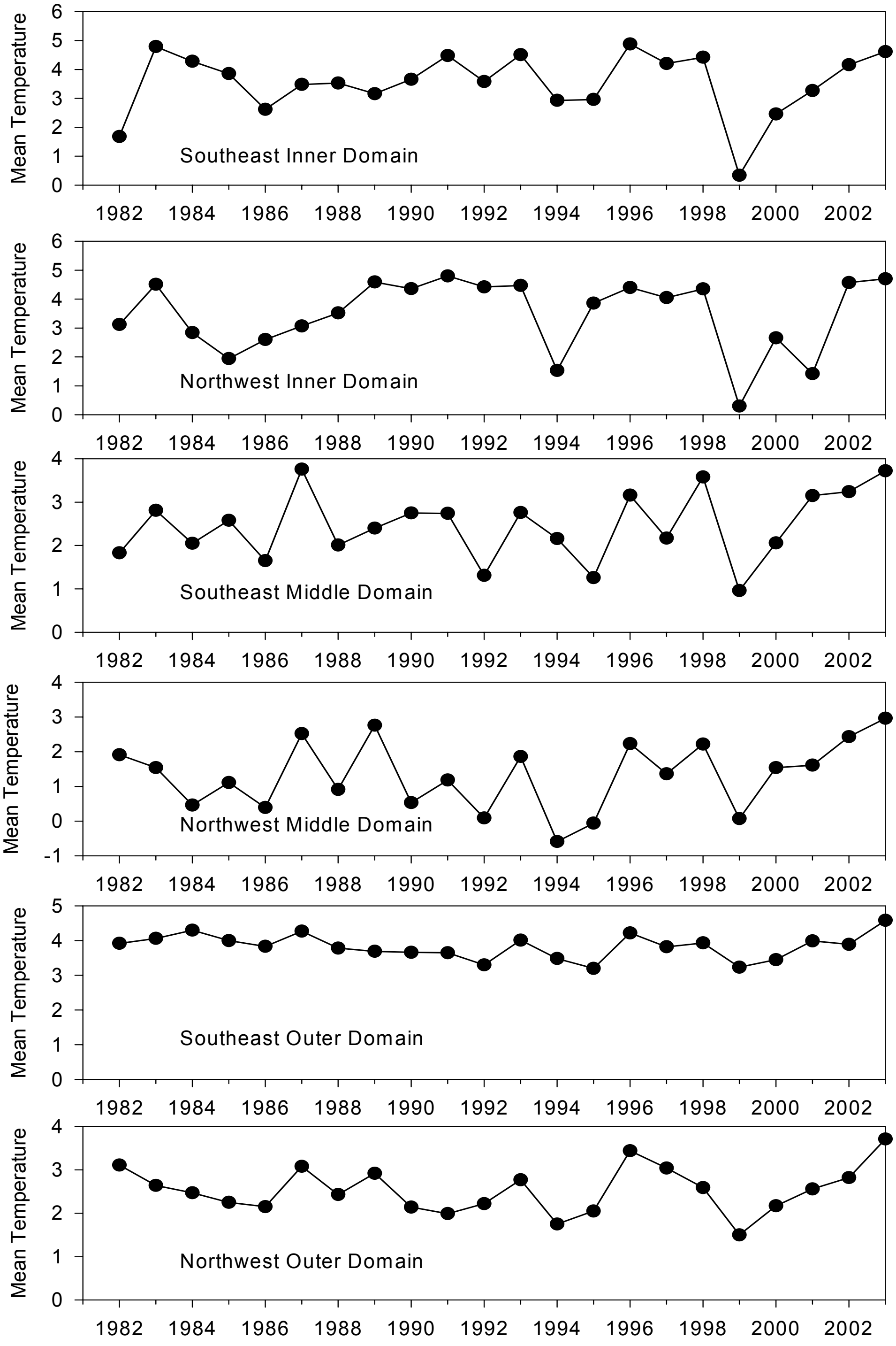
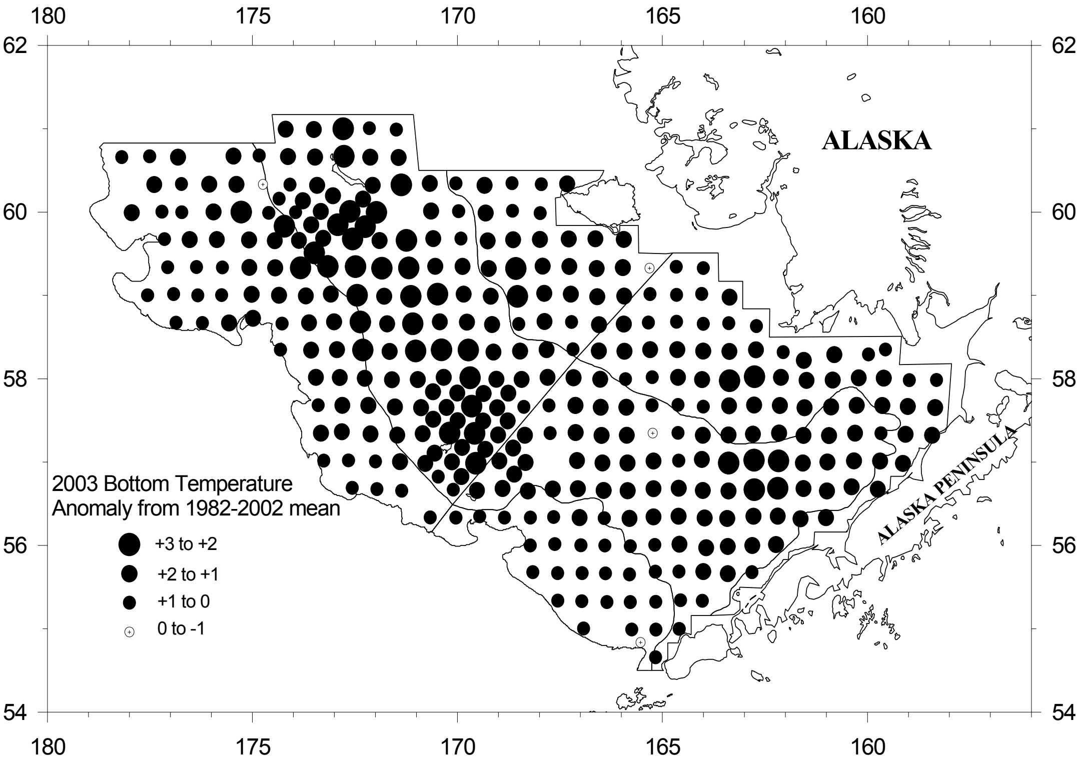


Figure 2. Mean summer bottom temperature (degrees C) by domain in the standard bottom trawl survey area of the eastern Bering Sea, 1982-2003.



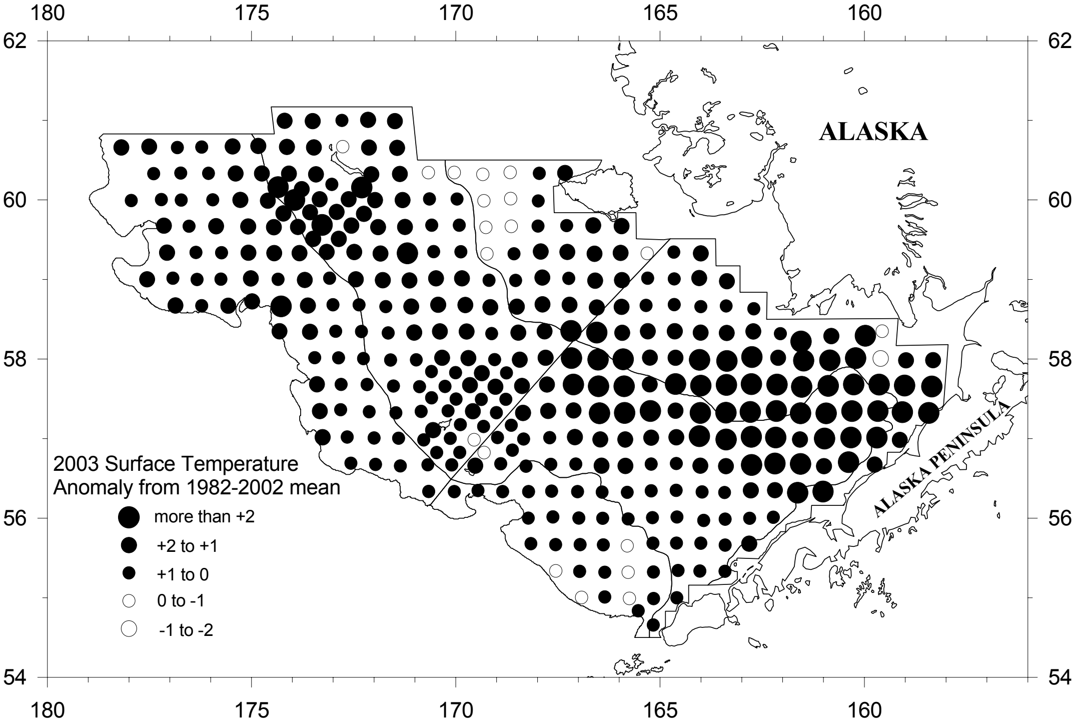


Figure 3. Summer bottom (top panel) and surface (bottom panel) temperature anomalies in 2003 from the 1982-2002 means at standard bottom trawl survey stations in the eastern Bering Sea.

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 may 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 influence of clockwise rotating water, flowing past spawning grounds and westward over the southern shelf, or within the northern margin of the Alaskan Stream, on transport of post-larval or young-of-the-year fish to 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. 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.

Alaska Fisheries Science Center (AFSC) 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 (Figure 1). Of the eight survey years cited in the figure below, all except 1991 had temperature profiles 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: http://www.cdc.noaa.gov/~kew/MEI or contact Klaus Wolter (kew@cdc.noaa.gov). Comments on the timing of ENSO events cited herein reference that graph. As shown in the figure below, the year 2000 produced the coldest bottom temperatures yet detected during summer AFSC groundfish surveys. The warmest years tend to be associated with El Niño events (Figure 1). 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 1). 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 thinner than during other surveys. Unfortunately, we have no data to compare for the intervening years.

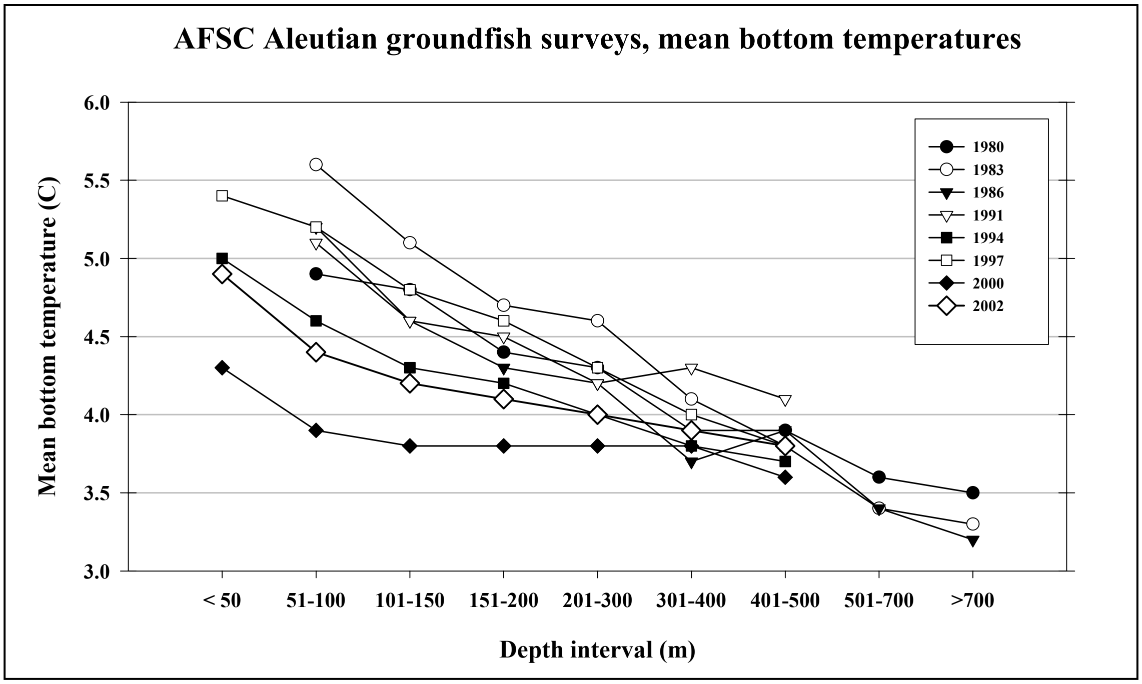


Figure 1. Mean bottom temperatures from the Alaska Fisheries Science Center (AFSC) groundfish surveys.

ENSO events are monitored with the use of the Multivariate ENSO Index (MEI) which is based on six main 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 (Figure 2). 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. In the following figure, mean MEIs for the period from March to the end of each survey period are plotted against mean bottom temperature for four depth intervals. 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 trendline and range from 0.78 and 0.87 suggesting that mean MEI and bottom temperatures are somehow related (Figure 2). The weakest correlation is in the shallowest depth interval, where one might expect to find the most influence of seasonally warmed surface water and storm-caused mixing. Such short term, within-year effects are likely the result of atmospheric forcing and the position and strength of the Aleutian low-pressure phenomenon (Hollowed *et al*. 2001).

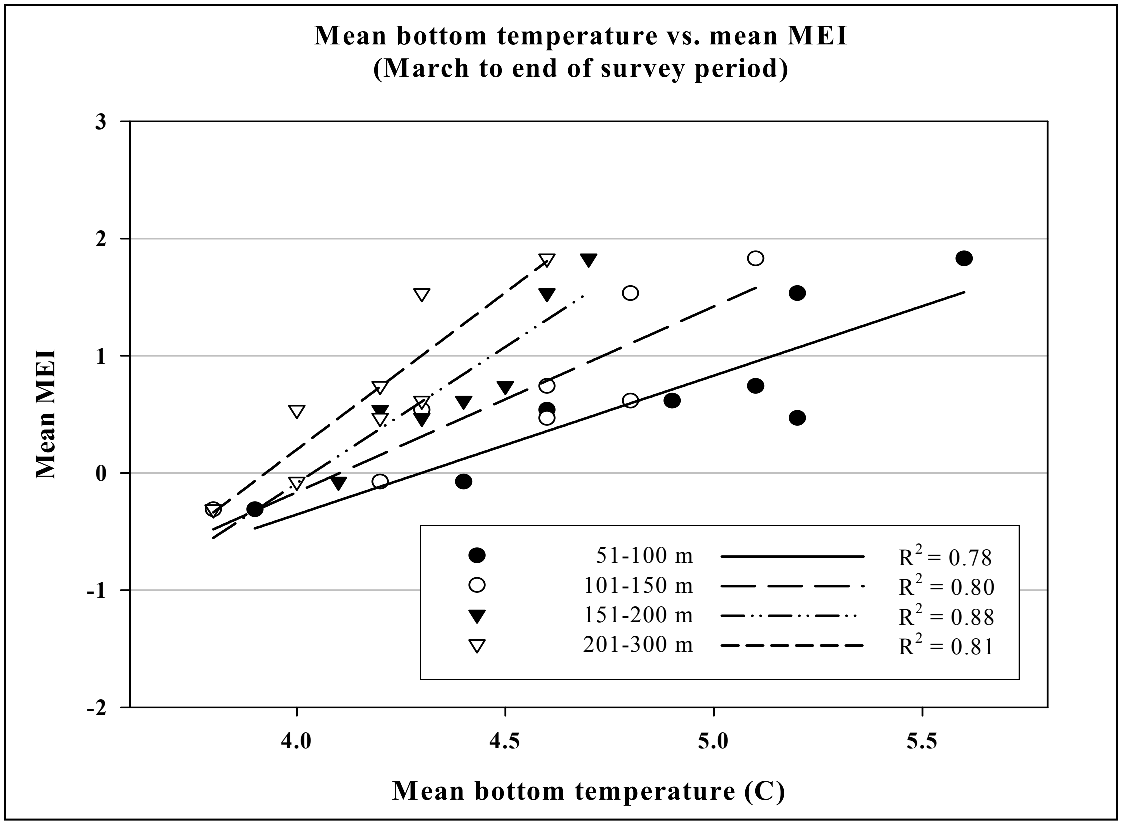


Figure 2. Multivariate ENSO Index (MEI) as a function of summer mean bottom temperatures in the Aleutian archipelago.

Water Temperatures Across the Survey Area

Figure 3 summarizes station-specific bottom temperature distributions by longitude for the 1994, 1997, 2000, and 2002 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 and 176° E longitudes probably resulting from Alaskan Stream water washing over Tahoma Bank and Walls Plateau. Relatively cold temperatures found between 172 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 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 4 shows 2002 survey water temperatures at 12 depths from near surface to near bottom, by longitude. There were areas of warm near-surface water between approximately: (a) 170 to 172° W, (b) 173 to 174° W, and (c) 175 to 177° W longitudes. Relatively warm temperatures continued to be evident with increasing depth, but were more confined between 170 and 172° W longitudes. The warm near-surface water temperatures at (a) were mostly restricted to the southern side of the islands; to the northern side of Amlia Island at (b); and to the southern shelf between Atka and Adak Is. at (c).

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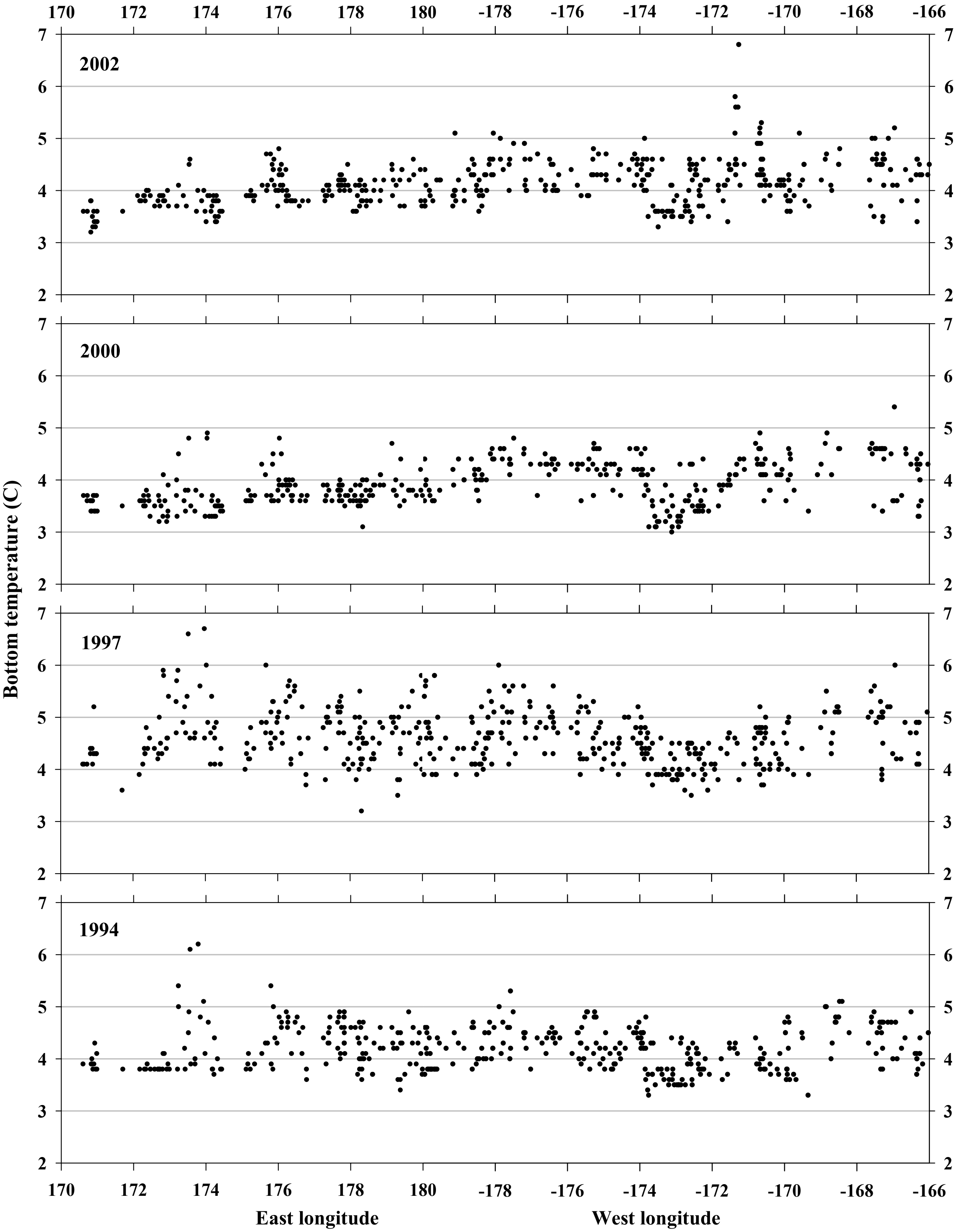

Figure 3. .--Bottom temperatures collected during the four most recent AFSC Aleutian Islands bottom trawl surveys.

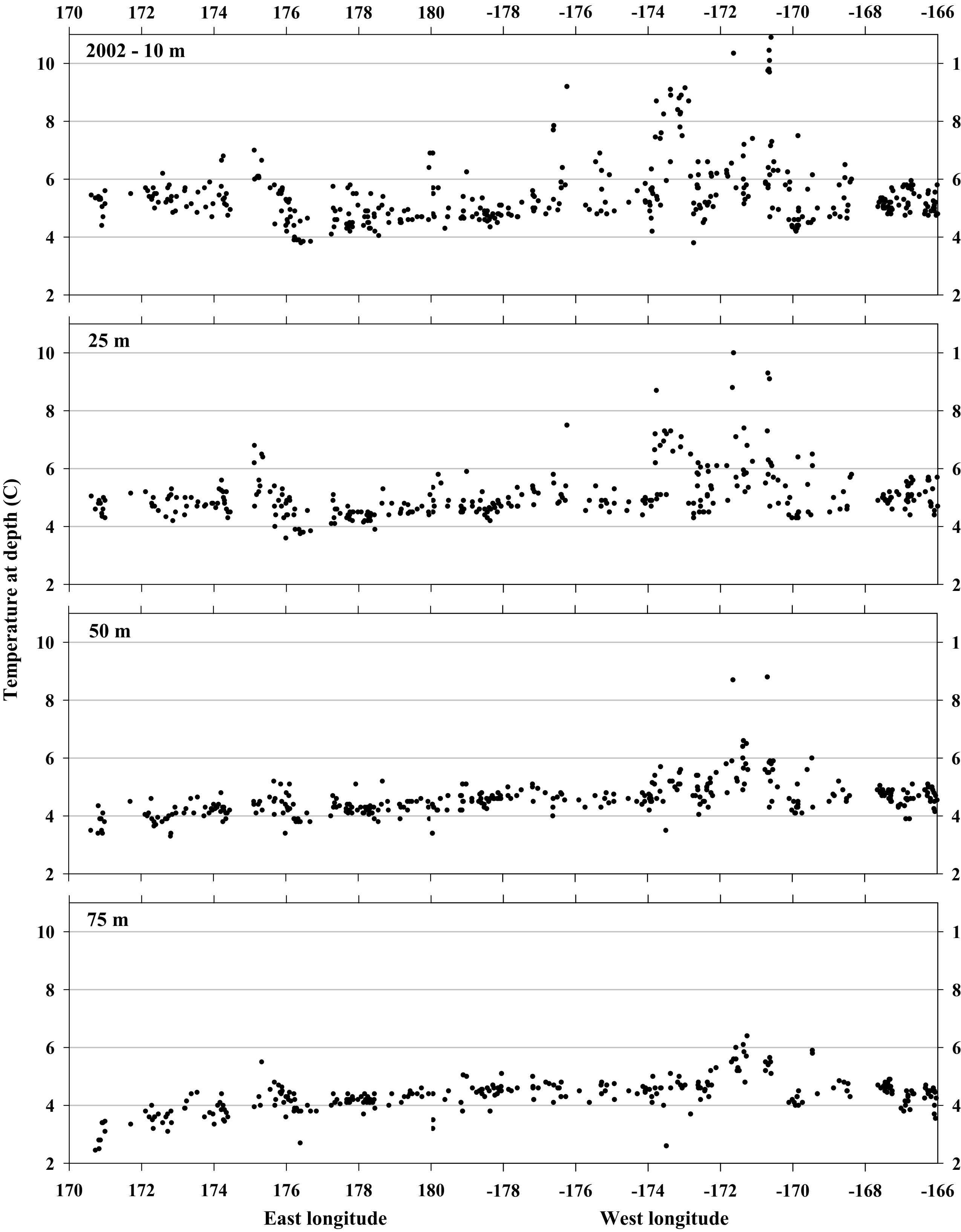

Figure 4 --Temperatures at depth by longitude, collected during the 2002 AFSC Aleutian Islands bottom trawl survey.

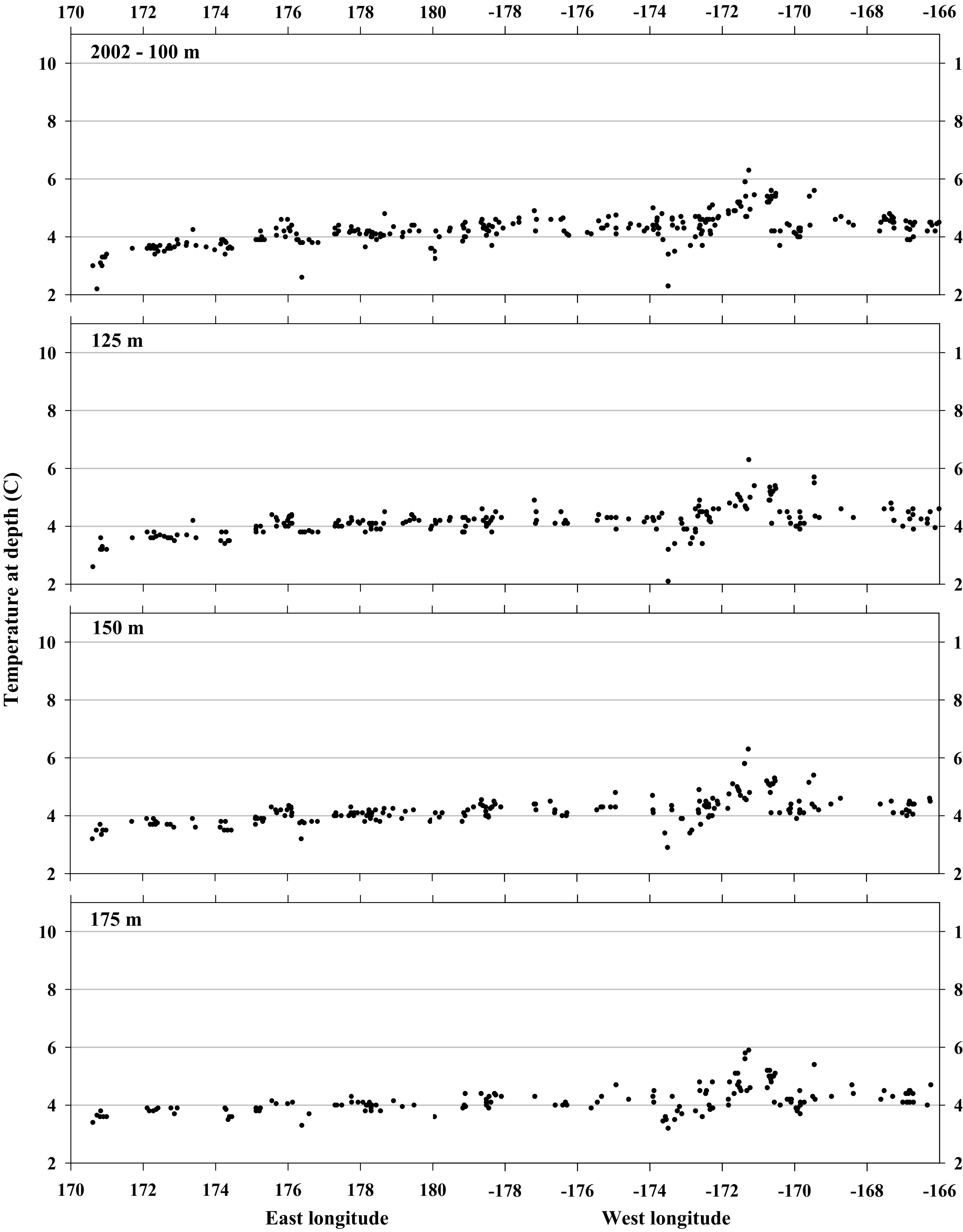

Figure 4. --Temperatures at depth (continued).

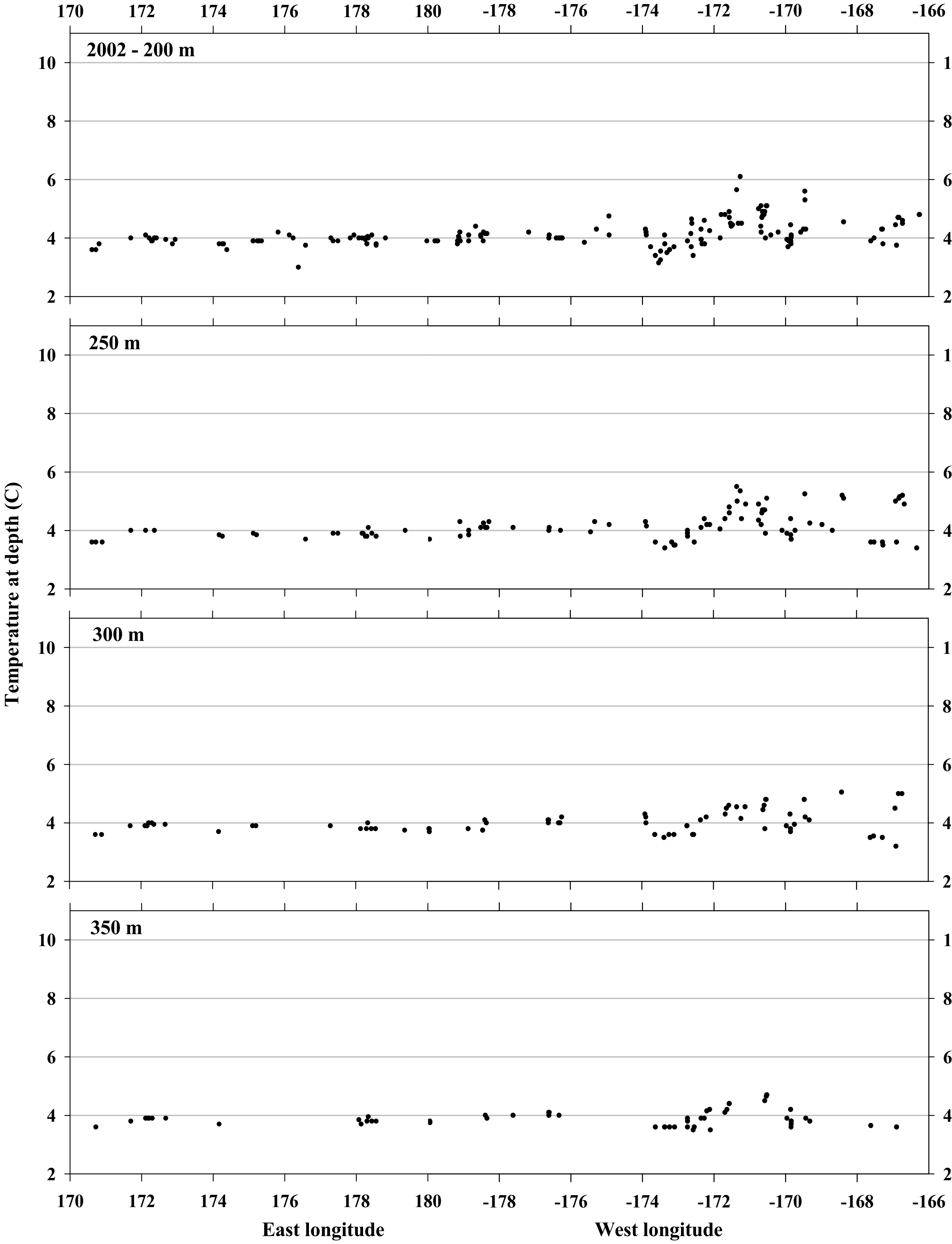

Figure 4. --Temperatures at depth (continued).

Summary of Ecosystem Indicators and Trends Used by FOCI – 2003

Edited by S. Allen Macklin, NOAA/PMEL

On the climate scale, events during the winter and spring of 2003 did not support a regime shift in North Pacific climate that has been hypothesized to have occurred in 1999. In many ways, the winter of 2003 was similar to those from the first part of the post-1977 regime. Although the period 1999-2003 was different from a typical positive PDO pattern, current conditions do not suggest a return to the pre-1977 climate.

Local measurements in the Gulf of Alaska and Bering Sea again demonstrate the wide range of interannual variability in physical attributes of these ecosystems. Ongoing research on transport by eddies and refinement of numerical models bring the promise of additional indices relating to ecosystem productivity for future editions of this report.

Habitat

Harmful Algal Blooms in Alaska

Contributed by F. Gerald Plumley[1], Julie Matweyou[1], and Raymond RaLonde[2]
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Overview

This report reviews the current status of paralytic shellfish poisoning (PSP) in Alaska, with a focus on two study areas on the eastern shores of Kodiak Island. The report focuses on the causative organism of PSP toxin events, the dinoflagellate Alexandrium, and newly emerging DNA probe technologies that quantitatively detect these algae, and possibly predict PSP events. The newly emerging geoduck industry is also described with an emphasis on PSP contamination. The long and legendary history of PSP in Alaska will not be reviewed here, as this topic was thoughtfully covered in a recent report (Trainer 2002). Domoic acid contamination has also been reported in Alaska (Horner et al. 1997), however, the problem appears to be limited in scope and dangerous levels have not yet been reported. Bitter crab disease in the southeast (Horner et al. 1997), though not technically a harmful algal bloom (HAB) phenomenon, is caused by dinoflagellates, related to those that cause PSP. Bitter crab disease is apparently localized to a few regions, but the local impacts are significant. Neither domoic acid or bitter crab disease will be discussed in this report.

Alaska has a well-known history of problems with PSP. Research scientists in the 1930-1950's made frequent summer trips to Alaska to collect contaminated shellfish. Saxitoxin, the etiological agent of PSP, is named for the Alaska butter clam, *Saxidomus giganteus*, a frequently collected, and very toxic, species. Early work conducted by the Alaska Department of Health centered on determinations of PSP toxin levels in shellfish in southeast Alaska, but the data were never published. Similarly, data collected by the Alaska Department of Environmental Conservation since 1985, focused on commercial sites, has not been published. What emerges from these two datasets is a clear and persistent pattern of PSP problems along the Pacific Gulf of Alaska shoreline, but without detailed analysis, there is no way to determine if the problem has been increasing or decreasing over time, shows predictable patterns in response to El Nińo events or to decadal long cycles related to the Aleutian Low Pressure cell. NOAA has recently provided funding to perform a retrospective analysis of these datasets.

On a global scale HAB events appear to have been steadily increasing over the past few decades in frequency, intensity and geographic distribution (Anderson 1989; Smayda 1990; Hallegraeff 1993). Hallegraeff (1993) suggests possible explanations for this trend including human-related nutrient enrichment selecting for HAB species (Lam and Ho 1989; Okaichi 1989), dispersal of HAB species via ship ballast water (Hallegraeff et al. 1988; Hallegraeff et al. 1990) and shellfish seeding activity, increased utilization of coastal waters for aquaculture (Shumway 1990), and long term climate trends (Ebbesmeyer et al. 1995), i.e., global warming. Unfortunately, historical records of PSP events in Alaska are sparse, making it difficult to determine if there have been parallel increases in HAB events.

Health Impacts

From 1973 through 1994 the Alaska Division of Public Health documented 71 outbreaks of PSP involving 141 people from coastal communities around the state (Division of Public Health www.epi.hss.state.ak.us). Cases were reported in all months except November and December during this time period, and a variety of shellfish were implicated in these illnesses. Since 1994 at least 17 additional illnesses, from five separate outbreaks, have been documented, and many cases are thought to go unreported (www.epi.hss.state.ak.us). Gessner and Middaugh (1995) were unable to find an association between race, age or sex of the victim and PSP illness, suggesting that all persons are at equal risk from consumption of shellfish taken from uncertified beaches.

Economic Impacts

Commercially, the loss of revenue due to PSP toxins has been extensive, affecting both the crab and clam fisheries (Ralonde 2001). Crab processing and handling have been changed from a whole, live product to a sectioned, cooked one due to PSP toxins found in crab viscera. Once a growing industry, the Alaska clam industry today is virtually nonexistent due to the destruction of the market by PSP contaminated product in the 1940's. It remains perhaps "the largest untapped fisheries resource in the United States" (Neve and Reichardt 1984). The difficulties, expenses and fear of contamination make developing a viable shellfish market a financial risk. The Alaska Department of Environmental Conservation (ADEC), located in Palmer, AK, operates a testing program that requires commercially harvested shellfish to comply with strict, tiered, lot sampling (RaLonde 2001). Under this program, commercial operations pay for the collection, shipping and holding of their shellfish.

Causative Organisms of PSP

In the North Pacific, PSP is caused by dinoflagellates of the genus *Alexandrium*, primarily *Alexandrium catenella* (Prakash and Taylor 1966; Price et al. 1991; Horner et al. 1997). However, three morphologically similar species have been recognized in Alaska: *A. catenella* (Whedon and Kofoid) Balech, *A. tamarense* (Lebour) Balech, and *A. fundyense* Balech. Scholin et al. (1994) sequenced rRNA from several *Alexandrium* species and found that the large subunit (LSU) rDNA sequences provided fine-scale species and population resolution. From this sequencing work, five distinct ribotypes were identified, one of which was the *tamarense/catenella/ fundyense* species complex. Each ribotype was named with reference to its geographic origin. *Alexandrium* spp. present in Alaska waters are grouped in the "North American" ribotype group. Preliminary data suggests that *A. catenella* from the "Temperate Asian" group may also be present in Alaska (Matweyou 2002). Finally, it should be noted that there are re-occurring reports of variants of *Alexandrium* that live in the Arctic (e.g., Barrow, AK), but these reports have not been unequivocally substantiated, as this genus appears to be restricted to regions south of the Aleutian Island chain.

There are 29 recognized species within the genus *Alexandrium*, with at least 8 – 10 toxic species (*A. acatenalla, A. catenella, A. cohorticula, A. fundyense, A. ostenfeldii, A. minutum, A. tamarense* and *A. tamiyavanichi*). The genus name has changed as new species and morphological traits have been identified. *Alexandrium*, *Protogonyaulax*, *Gessnerium*, *Pyrodinium*, *Goniodoma* (in part), and *Gonyaulax* (in part), have all been used synonymously

(Steidinger1993). The genus name *Alexandrium* was agreed upon at the 4th International Conference on Toxic Marine Phytoplankton under the classification proposed by Balech (1985).

For completeness, it should be pointed out that at least two other dinoflagellates, *Pyrodinium bahamense* and *Gymnodinium catenatum,* synthesize PSP toxins. Both species appear to be restricted to more temperate waters than are found in Alaska. Cyanobacteria (blue-green algae) are also known to synthesize PSP toxins, but thus far, all species are from freshwater habitats. At least one red alga synthesizes PSP toxins (reviewed in Cembella 1998). Finally, it has been frequently hypothesized that bacteria (e.g., *Pseudomonas* spp.) synthesize PSP toxins, but this rather hotly contentious issue has not been confirmed (Baker et al, 2003). The production, or potential production, of PSP toxins by species other than *Alexandrium* is problematic and could, in theory, explain earlier reports from Alaska (see below) that PSP toxins in shellfish were not correlated with *Alexandrium* abundance in the water column. Transport of toxic algae (and other nuisance species) in ballast waters either into or out of Alaska remains a potential problem.

The Complex Interplay between Genetic Factors and Environmental Factors Makes it Difficult to Predict Ecosystem Level Responses to *Alexandrium* Blooms

Toxic species of *Alexandrium* synthesize saxitoxin, the etiological agent of PSP poisoning, as secondary cell byproducts (Cembella 1998). Saxitoxin is a neurotoxin that acts as a sodium channel blocker, preventing the uptake of Na^+, thus stopping the flow of nerve impulses (Strichartz and Castle 1990). Saxitoxin is typically accumulated in filter feeding shellfish that are relatively immune to the toxin, and is transferred through the food chain by secondary consumers (Hall et al. 1990). Symptoms in humans include tingling and/or numbness in the lips and extremities, nausea, dizziness, shortness of breath, and in extreme cases, paralysis and death (Meyers et al. 1928). The toxins are water-soluble and will pass from the system without causing permanent damage if victims are kept alive during the stages of respiratory paralysis. The toxins can also be passed through the pelagic food web via zooplankton and forage fishes, ultimately affecting upper trophic levels; i.e., fish, seabirds and marine mammals (Geraci et al. 1989).

There are at least 22 recognized saxitoxin congeners, chemical forms that differ slightly (e.g., addition of an hydroxl or sulfate group) in chemical structure, but differ significantly (>100 X) in toxicity. Some congeners are "essentially non-toxic" while others are extremely potent neurotoxins. Saxitoxin congeners are differentially synthesized by different species of *Alexandrium*. Some species accumulate "non-toxic" congeners while other species accumulate more toxic forms. Similarly, there are recognized strain-to-strain variations within the same species. By way of analogy, saxitoxins are alkaloids, along with the more familiar alkaloid caffeine, which is well known to vary in potency in different species and varieties of *Coffea* spp and to accumulate to different levels when plants are grown under different environmental conditions.

Environmental conditions can have a pronounced impact on the synthesis of different saxitoxin congeners (i.e, toxin profile) as well as on the total cellular accumulation of all saxitoxin congeners (i.e., toxin content). For instance, growth of *Alexandrium* under P-limited conditions results in elevated toxin levels (Hall 1982; Anderson et al. 1990) whereas growth under N-limited conditions results in low toxin levels (Anderson et al. 1990). Both P- and N-limited growth result in reduced division rates, such that from an ecosystem standpoint, there would be fewer cells under both conditions, but these cells would either be highly toxic (P-limited) or less toxic (N-limited).

Life Cycle Strategies of Alexandrium also Complicate Our Understanding of Blooms at the Ecosystem Level

The complexity of the *Alexandrium* life cycle, altering between an asexual and a sexual stage, enables cells to persist through unfavorable conditions as well as to thrive in a spectrum of habitats and hydrographic regimes (Anderson 1998). The vegetative cells are able to divide rapidly during favorable conditions. Under nutrient stress, typically limitation in nitrogen or phosphorous (Anderson et al. 1984), gametes (isogamous or anisogamous depending on species (Turpin et al. 1978; Anderson 1980)) are formed, and fuse to form a zygote. The swimming zygote (planozygote) becomes a dormant, resting cyst (hypnozygote) that can survive in sediments for years (Cannon 1993). Cysts must undergo an obligatory dormancy period during which physiological "maturation" is presumed to occur. Once maturation is complete, cysts enter a quiescent period when they are physiologically capable of germination, but may be prevented from doing so by some environmental factor. Germination requires favorable temperatures, light, salinity, and oxygen conditions (Cannon 1993; Anderson 1998). Although nutrient stress induces cyst formation, nutrient concentrations do not appear to affect germination (Cannon 1993). The dormancy and germination cycles are even more complicated, as an endogenous clock also regulates these processes in *A. tamarense* (Anderson and Keafer 1987).

Alexandrium Seedbeds and Bloom Dispersal: A Hypothesis

The complex requirements for cyst dormancy and subsequent germination raise the distinct possibility that germination can only take place in a limited number of habitats. In other words, it is a common assumption that overwintering cyst "seedbeds" provide the inoculum for *Alexandrium* blooms (Anderson 1998). Under this scenario, blooms would be initiated only in areas where light, oxygen, salinity, and temperature favored germination after the winter dormancy period. Persistent, reoccurring PSP problems would be expected in "seedbed regions" whereas PSP problems in adjacent areas would depend upon currents and wind conditions. Although cyst seedbeds have not be documented in Alaska, it is well known that some areas have persistent and seasonally recurring problems with PSP toxins, some areas have intermittent problems from year to year, while PSP problems are surprisingly absent in other areas. Similar area-specific patterns of PSP problems have been observed in the New England states bordering the Gulf of Maine. Franks and Anderson (1992a and b) determined that the temporal and spatial patterns of shellfish toxicity along the coast were consistent with buoyancy-driven, alongshore transport of *Alexandrium* populations (as opposed to *in situ* growth of *Alexandrium*), with blooms arising from specific seedbeds in the Casco Bay region (Anderson 1997). *Alexandrium* cells from Casco Bay become trapped in the freshwater buoyant plume and carried south. The plume behavior was influenced by the volume of freshwater outflow, as well as alongshore winds. Downwelling-favorable winds from the northeast trapped the plume onshore and accelerated the plume southward. Upwelling-favorable winds slowed the plume and moved the cells offshore. Timing and toxin intensity south of the plume were dependent on the strength and speed of the plume. Other habitats in the region are likely to be controlled by a combination of these physical processes, as well as tidal mixing and tidal fronts (Anderson

1997). More detailed studies (Anderson 2002) have refined these earlier studies, resulting in minor alterations of the basic points, while presumably maintaining the overall theme that seedbeds, plumes, currents, and wind induced upwelling/downwelling conditions impact the dynamics of *Alexandrium* blooms and the spread of PSP toxins throughout an ecosystem. The seedbed hypothesis remains an attractive, yet unproven, model to explain ecosystem level PSP problems in Alaska.

Other studies have linked toxic dinoflagellate blooms with upwelling relaxation in Spain (Fraga et al.1988), California (Price et al. 1991), South Africa (Pitcher 1998) and, theoretically, off the northern California coast (Horner et al. 1997). These studies provide further evidence that large-scale physical processes affect bloom dynamics. Unfortunately, no sustained field studies have been conducted in Alaska that combine physical oceanography with study of *Alexandrium* blooms. No evidence is available to support, for instance, the hypothesis that low abundance winter populations of *Alexandrium* survive in offshore waters and that these populations provide an inoculum for nearshore habitats when wind and temperature regimes shift in the summer. This hypothesis provides an attractive alternative to the seedbed hypothesis, and further emphasizes the need to couple biological studies of *Alexandrium* with physical oceanography and climatic (e.g., El Nińo) events that affect ecosystem functions.

New Technologies to Detect and Predict PSP Events

One goal of PSP research has been to develop protocols and strategies for predicting the onset and severity of harmful algal blooms, such as those associated with *Alexandrium*. The following section describes efforts to implement a monitoring program in Alaska that focuses on *Alexandrium* as an indicator species of future PSP events in shellfish. We start with a rational for these approaches, and note first that monitoring shellfish for the presence of PSP toxins is, by far, the only safe way to determine if there has been a bloom of *Alexandrium*. This approach provides very little data about when the bloom started, its density or its duration. These data require direct analysis of *Alexandrium* abundance and distribution. In contrast, *Alexandrium* abundance measurements taken repeatedly potentially can predict future PSP toxin events in shellfish. In light of the relationship between *Alexandrium* and shellfish toxicity, phytoplankton monitoring programs are now being used in several parts of the world and have proven to be an effective “first line” strategy for estimating shellfish toxicity (Ono et al. 1996; Trusewich et al. 1996; Rhodes et al. 2001).

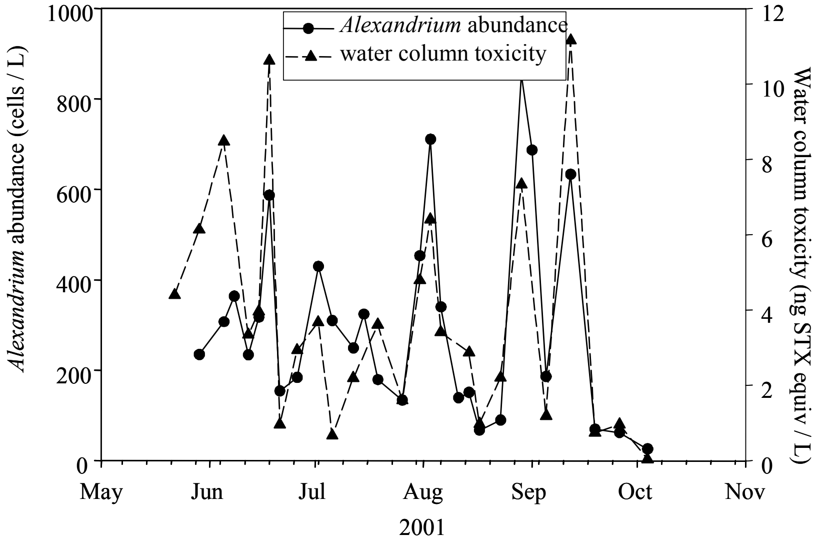

Figure 1. *Alexandrium* abundance, estimated with the sandwich hybridization assay, and water column

One critical question is whether there is a relationship between the amount of PSP toxin in the water column and the abundance of Alexandrium spp. A plot of Alexandrium abundance vs. water column toxicity showed a strong correlation in 2001 (Figure 1; r^2 = 0.71 based on linear regression analysis). This is a surprisingly high correlation given the inherent errors involved in the sandwich hybridization assay as well as the well-known variations in toxin content of Alexandrium grown under different environmental conditions (Cembella 1998). This high correlation speaks well of the sandwich hybridization assay and suggests that it may be possible to use this assay to predict PSP toxin events in shellfish.

Toxicity averaged 13.7 pg saxitoxin equivalents per Alexandrium cell throughout 2001, a value similar to that reported for Alexandrium in other regions (Cembella 1998**.** To the best of our knowledge, cellular toxicity values have not been previously reported for Alaska. As noted previously (Trainer 2002), Alaska has some of the highest shellfish PSP toxin levels in the world. These cellular toxicity values for Alexandrium allow us to speculate that high toxin levels in shellfish in Alaska result from high populations of Alexandrium, not from strains (or species) of Alexandrium that are "more toxic" than those routinely encountered. This speculation requires verification.

Mussel Toxicity – Correlations with *Alexandrium* Abundance

We next asked if there were seasonal trends in *Alexandrium* abundance that could be detected with the sandwich hybridization assay and, more importantly, whether these trends were correlated with PSP toxin levels in shellfish. We chose to use blue mussels (*Mytilus edulis*) as a "sentinel" shellfish for this work, as this species has the ability to accumulate extremely high levels of toxins when *Alexandrium* blooms are present and subsequently depurate the toxins at fairly rapid rates (on the order of weeks) once the toxic algae disappear from their food source (Price et al. 1991). In other words, mussels are excellent integrators of "current events" in the water column. For this study, approximately 40 mussels were collected weekly from beaches close to the water collection sites. Mussels were selected with an average shucked wet mass of 3-5 grams per mussel. Mussel toxins were extracted according to the Association of Analytical Communities (AOAC) protocol (AOAC 1995) and toxins analyzed with the receptor-binding assay (Trainer and Poli 2000). *Alexandrium* abundance was estimated from the sandwich hybridization assay as described above.

Alexandrium cell densities during the summer of 2000 ranged from near zero to 1100 cells/L with two distinct peaks in late May and late August (Figure 2). During the summer of 2001, *Alexandrium* abundance ranged from near zero to about 850 cells/ L (Figure 2). *Alexandrium* densities fluctuated throughout the summer with five peaks of 400 cells/L or greater, occurring in June, July, August, and two in September.

When the *Alexandrium* abundance data are compared to mussel toxicity levels (Figure 2), there appears to be a positive correlation between the two measurements. Statistically, the relationship between *Alexandrium* abundance and mussel toxicity was moderate to weak (r^2= 0.44 in 2001; r^2= 0.10 in 2000). However, a generally weak correlation is expected for several reasons. A newly initiated bloom of *Alexandrium* would presumably require several days to appear in the toxic profile of shellfish and, once the bloom terminates, shellfish toxicity would remain high due to the lag in depuration of accumulated toxins. This scenario, in general, appears to explain the relationship between *Alexandrium* abundance and mussel toxicity in these samples (Figure 2), especially in 2000. Both *Alexandrium* abundance and mussel toxicity showed two distinct peaks, with the general trend of increased *Alexandrium* abundance followed by, or at least closely linked to, a rise in mussel toxicity.

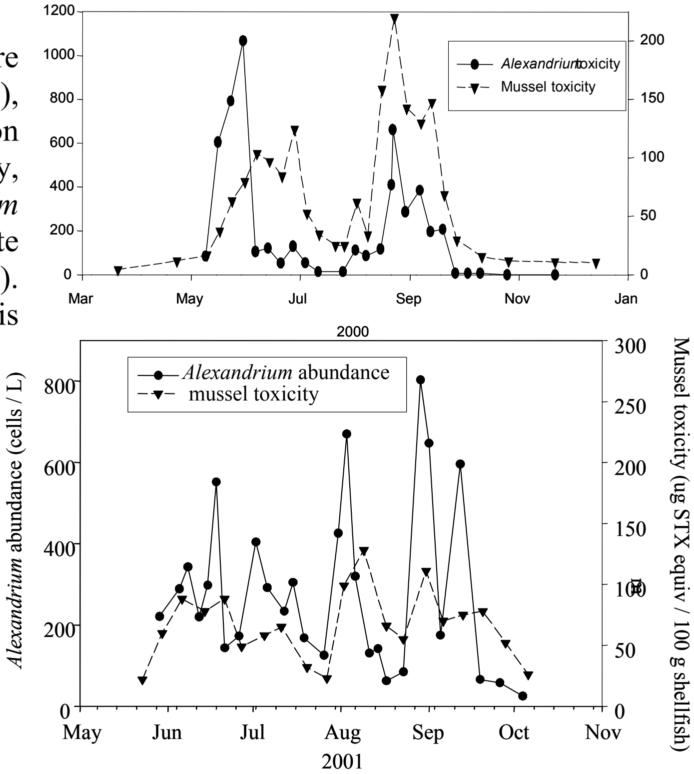

Figure 2. *Alexandrium* abundance, as determined by the sandwich hybridization assay, and mussel toxicity in 2000 and 2001 at a single location on Kodiak Island.

Although much work remains to be completed, the data collected thus far indicate that increases in *Alexandrium* abundance precede elevated toxin levels in shellfish. We tentatively suggest that a monitoring program focused on *Alexandrium* could be a valuable tool to predict toxic events in shellfish before they are harvested.

Mussel Toxicity at Various Sites on Kodiak Island -- Are *Alexandrium* blooms local?

One question that still needs to be addressed before deploying a full-blown monitoring program pertains to the extent to which a few localized monitoring stations can provide *Alexandrium* data for a broad geographical area. To address this question, we collected mussels from four to seven sites on the eastern end of Kodiak Island during the summers of 1999, 2000, and 2001.

Mussel toxicity was at moderately high levels (> 200 µg toxin/100 gm shellfish meat) at 5 of the 7 test sites when sampling was initiated in early July 1999 (Figure 3).

Despite the site-to-site variation in mussel toxicity levels as well as the year-to-year variations in the timing of PSP toxins in mussels, there were clear indications that all sampling sites on the southeastern shores of Kodiak Island showed the same general patterns of toxicity within a specified bloom period. From these data, it seems reasonable to speculate that a few strategically placed monitoring systems could be used to predict PSP events in shellfish over a fairly broad region.

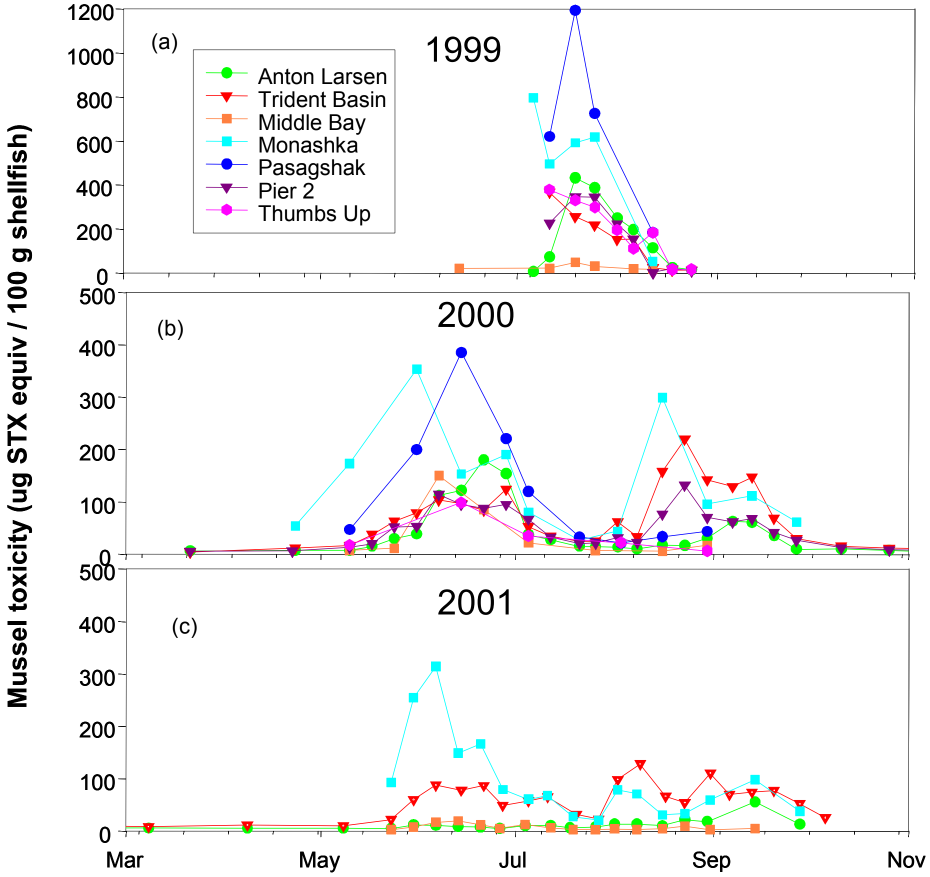

Figure 3. Toxicity of mussels collected at various sites in the NE Kodiak Island vicinity in (a) 1999, (b) 2000 and (c) 2001.

Two sites, Anton Larsen and Trident Basin (Figure 3) were sampled monthly throughout the winter of 2000. Mussel toxicity remained below 10 µg STX equivalents/ 100 g shellfish from October 2000 to May 2001. This is the first direct evidence that shellfish such as mussels, which are known to rapidly depurate toxins, do not show wintertime spikes of PSP toxins, presumably arising from ingestion of cysts resuspended from bottom sediments. This pattern of PSP toxin levels in mussels, which reside in the upper intertidal reaches, may not be typical of shellfish, such as geoducks, which are found at depth.

Oysters

Another case study that is currently under construction involves the southern southeast section of Alaska north of Ketchikan. Oyster farmers in 1978 through the 1980s experienced repeated PSP occurrences that interrupted sales to market. Levels in the southern Etolin Island complex have reached toxin levels of 900 µgs/ 100 grams of tissue (RaLonde and Painter 1995). More recent data are being analyzed to determine if seasonal and/or longer-term trends are evident in this important Alaska fishery.

Alaska Geoduck

The meat of geoduck clams does not accumulation PSP toxins. However, the visceral ball can accumulate PSP above regulatory limit. Viscera toxin concentrations vary significantly between individuals harvested from the same general location in Alaska. As an example, during a single harvest day at Gravina Island near Ketchikan, toxin levels from individual clams varied from 41-559 µgs. The Food and Drug Administration limit is 80 µg/100 grams of tissue. The PSP toxin level is unacceptably high year around, leading to suspicion that toxin bearing cysts in the sediment are causing the visceral toxicity. Visceral concentrations appear to be regional with the highest levels recorded in the southern fishery near Ketchikan, while Symonds Bay near Sitka seldom exceeds the regulatory limit. Water currents in the region nearer the mainland and east of the archipelago appear to be flowing in a prevailing northerly direction which may be the reason the entire region is susceptible to PSP while the more western area open to the Gulf of Alaska current have relatively few occurrences of PSP (Figure 4). Seasonal trends occur with relatively low toxin levels during the summer and early fall, increasing in late fall and generally reach maximum levels during the late to early spring (Figure 5).

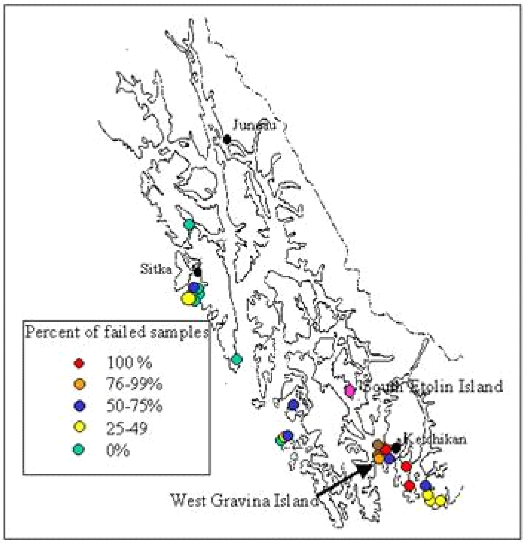

Figure 4. Percentage of failed geoduck clam samples (greater than 80 ug STX/100 g of shellfish meat) from the southeast Alaska commercial fishery.

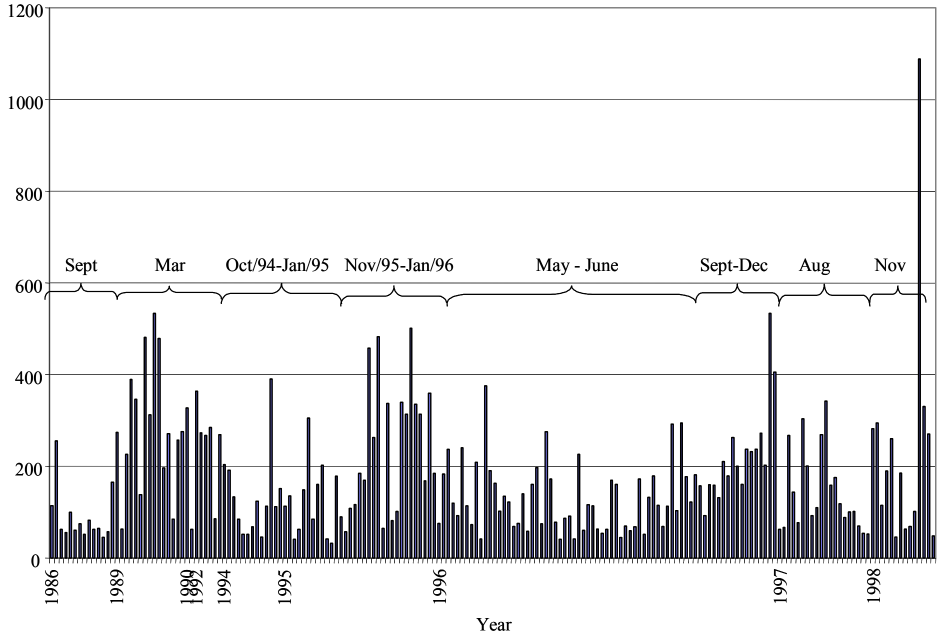

Figure 5. Paralytic shellfish poison toxin measurements from the West Gravina Island geoduck clam fishery.

Finally, it is important to point out that these geoduck data, as well as all available shellfish PSP data, are limited in scope because marine toxins are measured only in commercially farmed or harvested data in Alaska. Determining the oceanographic characteristics that impact the PSP toxin levels and distribution will require additional research that also includes measurement of toxins levels in non-commercial shellfish.

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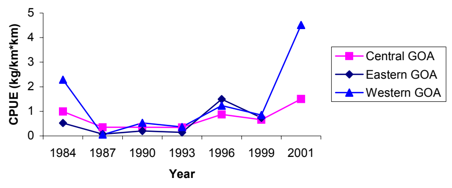
HAPC Biota – Gulf of Alaska (not updated for 2003)

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.

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 large 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. 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.

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.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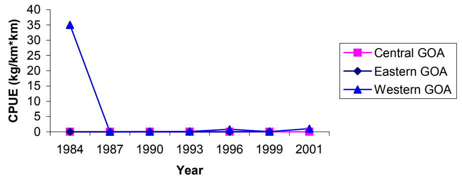
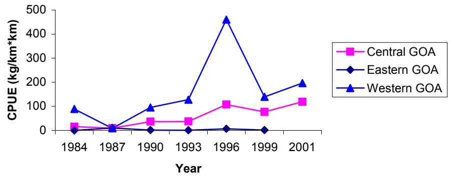

Soft Coral GOA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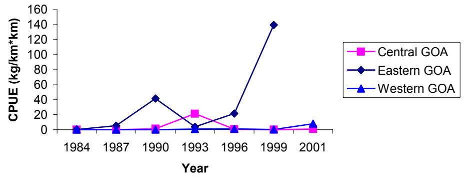
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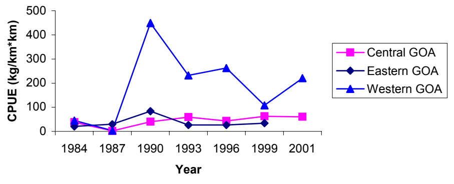
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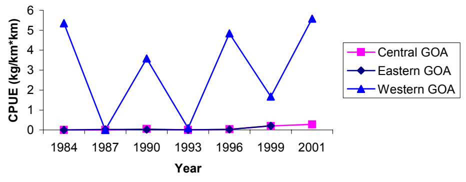

Stony Coral GOA

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 2003 show trends in the biomass index of these groups on the Bering Sea shelf (Figure 1). Seapens/whips trends show the possibility of three peaks in abundance: in the late 1980's, late 1990's, and in 2003 (the highest catch in the time series). Anemone biomass appeared to be higher in the 1980's than in the 1990's, although there are large fluctuations in anemone biomass estimates from year to year. The sponge biomass index 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 biomass trends.

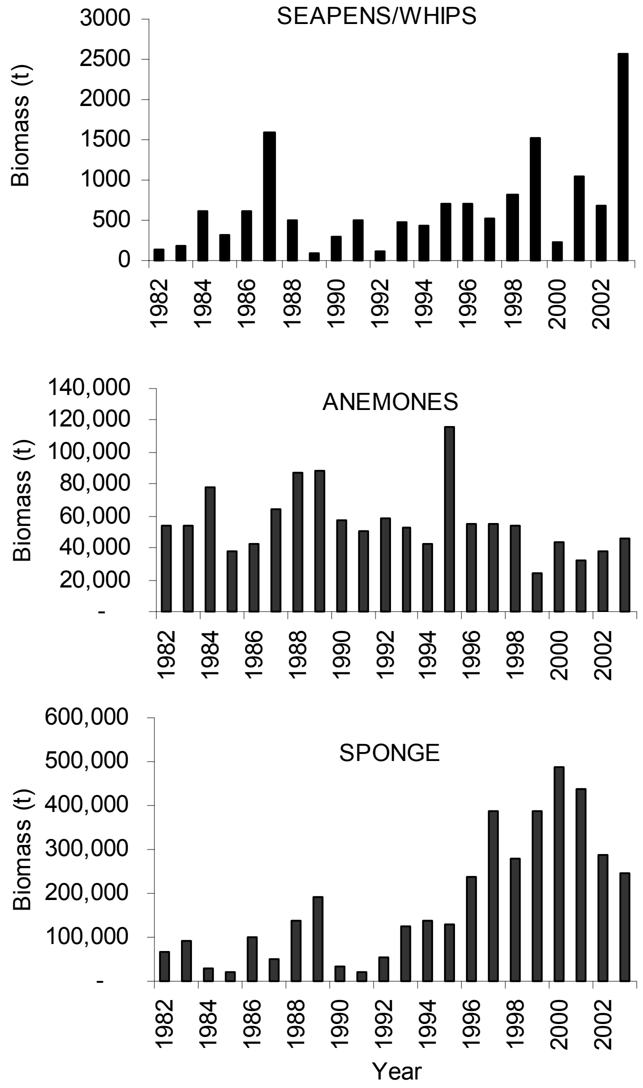


Figure 1. Biomass trends of HAPC biota from the RACE bottom trawl survey of the Bering Sea shelf, 1982-2003.

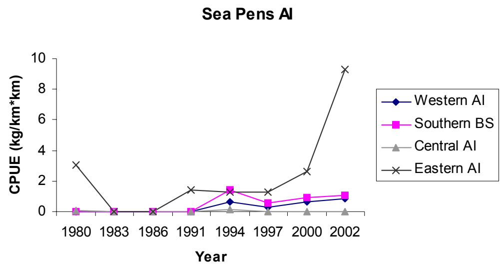
HAPC Biota – Aleutian Islands

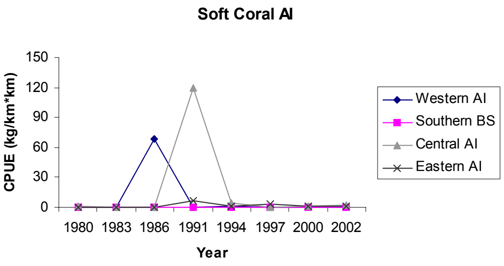
Contributed by Eric Brown, Alaska Fisheries Science Center

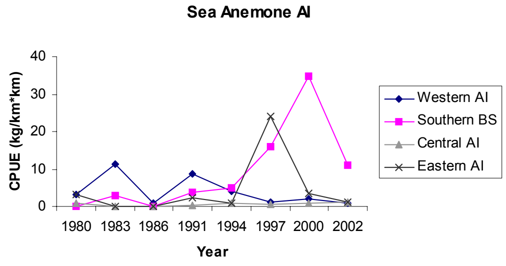
This is the first look at biomass index trends of HAPC biota (seapens/whips, coral, sponges, and anemones) from the RACE bottom trawl survey in the Aleutian Islands. This survey is not designed to assess these organisms and further detailed examination of these results is needed to assess whether there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

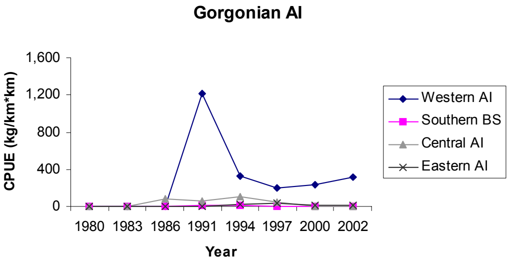
Sea anemones are common in trawl catches but the apparent large increase seen in the southern Bering Sea in 2000 was due to two large catches of 27 kg and 48 kg with other catches rarely exceeding 3 kg. Similarly, the apparent increase in abundance of soft corals in the central Aleutians in 1991, gorgonian corals in the western Aleutians in 1991 and stony corals in the central Aleutians in 1997 was 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. 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.

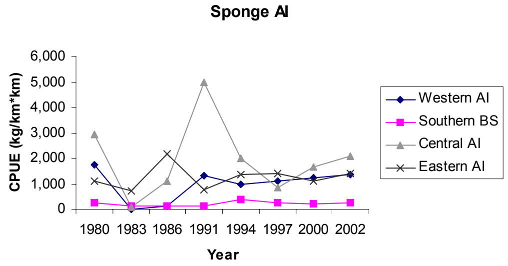
The 2002 survey results point to a continuing trend of increasing abundance for sponge which showed modest gains in all four areas and sea pens which were highlighted by a three-fold increase in the eastern Aleutians. The abundance of soft corals, stony corals and the Gorgonian group were relatively unchanged from recent surveys but still far below the highest abundance levels observed in the 1991 survey.

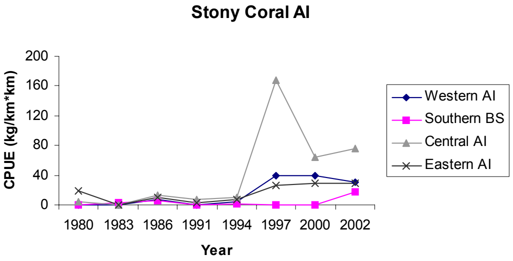












Progress Report on Essential Fish Habitat Research

Habitat associations of juvenile Pacific cod.

Contributed by Alisa A. Abookire, RACE Division, Alaska Fisheries Science Center

Very little is known about the habitat requirements of Pacific cod (*Gadus macrocephalus*) particularly during their early-life stages. Yet, the economic importance of the Pacific cod fishery in coastal Alaskan communities is considerable, and Pacific cod are a major prey item for Steller sea lions (*Eumetopias jubatus*) around Kodiak Island. Much of what we assume about the distribution of Pacific cod is based on either ancillary data from investigations focused on other species or investigations of Atlantic cod (*Gadus morhua*). Defining the nursery areas utilized by Pacific cod is a preliminary step toward identifying essential habitat and monitoring growth, survival, and subsequent recruitment.

The objective of this one-year study was to identify juvenile Pacific cod habitat in Chiniak Bay, Alaska. A variety of nearshore habitats were sampled between August 10 and 22, 2002. Stations were sampled along depth transects such that each transect had one station at depths of <5, 10, 15, 20, 25, and 30 m. At each of the 68 stations sampled, the relative abundance of juvenile cod and groundfishes was measured along with habitat characteristics. Habitat complexity (sediment type, vertical relief, % algae cover, associated invertebrates) was recorded at each station with an underwater video camera with real-time video. Vertical profiles of water temperature and salinity were measured at each station, and a sediment sample was archived for grain size analysis to verify the sediment type observed in the video.

A total of 6077 fishes were captured, and juvenile Pacific cod ranked number 7 in abundance. There were a total of 254 juvenile Pacific cod captured, with lengths ranging from 42 to 110 mm. This study verified the presence of juvenile Pacific cod in nearshore areas of Chiniak Bay. Once the distribution of juvenile Pacific cod is related to habitat complexity and physical properties (such as sediment grain size, depth, temperature, and salinity) then the habitats utilized by juvenile Pacific cod can be defined.

Use of Nearshore Habitats by Commercially Important Fish Species

Contributed by Scott W. Johnson and John F. Thedinga, Auke Bay Laboratory

Out of necessity, groundfish sampling in Alaska has been predominately on the continental shelf and slope to obtain knowledge for fishery management. Thus, sampling has been limited in nearshore areas. This is especially true along the remote and rugged coastline of southeastern Alaska. Nearshore, rocky bottoms >50 m deep, are the most poorly known of all marine habitats because of the difficulties of sampling or studying them closely. In addition, the importance of nearshore vegetated habitats (e.g., eelgrass, kelps) for fish communities is also poorly known in southeastern Alaska. Information is needed on fish distribution and habitat use in nearshore areas so managers can protect and conserve those habitats essential to maintain healthy fisheries. Nearshore habitats are a priority because of the potential risks of adverse effects from shoreline and upland development.

In 2003, we completed a three year study to establish index sites for monitoring long-term changes in habitat quantity, habitat quality, and species diversity that may result from human disturbance (e.g., shoreline development) or changes in climate (e.g., global warming). Six eelgrass (*Zostera marina*) meadows sampled in summer 2001 and 2002 were again sampled in summer 2003 for fish assemblages, and area of each meadow was measured by GPS. Other habitat parameters measured included eelgrass stem density and biomass. Additionally, because information is scarce on the use of eelgrass habitat in winter, we also sampled these sites in January 2003. Total number of fish captured has been dominated by a few species (e.g., Pacific sandlance, chum salmon) that were sometimes captured in large numbers. Other commercially important species captured were Pacific cod, Pacific herring, and juvenile coho salmon. Catch of fish varied between sites; catch was usually greater at sites closer to the outer coast than at sites in more inside sheltered waters. Additionally, at all sites, total catch was much smaller in winter than in summer. Area and density of eelgrass meadows varied by site; areas ranged from about 500 m^2 to over 75,000 m^2, whereas density ranged from about 450 stems m^2 to over 2,200 stems m^2. Establishing a solid baseline of habitat and fish diversity information will allow us to monitor these habitats periodically over the next 10 years for changes that may result from human or natural disturbance.

In 2002, we tested a GPS tracking system with a remotely operated vehicle (ROV) to quantify fish abundance in a variety of habitat types. Detailed 3-D bathymetry maps were first used to identify specific habitat types (e.g., ridges, troughs) and then the ROV was deployed in these areas to examine fish distribution and abundance. We successfully completed several ROV dives near Benjamin Island in southeastern Alaska and were able to track and record fish observations along a route displayed by the tracking system. More tests will be conducted in August 2003, but it appears that we may be able to map habitat boundaries and quantify fish abundance in specific habitat types.

Characterization of nearshore fish assemblages and habitat by seine and ROV is also providing valuable information on available prey to Steller sea lions (SSL) in southeastern Alaska. One hypothesis for the decline in the western population of SSL is decreased prey availability. Some of our nearshore study sites are close to SSL haulout areas in southeastern Alaska. Thus, in conjunction with satellite tagging of SSL and scat surveys, our nearshore studies will help provide a complete picture of where SSL forage, what prey is available, and what they consume. At two of our sites, The Brothers Islands and Benjamin Island, we have identified at least 37 species of fish that are available to SSL in summer; 16 of the species we captured have been identified in SSL scat. The nearshore environment provides important habitat for SSL prey, especially in summer. Less available prey in winter may force SSL to travel farther from haulouts to forage.

Estuarine EFH Surveys

Contributed by Mitch Lorenz, Alaska Fisheries Science Center - Auke Bay Laboratory

Work continues on development of a geospatial database for estuarine fish habitat in Alaska. This GIS will be used to help develop means of using that data for EFH definition, management, and consultation. The work involves two components: 1) Acquisition, interpretation, and analysis of available geospatial data, and; 2) Ground-truthing and biological classification of the geospatial baseline. Field data is being used to refine the estuarine basemap and to help develop habitat classifications that can be used to assess EFH distribution and relative fish productivity of Alaska estuaries.

Currently, the GIS covers southeast Alaska from the southern border with Canada north to Cape Suckling near Cordova. Analysis is underway that will extend the GIS from Cape Suckling to Resurrection Bay in Prince William Sound. Under a national Memorandum of Understanding with The Nature Conservancy (TNC), NMFS hosted the TNC west coast GIS analyst on one cruise to help evaluate differences and similarities between the NOS Environmental Sensitivity Index (ESI) and the ShoreZone Classification system being used by TNC. This work is ongoing but is expected to provide another means of ground-truthing NOS's ESI mapping.

Fish and habitat characteristics at fourteen estuaries in northern southeast Alaska are being sampled in 2003 to help develop the database for EFH mapping of Alaska estuaries. Selected sampling locations were representative of habitat conditions along an east-west transect in northern southeast Alaska. The estuaries ranged from relatively exposed coastline with prevailing fetch directly from large water bodies such as Chatham Strait and the Gulf of Alaska to estuaries associated with protected bays and inlets. Several of the estuaries drained logged watersheds while others drained pristine forested areas. Three of the estuaries were on glacial drainages.

Both exposed and glaciated estuaries were generally characterized by well defined deltaic formations and gravel beaches that supported narrow bands of emergent marsh. Clear water drainages in that category were characterized by narrow bands of eelgrass and abundant kelp whereas glaciated drainages supported little submerged vegetation. Protected estuaries generally had more complex deltaic formations ranging from cobble beaches to wide tideflats of mud or sand. Those sites were characterized by extensive emergent marshes and macroalgae communities. In inside waters, protected estuaries supported isolated eelgrass beds, while outside estuaries generally had extensive eelgrass beds.

Fishery Management Plan (FMP) species diversity at exposed estuaries in inside waters was low compared to other sites, although some FMP species (e.g., salmon and Dungeness crab) were abundant at many of those sites. FMP species diversity was generally similar at other sites sampled, but species composition varied considerably between inside and outside waters. For example, flatfish were more abundant in protected estuaries inside but were relatively rare at similar sites nearer the Gulf. Greenling and sandlance were common to abundant both inside and outside. Species such as lingcod, Pacific cod, and copper rockfish were common outside but were not caught at sites in inside waters.

Effects of Fishing Gear on Seafloor Habitat – Progress Report for FY 2003

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 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 and a searchable bibliography on the effects of mobile fishing gear on benthic habitats.

Exploration of coral and sponge habitat in the Aleutian Islands. Principal Investigator - Robert Stone (Alaska Fisheries Science Center - ABL)

In July 2002 the manned submersible *DSV Delta* and scuba was used to explore coral and sponge habitat in the Central Aleutian Islands. Observations confirmed that coral and sponges are widely distributed in that region (corals and sponges were found at 30 of 31 submersible dive sites) and yielded the discovery of previously undocumented coral habitat consisting of high density "gardens" of corals, sponges, and other sessile invertebrates. Coral gardens were similar in structural complexity to tropical coral reefs with which they shared several important characteristics including a rigid framework, complex vertical relief, and high taxonomic diversity. A video documentary of coral habitat exploration was completed in 2003 and can be viewed at http://www.afsc.noaa.gov/abl/MarFish/coral_gardens_video.htm or obtained from the Auke Bay Laboratory (ABL).

Following the initial exploratory efforts, ABL scientists, in collaboration with Alaska Department of Fish and Game and University of Alaska scientists, submitted two proposals for funding to expand this work. The first proposal to document deep-water (> 350 m) coral habitat, titled "Distribution of deep-sea corals and associated communities in the Aleutian Islands", was successfully funded by the National Underwater Research Program (NURP) for 2004 to use the remotely operated vehicle *Jason II*. The second, more comprehensive proposal, titled "Deep sea coral distribution and habitat in the Aleutian Archipelago" was successfully funded by the North Pacific Research Board (NPRB) and the first phases of that research began in June 2003 (see below: "Deep sea coral distribution and habitat in the Aleutian Archipelago").

In June and July 2003, the manned submersible *DSV Delta* was used to initiate the first phase of this project–shallow- water (<350 m) observations. This component of the study was funded by the Alaska Fisheries Science Center. Scientists visited 10 of 16 proposed sites and collected video of the seafloor on 22 strip transects. Corals and sponges were widely distributed over the 23 km of seafloor observed (found at 21 of 22 transects) and at densities varying from 0% on low-relief pebble substrate to 100% coverage in coral gardens. Disturbance to epifauna, likely anthropogenically induced, was observed at seven dive sites and may have been more evident in areas where fishing effort is reportedly high (based on NORPAC database). Sixty six coral specimens were collected for molecular and morphological taxonomic identification and studies on reproduction. Scientists will use the *DSV Delta* in 2004, with funding provided by NPRB, to complete observations at the six sites not visited in 2003.

Deep sea coral distribution and habitat in the Aleutian Archipelago. Principal Investigators -Jonathan Heifetz (Alaska Fisheries Science Center - ABL), Jennifer Reynolds (University of Alaska Fairbanks), and Doug Woodby (Alaska Department of Fish and Game)

This project funded by the North Pacific Research Board (NPRB) seeks to provide the first detailed mapping of coral and sponge habitats for the Aleutian Islands, where species diversity appears to be unusually high and where incidental mortality of corals and sponges is a challenging problem in the area's fisheries that use bottom contact gear. The goal of this multidiciplinary study is to construct a statistical model to predict coral and sponge distribution as a function of measurable environmental characteristics, and if successful, this predictive model can be used to inform management decisions for protecting corals and sponges in areas lacking detailed mapping and dive-supported observations. Further, this work in collaboration with other projects, will provide estimates of the relative abundance of corals and sponges, their importance to commercially valuable fish and invertebrates, and the degree to which these living substrates have been disturbed, including disturbance by fishing gear.

This study focuses on the 500 km central section between Seguam Pass (174 W longitude) and Petrel Bank (180 W longitude). Field operations began in June 2003. The seafloor mapping operations were successfully conducted during a 22.5-day cruise on the R/V *Davidson* when multibeam bathymetry and backscatter surveys of 17 representative sites were completed. A total of seventeen sites were mapped throughout the central Aleutians with a combination of 100 kHz and 24 kHz multibeam systems. Wherever possible, the sites were mapped from 50m to 3000m water depth, using a 100 kHz multibeam sonar system down to ~400m water depth, and 24 kHz system at greater depth. The 100 kHz sonar produced excellent bathymetric and backscatter data (Figure 1). The 24 kHz bathymetry data were also excellent, though necessarily of lower resolution. Unfortunately, the 24 kHz backscatter data does not appear to be useful, as they are strongly dominated by slope effects and therefore repeat information already contained in the bathymetry data

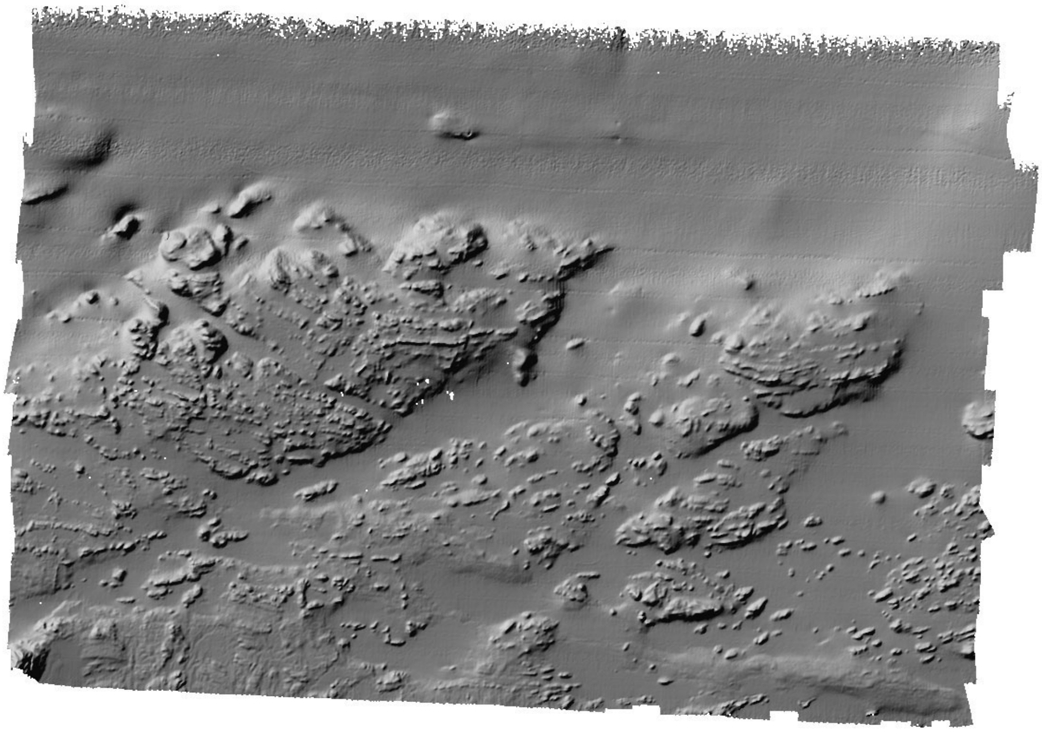


Figure 1. Example of a preliminary bathymetric map produced with the 100 kHz multibeam mapping system during the R/V *Davidson* cruise to the Aleutian Islands.

Juvenile rockfish habitat and energetics in the Aleutian Islands. Principal Investigators Chris Rooper and Mark Zimmermann (Alaska Fisheries Science Center – RACE)

In May 2003, a pilot study was conducted to examine the feasibility of using echosounder data to delineate and map fish habitats in the eastern Aleutian Islands near the Islands of Four Mountains. The pilot study was carried out at three sites over two days prior to the beginning of the Gulf of Alaska trawl survey aboard the F/V Gladiator. At each site acoustic data from the vessel's echosounder were collected for analysis. These data are currently being processed with *QTC View* software that will generate data necessary to classify the area into habitat types. At each site a sediment sample was taken using a Shipek grab, and underwater video was collected using a drop camera to ground-truth the acoustic data. The preliminary results indicate one of the sites was heavily covered with epibenthic invertebrates (sponges and corals) over hard bottom. The other two sites are composed of sand and hard substrate, with the intermittent hard substrate supporting coral, sponges and other epibenthic organisms. If the features observed on the video and in the sediment collections are represented in the acoustic bottom classification, this method will prove to be a cost effective method of collecting habitat information using vessels of opportunity (NMFS contracted vessels) that conduct annual bottom trawl surveys throughout Alaskan waters.

Studies from wide ranging areas have indicated that many commercially important species are associated with specific habitats. Rockfish of many species are often found in association with structured habitats (rock piles, coral patches, etc.) of some kind. Some effects of fishing on epibenthic invertebrates have been observed, however it is unclear what the consequences of the fishing activity on fish species associated with these sheltering invertebrates may be. A second purpose of the 2003 pilot study was to initiate techniques to identify links between habitat forming organisms (primarily sponges and corals), rockfish density, and rockfish condition. Since the energetic content of fish can be used as an indication of fish condition, the energetic content of fish collected from various habitats should reflect the relative value of the habitat to the fish. For example, poor quality habitat should be reflected by lower energetic content of individuals occupying the suboptimal habitat. Trawl collections at the three study sites were dominated by rockfish (Pacific ocean Perch and northern rockfish), Atka mackerel, and Pacific cod, as well as substantial sponge and coral. Juvenile rockfish were collected and frozen for laboratory analysis of energetic and stomach content (both at the three study sites and throughout the Gulf of Alaska during the 2003 survey). Zooplankton samples were also collected at each trawl location. Energetic content and zooplankton abundance will be compared among sites and treatments to determine the relative benefit to rockfish growth and condition of one site over another. This will allow us to evaluate the linkage between the function of structured habitats and the fish that are associated with these complex habitats. In 2004 we hope to extend this study to further evaluate acoustic mapping techniques, and explore the relationships between fish and structured habitat in the Aleutians thus supporting interpretation of gear impact studies.

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

The 1976 Magnuson Act effectively eliminated the Bristol Bay no-trawl zone known as the Pot Sanctuary. Implemented by the Japanese in 1959, the boundaries of the Pot-Sanctuary refuge closely matched the well-defined distribution of the red king crab 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. 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 filled 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 alternating, sex-specific sources of fishing mortality were at work. Initially there were ten years (1970-1980) of increasing, male-only exploitation, 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 residing within the Unimak area, known to be the most productive spawning ground for Bristol Bay red king crab. There has been considerable discussion about possible natural causes (e.g. meteorological regime shifts, epizootic diseases) of the abrupt collapse of the Bristol Bay red king crab population in the early 1980s. This project focuses on the association between the overharvest 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.

Distribution of flathead sole by habitat in the Bering Sea. Principal Investigators Chris Rooper and Mark Zimmermann (Alaska Fisheries Science Center – RACE Division)

During 2003, biotic and abiotic variables were analyzed to identify preferred habitat for flathead sole in the Bering Sea. A model was constructed based on data from three Bering Sea bottom trawl surveys and then tested on data from two different years. Habitat variables were chosen based on their presumed importance for growth and survival, and included sediment type, temperature, depth, prey biomass, and invertebrate cover. Bottom temperature and depth were available for each trawl haul. Additional data was used to calculate the ratio of mud to sand at each site. Sheltering organisms included sea anemones, soft and hard corals, surface bivalves, empty bivalve shells, ascidians, gastropods, sponge, bryozoans and sea pens. The total weight of important prey items such as decapods (including shrimp and pagurid crabs), juvenile walleye pollock, and ophiurids was summed for each tow. Three models were used to describe the relationships between flathead sole catch (ln CPUE) and each of the five habitat variables. The most complex model was a three-parameter model representing the response of CPUE as a dome shaped function of the habitat variable. A second model describes CPUE as a density dependent function of the habitat variable. The simplest model predicted a linear relationship between flathead sole density and the habitat variable. In addition a functional response model was used to describe the relationship of flathead sole to their prey. The initial (full) model for analysis estimated 14 parameters. Models were reduced by sequentially removing one parameter for each variable, and then the models were compared using the Akaike Information Criterion (AIC) for non-nested models, and the process was repeated until reduction in the number of parameters resulted in no gain in AIC score. The correlation between the observed and predicted values was used to determine the percentage of variance in the data set explained by the model. Once a final model was determined for 1998-2000, the model was tested on survey data from 2001 and 2002.

The best model of flathead sole habitat use included four habitat variables; depth, temperature, invertebrate cover and mud-sand ratio. Predicted values from the 7-parameter model were highly correlated ($r = 0.78$) with the original observations. Flathead sole abundance increased sharply from 0 to 150 m and then decreased at greater depths. Flathead sole CPUE increased in proportion to the amount of available cover, and CPUE increased quickly from –2 to 3 ^{0}C and then leveled out at temperatures higher than 5 ^{0}C. Flathead sole had an inverse proportional relationship with the mud-sand ratio. Including the prey abundance variable in the model did not provide any advantage in predicting flathead sole CPUE according to the AIC. This was the only variable dropped from the original five variable model. The fit of the model to the test data (2001-2002) was almost as good as the original fit on the 1998-2000 data, as the predicted values were also highly correlated ($r = 0.76$) to the observations. The model had difficulty predicting the largest observations of flathead sole catch, and residual plots of the model fits from each year suggest the model tends to under-predict observations in the southern region of the Bering Sea shelf, while over-predicting the observations in the northern shelf in 1998-2000. This suggests an important habitat variable is not included in the model and the matter will be investigated further.

A model for evaluating fishery impacts on habitat. Principal investigators - Jeffrey Fujioka and Craig Rose (Alaska Fisheries Science Center - ABL and RACE)

A mathematical model to evaluate the effects of fishing on benthic habitat was developed. The model has been applied within the framework of the both the Programatic and Essential Fish Habitat (EFH) supplemental environmental impact statements prepared by Center scientists. The model is comprised of equations that incorporate the basic factors determining impacts of fishing on habitat. Given values, either estimated or assumed, of 1) fishing intensity, f (= absolute effort in area swept per year ÷ area size), 2) sensitivity of habitat to fishing effort, q_H, and 3) habitat recovery rate, ρ, the model predicts a value of equilibrium (i.e., long term) habitat level, H_{eq}, as a proportion of the unfished level, H_0.

$$H_{eq} = H_0 \cdot \rho S/(I + \rho S) \quad \text{Where } H_0 = \text{unfished habitat level, } I = f q_H \text{, and } S = e^{-I}.$$

Habitat impact or effect level, E, for the given effort, sensitivity, and recovery rates, would be 1-H_{eq}. Letting H_0 = 1.0, then

$$E = I/(I + \rho S)$$

Habitat is defined as any feature of the seafloor that could be impacted by fishing gear. Initially, application of this model focused on the impact to biostructure habitat feature where biostructure is living habitat provided by organisms such as corals, tunicates, and sponges.

The habitat sensitivity rate, q_h, is the proportion of habitat in the path of the fishing gear that is impacted by one pass of the gear. Vulnerability of a particular habitat feature varies greatly depending on their physical characteristics and the characteristics of the fishing gear. The vulnerability may be difficult to determine. Certain features of the gear may make the gear more damaging to one type of organism than to another type.

Recovery rate, ρ, reflects the rate of change of impacted habitat back to unimpacted habitat, H_0. In the absence of further impacts, impacted habitat would decrease exponentially until all habitat was in H_0 the condition. The recovery time, R, can be thought of as the average amount of time the impacted habitat stays in the impacted state, which would equal $1/\rho$ (in the absence of further impacts). The recovery rate includes any recruitment required to initiate recovery and the growth necessary to reach a size that is necessary to provide habitat function.

Fishing intensity is the absolute effort in area swept per year ÷ area size. To keep a geographic perspective, application of the model used fishing effort estimated for each 5x5 km block within the EEZ. Fishing intensity of a block is the fishing effort per year measured in area swept as a proportion of area of the block. For the given values of sensitivity q_h, recovery rate ρ, and bottom fishing intensity f estimated for each 5x5 km block, habitat impact, $E_i = I_i/(I_i+\rho S_i)$, can be calculated for the 5x5 km block represented by the I parameter. Larger values of E equate with more impacts. Results for a region can be presented in a single value as a mean impact, frequency distribution of impacts for each block, and the geographic distribution of the impacts.

Ecological value of physical habitat structure for juvenile flatfishes. Principal Investigator – Allan W. Stoner (Fisheries Behavioral Ecology Program, RACE Division, Alaska Fisheries Science Center)

Distributions of flatfishes are ordinarily associated with depth, temperature, and sediment type. In fact, new experiments conducted at the Newport Laboratory show that juveniles of both northern rock sole and Pacific halibut have strong preferences for sediments with specific grain sizes which are related to the fish's burial capabilities. These preferences are strongest in the smallest age-0 fish and decrease with fish size. However, both experimental and descriptive studies conducted in the Fisheries Behavioral Ecology Program also show 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. Fine-meshed beam trawl collections made near Kodiak revealed that densities of age-0 rock sole and Pacific halibut were correlated with physical structures provided by empty shells and sedentary invertebrates collected as bycatch in the tows. Additional laboratory experiments conducted in the Newport Laboratory show that age-0, age-1, and age-2 Pacific halibut all choose habitat with structure over bare sand habitat. Strength of the preference decreases with fish size, and depends upon both feeding history and light level.

Reductions in habitat heterogeneity may have important ecological consequences for juvenile flatfishes. Complex habitats with sponges, bryozoans, shells and other physical structures can reduce mortality rates on juvenile flatfishes compared with habitats not containing physical structure. Predation rates on age-0 rock sole and age-0 Pacific halibut by age-2+ halibut were tested in large laboratory mesocosms with and without physical structure (sand plus sponges versus smooth bare sand). Predators consumed more flatfish prey in sand than in habitat with sponges, and they consumed more age-0 halibut than rock sole. Predator-prey encounter rates were decreased in the sponge habitat as predator search was impeded. Predators paused more frequently and swam more slowly to maneuver through the complex habitat. Structures also hindered the pursuit of prey. These experiments support an accumulating body of evidence that emergent structure, in otherwise low-relief benthic habitats, may play an important role in the ecology of some juvenile fishes. Removal of emergent structure by towed fishing gear and other anthropogenic or natural disturbances may influence patterns of distribution for juvenile halibut as fish redistribute to less preferred habitat, and may decrease survival rates through increased losses to predation.

During 2003, field studies were expanded with a grant from the North Pacific Research Board to include a descriptive analysis of flatfish/habitat associations in flatfish nursery grounds near Kodiak Island using a new towed camera system that is integrated with navigation. Approximately 50 hours of videotape were recorded and analysis is currently underway. Also, a field experiment was designed to examine the role of habitat structure by enhancing large plots of bare sand with bivalve shells. The plots were then surveyed with the camera sled at several intervals over the following month. The experimental results are currently being analyzed, but it is already clear that certain flatfishes were attracted to the enhanced habitat. Similar field studies will continue in 2004.

Mapping of habitat features of major fishing grounds. Principal investigators Jonathan Heifetz and Dean Courtney (Alaska Fisheries Science Center - ABL)

Very few areas of the continental shelf and slope where major fisheries occur have been adequately described using geophysical and biological data. Any regulatory measures adopted to minimize impacts without the information of whether or where vulnerable habitat is at risk, may be ineffective or unnecessarily restrictive. Habitat mapping along with direct in-situ observations is a way of obtaining such information. The objective of this study is to map limited areas of the Alaska EEZ for habitat characterization using state-of-the-art technology. In 2001 and 2002 approximately 1,600 km^2 of seafloor was mapped using a high-resolution multibeam echosounder that includes coregistered backscatter data. This mapping consisted of 500 km^2 off Yakutat, 900 km^2 on Portlock Bank northeast of Kodiak, and 200 km^2 off Cape Omaney, Baranoff Island. Survey depths ranged from about 100 m to 750 m. During 2003 we mapped areas in the central Aleutian Islands and in the vicinity of Albatross Bank southwest of Kodiak Island in the Gulf of Alaska.

Analysis of the multibeam and backscatter data for Portlock Bank indicated at least a dozen macro- or meso-habitats. The megahabitats are the result of past glaciation and are presently being reworked into moderate (cm-m) relief features. Submarine gullies notch the upper slope and provide steep relief with alternating mud-covered and consolidated sediment exposures. The Cape Omaney site ranged in depth from approximately 50 m - 300 m (Figure 2). This site is characterized as an irregular seabed with mixed sediments (mostly sand and gravel) and high-relief rocky outcrops and pinnacles. The habitat at the Cape Omaney site is the result of past glaciation and plate tectonics highlighted by the presence of an uplifted fault zone. The Yakutat site is characterized as a formerly glaciated area of irregular seabed with mixed sediments (mostly sand, mud, and gravel) and high-relief areas consisting mostly of boulders.

At the Cape Omaney and Portlock Bank sites the mapping was complemented by submersible *Delta* dives. The uplifted fault zone (shatter ridge) was the focus of the *Delta* dives at the Cape Omaney site. The ridge is comprised of a series of pinnacles. The substrate is primarily bedrock and large boulders. The epifaunal community is rich and diverse, much more so than the surrounding low-relief habitat. The largest epifauna were gorgonian red tree coral colonies and several species of sponges. Numerous species of fish, including several species of rockfish, were abundant. Redbanded rockfish and shortraker/rougheye rockfish were often associated with gorgonian coral colonies and at least one species of sponge. Also of interest was the presence of a pod of several hundred juvenile golden king crab on acorn barnacle shell hash on a sloping ledge on one of the pinnacles. We believe this is the first documented observation of juveniles of this species in the Gulf of Alaska. Water currents at the site are generally very strong, but are variable in both direction and strength depending on location. Numerous sections of derelict longline gear were observed on certain areas of the pinnacle, and damage to red tree corals was evident.

Six sites were surveyed with the *Delta* on Portlock Bank. Two were relatively flat sites on the north end of the Bank, one lightly fished and one in an area fished for Pacific Ocean perch. Two were sloping sites along the eastern slope edge and two sites were toward the middle of the Bank, one fished for flatfish, the other lightly fished. Little evidence of trawling was observed on the low relief grounds of the continental shelf where perhaps the level bottom did not induce door gouging and there was a lack of boulders to be turned over or dragged. The most common epifauna were crinoids, small non-burrowing sea anemones, glass sponges, stylasterid corals and brittlestars. Occasional large boulders located in depressions were the only anomaly in the otherwise flat seafloor. These depressions may have afforded some protection to fishing gear, as the glass sponges and stylasterid corals attached to these boulders were larger than were typically observed. In contrast, there was evidence of boulders turned over or dragged by trawling in the areas of the upper slope. The uneven bottom perhaps induced gouging by the trawl doors. The substrate was mostly small boulders, cobble, and gravel. In summary, for this very limited sample of the outer Portlock Bank, there was very little high relief benthic habitat that would be at risk to further fishing. No large corals and very few large sponges were seen. The extent past fishing may have contributed to this condition is not known.

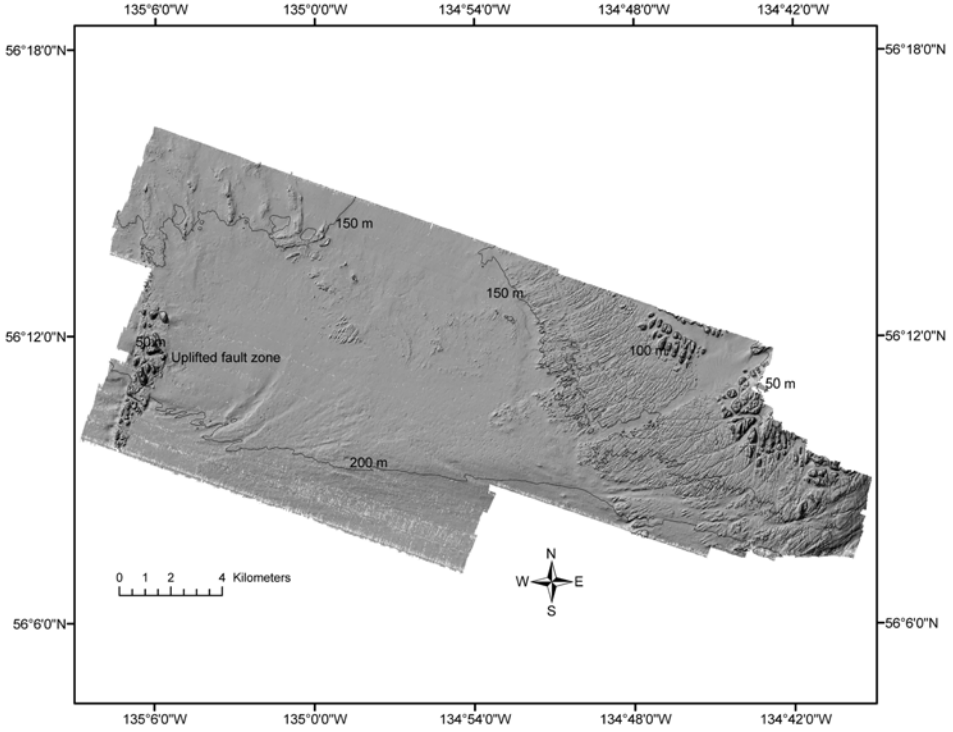


Figure 2. Bathymetric map of southeastern Alaska in the vicinity of Cape Omaney.

Effects of bottom trawling on soft-sediment epibenthic communities in the Gulf of Alaska. Principal Investigator - Robert Stone (Alaska Fisheries Science Center - 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 (Figure 3). 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.

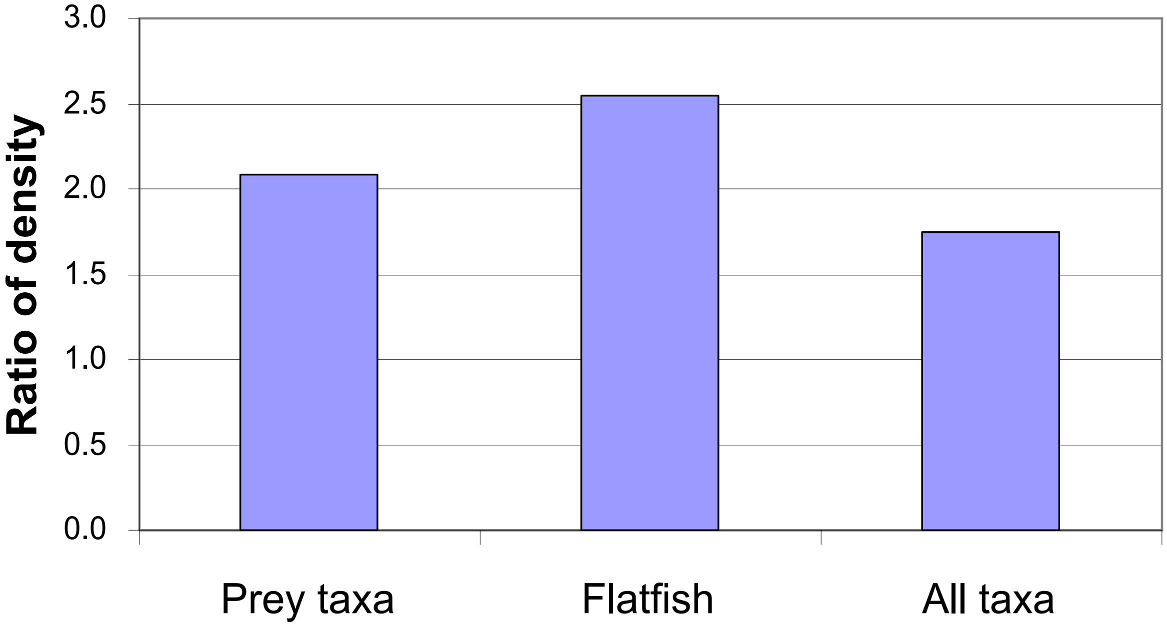


Figure 3. Ratio of density inside and outside of sea whip groves at a site in the central Gulf of Alaska.

Effects of experimental bottom trawling on soft-sediment sea whip habitat in the Gulf of Alaska. Principal Investigator - Robert Stone (Alaska Fisheries Science Center - 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 were completed in 2002. Video analysis of epifauna data was completed in spring 2003 and data analyses are underway.

Living substrates in Alaska: distribution, abundance and species associations. Principal Investigator - Patrick W. Malecha (Alaska Fisheries Science Center - ABL)

“Living substrates” have been identified as important marine habitat and are susceptible to impacts from fishing activities. In the Gulf of Alaska and Bering Sea, little is known about the distribution of deepwater living substrates such as, sponges (Phylum Porifera), sea anemones (Order Actiniaria), sea whips and sea pens (Order Pennatulacea), sea squirts (Class Ascidiacea), and bryozoans (Phylum Ectoprocta). In order to facilitate management practices that minimize fishery impacts to these living substrates, distributional maps were created based on National Marine Fisheries Service trawl survey data from 1975 through 2000. In general, the five groups of living substrates were observed along the continental shelf and upper slope in varying densities. Catch per unit effort (CPUE) of sponges was greatest along the Aleutian chain, while CPUE of sea squirts and ectoprocta was greatest in the Bering Sea. Large CPUEs of sea anemones, sea pens and sea whips were observed in both the Bering Sea and Gulf of Alaska. Broad-scale species associations between living substrates and commercial fish and crab were also investigated. Flatfish were most commonly associated with sea squirts and bryozoans; gadids with sea anemones, sea pens and sea whips; rockfish and Atka mackerel with sponges; and crab with sea anemones and sea squirts.

Sea whip (Order Pennatulacea) resiliency to simulated trawl disturbance. Principal Investigator - Patrick W. Malecha (Alaska Fisheries Science Center - ABL)

Sea whip (*Halipteris willemoesi* and *Protoptilum* sp.) responses to simulated trawl disturbances were observed *in situ* and in laboratory aquaria. An aggregation of *H. willemoesi* was located at a depth of approximately 30 m in Auke Bay, Alaska. *H. willemoesi* were randomly assigned to three disturbance treatments and one control group and were observed *in situ*. Treatments included dislodgement, fracture of the axial rod, and tissue abrasion. *Protoptilum* sp. were collected with a shrimp trawl from a heavily colonized area of the seafloor in the Gulf of Alaska at a depth of 145 m. The ability of *Protoptilum* sp. to re-bury was observed in laboratory aquaria. Dislodged *H. willemoesi* showed a greater ability to re-bury and position themselves upright than did the smaller *Protoptilum* sp. After three months, *H. willemoesi* were not able to repair fractured axial rods but light tissue abrasion had little effect on survival. Dislodged and damaged *H. willemoesi* were much more vulnerable to predation by the nudibranch *Tritonia* *diomedea,* that appeared to illicit a strong scavenging/predatory response to sea whips in contact with the seafloor.

Growth and recruitment of an Alaskan shallow-water gorgonian. Principal Investigator - Robert Stone (Alaska Fisheries Science Center - ABL)

Little is known about the growth rates and lifespan of cold-water gorgonians. Some evidence exists that growth rates for these habitat-forming octocorals are low and that they are long-lived. Consequently, recovery rates from disturbance are likely low. 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. This is the first study to directly measure coral growth *in situ* in the North Pacific. Two sites established in July 1999 were revisited during Cruise 03-09 aboard the NOAA Ship John N. Cobb. At these two sites, 36 of 38 colonies tagged in 1999 were relocated and video images recorded. These images will be digitized and growth determined from baseline images collected during the four 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 19 of 30 colonies were relocated in August 2003 and video images were recorded. A manuscript describing the growth of this species, based on 5 years of growth data, is planned after the 2004 sampling season. 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 is the first research on the reproductive biology of any Alaskan coral species and 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 (Alaska Fisheries Science Center - 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 indicate that the calcein produced clear detectible marks on the axial rods. Examination of these specimens after one year will 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 long-term bottom trawling in the eastern Bering Sea (1996-2003). Principal Investigator - Robert A. McConnaughey (Alaska Fisheries Science Center - RACE Division)

Although chronic bottom trawling can reduce benthic biomass, it is generally unknown whether this represents a decrease in numbers of individuals or their mean body size. Body size directly affects the fitness of individuals, thereby influencing the structure and function of populations, communities and ecosystems. Although easily measured, it is rarely considered in the context of mobile fishing gear effects. Using data from the original study in 1996, we compared the mean sizes (kg) of 16 invertebrate taxa in heavily trawled (HT) and untrawled (UT) areas straddling the Crab and Halibut Protection Zone 1 (CHPZ1; area 512) closed area boundary in Bristol Bay (Figure 4). On average, fifteen of these taxa were smaller in the HT area and the overall HT-UT difference in body size was statistically significant. However, only the whelk *Neptunea* and the Actiniaria (sea anemones) were significantly smaller in the HT area after correcting for multiple tests. Mean size of red king crab was 23% *greater* in the HT area (*P*=0.17). Supplemental length-frequency data indicate that substantially fewer small red king crabs, rather than more large individuals, occupy the HT area. For comparison with experimental results, we estimated natural size variability of benthic invertebrates by examining catches at standard NMFS trawl survey stations located within the CHPZ1 closed area. For each year from 1982 to 2001, the absolute values of the pairwise differences in mean size were calculated for all stations where a specific taxon was caught. These 10,018 within-year, within-taxon differences were then collected across years to generate an empirical distribution of differences in mean size based on natural variability among stations. Overall, these comparisons indicate natural variability of body size in the untrawled CHPZ1 is large relative to the observed HT-UT differences due to chronic bottom trawling. On average, spatial differences in body size exceeded the observed trawling effect in 91% of the comparisons involving sedentary taxa, 81% of those for motile taxa, and 22% of those for infauna.

When these results are considered in combination with biomass differences reported previously, it is possible to draw general conclusions about the overall status of the affected populations. In most cases, both biomass and mean body size were reduced as a result of heavy trawling suggesting a general population decline (Actiniaria, *Aplidium*, *Crangon*, *Cucumaria*, *Macoma*, *Neptunea*, *Oregonia gracilis*, pagurids, *Pagurus ochotensis*, *Serripes*, *Tellina*). In a few cases, greater overall biomass accompanied the observed body-size reduction, suggesting a proliferation of relatively small individuals in the HT area (*A. amurensis*, *Evasterias*, *Hyas*, *Mactromeris*). Mean size of red king crab (*P. camtschaticus*) was larger in the HT area. This was the only exception to the pattern of smaller individuals in the HT area. In this case, given lower biomass and substantially fewer small crabs in the HT area relative to the UT area, the red king crab response to chronic bottom trawling appears to be fewer individuals of greater mean size.

Overall, the observed effects are generally consistent with theoretical expectations but were probably limited in magnitude by several factors. First, the CHPZ1 study area has a relatively high level of natural disturbance and there is general consensus that sandy areas with strong tidal flow are less sensitive to mobile gear effects. Also our findings probably reflect conditions associated with an intermediate stage of recovery, since active fishing in the HT area declined to a very low level prior to field sampling in 1996 (only five tows during 1993-1995). Moreover, trawl intensities for Alaskan waters are low relative to other shelf areas in the United States and Europe and the intensity level at the CHPZ1 study area is only moderate for the eastern Bering Sea shelf as a whole. Finally, our ability to comment on the ecological consequences of the observed effects is very limited at this time because so little is known about the life histories and ecological roles of the invertebrate taxa studied, not to mention the complex linkages among them and with federally managed groundfish.

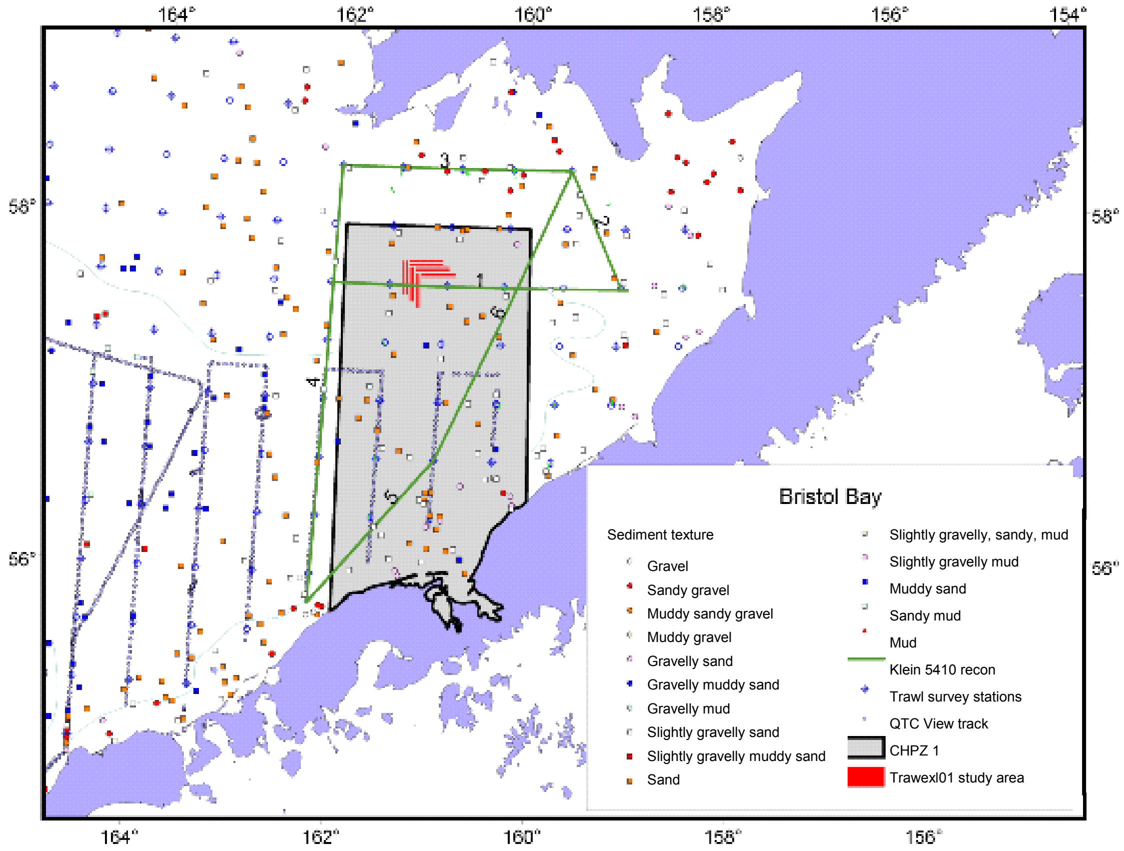


Figure 4. Bottom trawl study areas in Bristol Bay on the eastern Bering Sea shelf. Long-term (chronic) effects of trawling were investigated at heavily trawled and untrawled sites located along the northeast boundary of the CHPZ1 management area closed to trawling. Short-term effects and recovery are being studied in six pairs of research corridors within the CHPZ1. An exploratory survey of the Bristol Bay seafloor occurred along six reconnaissance tracklines.

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

Whereas 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 CHPZ1 closed area, approximately 25-50 mi south and west of the chronic effects site (Figure 4). During a 35 day cruise in 2001, 6 pairs of pre-designated 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 minute 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 re-sampled 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, all 2001 samples are fully processed and ready for analysis while 2002 data processing is ongoing. 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 (Alaska Fisheries Science Center – 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, 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 below: (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 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 (Alaska Fisheries Science Center – 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.; QTC) is capable of background data acquisition during routine survey operations. Nearly 8 million digitized 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 during a 1999 hydroacoustic fishery survey by the *Miller Freeman* (Figure 5). Collaborative analyses with the QTC are continuing in order to develop an optimum seabed classification scheme for the eastern Bering Sea shelf. Once this is accomplished, it will be possible to evaluate the system for benthic habitat studies using standardized measures of fish and invertebrate abundance from annual trawl surveys. Preliminary analyses indicate the system is able to detect and map seabed types with distinct acoustic properties. However, in order to have *habitat* mapping utility, this acoustic variability must correspond to environmental features that influence the distribution of demersal and benthic biota.

Acoustic diversity directly represents substrate diversity. Surface roughness, acoustic impedance, and volume homogeneity are characteristic of different seabed types; these factors influence echo returns from a vertical-incidence echo sounder. The standard QTC method uses a set of proprietary algorithms to extract features from individual echoes. Principal components analysis (PCA) reduces 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 scheme for any particular data set strikes a balance between high information content (i.e., many 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, or "cost function") was developed to guide the clustering process. However, because of the computational intensity of the Bayesian method and the very large size of the two data sets, preliminary analyses were based on subsets of the data. Even so, over 200 CPU-hours were required to locate the global minimum of the BIC function which indicates the true number of seabed classes for each data set. Significantly better methods for finding minima in multi-dimensional spaces have been developed in the study of inverse problems, particularly simulated annealing (SA) and further developments based on SA. We have incorporated some of these techniques into our process in order to improve the program's ability to locate the global minimum (rather than a local minimum) of the BIC function. With this work nearing completion, the next step is to test for associations between the acoustically determined seabed classes and survey-based estimates of invertebrate (and groundfish) abundance.

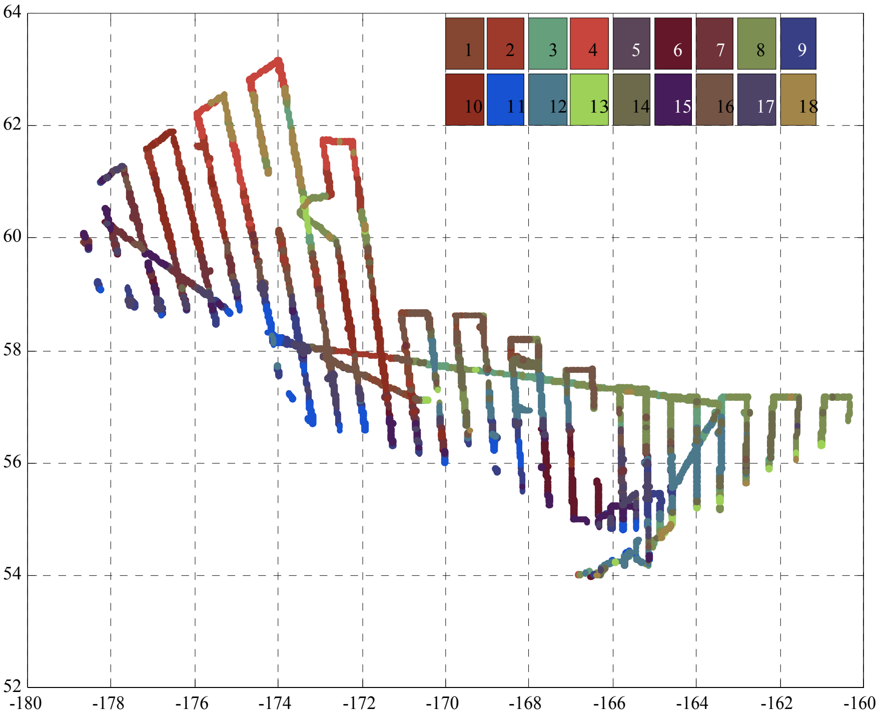


Figure 5. Seabed types on the eastern Bering Sea shelf, based on acoustic diversity measured with a 38 kHz echosounder and the *QTC View* seabed classification

Reconnaissance mapping with side scan sonar. Principal Investigator Robert A. McConnaughey (Alaska Fisheries Science Center – 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. A 150 m swath of bathymetric data and imagery were collected along survey lines totaling nearly 600 linear miles (Figure 4). 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 (Figure 6). The imagery is currently being processed and will be classified using supervised (geological) and unsupervised (statistical) methods in an effort to identify large homogeneous regions that would be the basis for more systematic study of mobile gear effects. Suitability for EFH characterizations will also be considered. Prior to deployments in Alaska in 2001 and 2002, a multi-institutional research team improved the commercial software interface for the sonar during laboratory testing and sea trials in Portsmouth Harbor, NH and Puget Sound, WA. In early 2003, the Klein system was co-purchased with the NOAA Office of Coast Survey (OCS) using accrued lease credits. In addition to joint fisheries habitat applications, reconnaissance data will also be supplied to OCS for nautical chart updates.

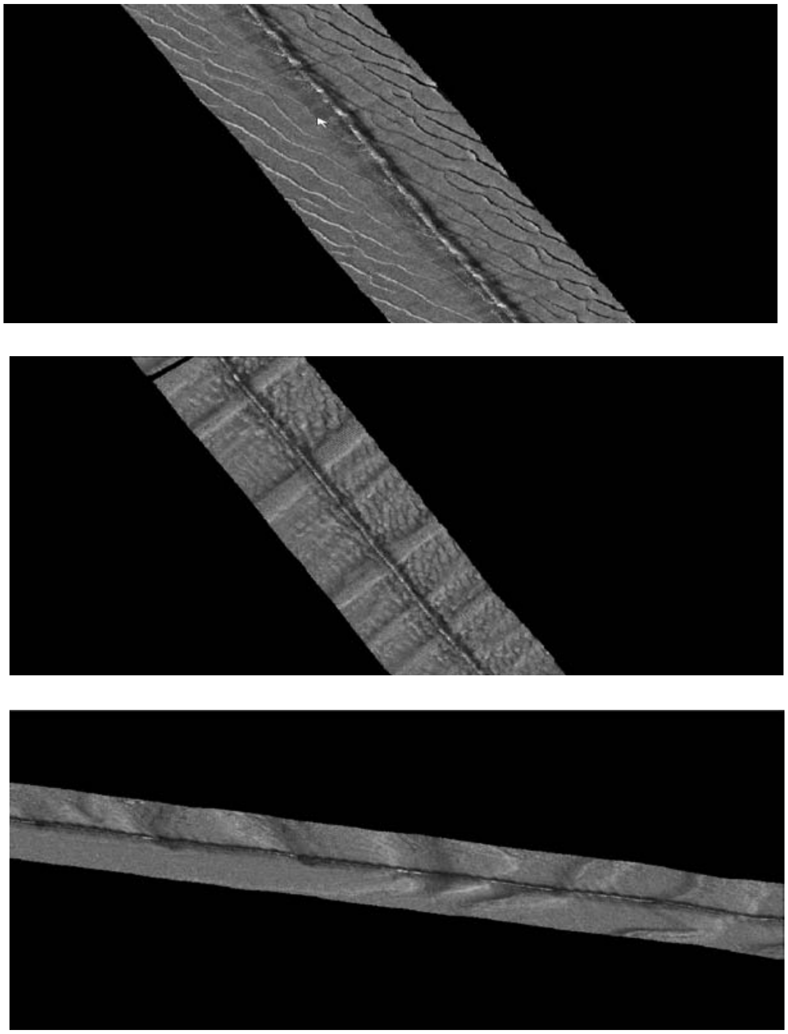


Figure 6. Representative side scan sonar images of sand bedforms acquired along Bristol Bay reconnaissance tracklines 2 and 3. Side scan technology is commonly used to map seabed features and characterize seafloor habitat complexity. A side scan towfish emits sound pulses and receives echos from the surrounding seabed while being dragged near the seafloor. Typical images contain information about the sediment type and general roughness of the seabed. For example, hard areas reflect more energy and are represented as dark areas on the image, while softer areas do not reflect energy as well and are represented with lighter shades. Digital multibeam systems, such as the Klein 5410, represent a significant improvement over the previous generation of digital "single beam" systems that require substantially slower towing speeds (2-3 knots vs 8 kts). Not only does this system produce extremely high-resolution backscatter images of the seafloor (pixels as small as 7.5 cm by 20 cm), co-registered swath bathymetry is also acquired simultaneously using interferometry. The swath bathymetry option enables direct measurements of small vertical features on the seabed, such as sand waves. Approximately 1 megabyte (MB) of data is collected each second from a 150 m swath.

Spatial and temporal patterns in Bering Sea invertebrate assemblages. Principal Investigator Cynthia Yeung (Alaska Fisheries Science Center – 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. These analyses will provide a better understanding of the eastern Bering Sea benthos and may also provide a basis for designing an experimental system to systematically study mobile fishing gear impacts.

Some 400 invertebrate taxa have been recorded over all the surveys, with < 200 taxa occurring in an individual survey. Twenty-eight taxa were selected as the 'core' group for some analyses. They represent the dominant taxa in every survey either by frequency of occurrence at stations (presence) or by CPUE (kg/ha) (Table 1). Only 8 of the 28 taxa were not simultaneously dominant by presence and by CPUE. The scale worm *Eunoe nodosa*, although only marginally dominant, was added to the group for the lack of any annelid infauna, despite the importance of this group in characterizing marine soft sediment habitats and in marine benthic food webs.

Table 1. List of 'core' taxa, in decreasing rank of dominance.

Rank	Taxon	Rank	Taxon
1	Paguridae	15	*Boltenia* sp.
2	Gastropoda	16	*Argis* sp.
3	*Chionoecetes opilio*	17	*Erimacrus isenbeckii*
4	*Chionoecetes bairdi*	18	*Paralithodes platypus*
5	*Asterias amurensis*	19	*Crangon* sp.
6	*Gorgonocephalus eucnemis*	20	compound ascidean
7	*Hyas coarctatus*	21	*Ctenodiscus crispatus*
8	Actiniaria	22	Nudibranchia
9	Gastropod eggs	23	*Oregonia gracilis*
10	*Paralithodes camtschaticus*	24	*Telmessus cheiragonus*
11	*Hyas lyratus*	25	*Halocynthia* sp.
12	Porifera	26	Ophiuroidea
13	*Pandalus borealis*	27	*Gersemia* sp.
14	Echinacea	28	*Eunoe nodosa*

Stations in a survey were clustered by the dissimilarity of their taxa composition. All taxa that occurred in > 6% of the stations in a survey were included. CPUE (kg/ha) was 4th-root transformed to balance the contributions of dominant and rare taxa, and Bray-Curtis dissimilarity was calculated on the station-by-taxa transformed CPUE matrix. A maximum of five clusters was kept. Above five clusters there was usually fragmentation into very small clusters with often just one member.

Consistently in almost every survey, two major groups of stations were found partitioned along either side of the 50 m isobath (Figure 7). Exceptions to this pattern are seen in 1982, 1988, and 1999, when the partition broke down and merged all stations essentially into one homogeneous group (1998 saw a contraction of the coastal cluster). The validity and significance of the possible 'anomalous' pattern is under investigation as is the utility of the two-group pattern for systematic studies of fishing gear effects. Trends and patterns in the biomass and spatial distribution of the invertebrate fauna are also being analyzed in relation to environmental variables and to the abundance and distribution of associated managed species.

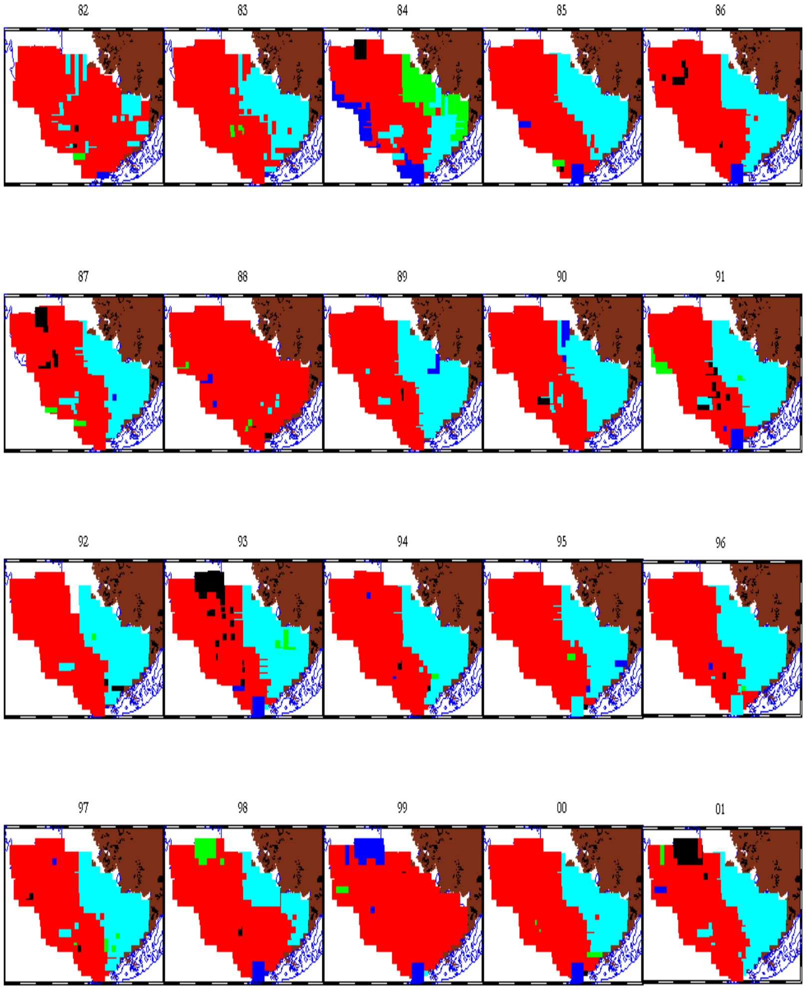


Figure 7. 1982-2001 eastern Bering Sea groundfish trawl survey stations clustered by taxa which occurred in >= 6% of the total number of stations. The maximum number of clusters kept was set at 5. Stations are color-coded by cluster membership for visual interpretation. Colors are assigned to facilitate the comparison of station groupings across surveys, not necessarily to imply the same colored stations across surveys have the same underlying "structure". The 2002 survey, not shown, resembles the 2001 pattern.

Resolving taxonomic inconsistencies in Bering Sea invertebrate catch data. Principal Investigator Keith Smith (Alaska Fisheries Science Center – RACE Division)

Benthic invertebrates are a key element of groundfish habitat and the primary measure of biological effects of mobile fishing gear. Since 1982, standard methods and gear have been used to sample benthic invertebrates in the eastern Bering Sea during an annual bottom trawl survey. However, due to differences in field practices and familiarity with taxa among years and vessels, specific organisms in the catch have historically been identified at various taxonomic levels. For example, the distinctive Alaskan hermit crab *Pagurus ochotensis* has been identified at the species level in some hauls and has been lumped with all other hermits in others. It is also frequently the case that common invertebrates have been identified to species while infrequent, less familiar ones were identified to higher taxonomic levels, without specific information about the extent of inclusion or exclusion of taxa in the larger groups. These situations are common for the hundreds of taxa routinely sampled and, if not handled carefully, will introduce significant biases into spatial and temporal analyses of survey catches. To overcome this problem and enable appropriate use of the survey data, a SQL-Plus application was developed that extracts user-selected invertebrate catch data for the eastern Bering Sea from the official AFSC survey database (RACEBASE) and groups them by the lowest common taxon (LCT). That is, using the example above, *P. ochotensis* records would be converted to and merged by haul with other Paguridae records when it could not be determined the larger group excluded the species-level records. This script is undergoing final testing and is currently configured to work with any combinations of years from 1982-2002 inclusive.

Identification of habitat areas of particular concern (HAPC). Principal Investigator - Lincoln Freese (Alaska Fisheries Science Center - ABL)

Habitat features such as deep water seamounts and shallower pinnacles are often highly productive because of their physical oceanography, and host a rich variety of marine fauna. Perusal of oceanographic charts for the Gulf of Alaska reveals that these features are relatively rare. In summer of 1999 and 2000 dives were conducted on isolated pinnacles from the research submersible *Delta*. The pinnacle surveyed in 1999 is located on the continental shelf approximately 40 nautical miles south of Kodiak, Alaska and rises from a depth of about 40 meters to within 16 meters of the surface. The surrounding habitat is relatively featureless sand. The pinnacle hosted large aggregations of dusky rockfish, kelp greenling, and lingcod, similar to aggregations noted on a pinnacle located in the vicinity of the Sitka Pinnacles Marine Reserve. The pinnacle provides substrate for dense aggregations of macrophytic kelps beginning at the 20 meter isobath and continuing to the top of the pinnacle. These kelp beds may provide essential rearing habitat, as evidenced by the numerous juvenile fish (presumably rockfish) observed swimming among the kelp fronds. Although no evidence of fishing gear impacts were noted from the submersible, it is located SW of Kodiak Island adjacent to areas that are extensively trawled.

The pinnacles surveyed in 2000 were located in southeast Alaska west of Cape Omaney. The survey was designed to determine if the site met the criteria for designation as HAPC. The extent of the site was successfully charted from the *R/V Medeia.* The site measures approximately 400 x 600 m and contains a series of pinnacles. Maximum vertical relief is approximately 55 m, and water depths range between 201 and 256 m. Seven dives at the site were completed to document habitat and associated biota. An additional 5 dives were performed to collect specimens of red tree coral, sponges, and predatory starfish. The substrate is primarily bedrock and large boulders, most likely composed of mudstone, and provides abundant cover in the form of caves and interstices of various sizes. The epifaunal community is rich and diverse, much more so than the surrounding low-relief habitat. The largest epifauna were gorgonian red tree coral colonies and several species of sponges. These organisms are not evenly distributed at the study site. Review of the video and audio data may provide insights into habitat features or oceanographic processes affecting distributions of coral and sponges. Numerous species of fish, including several species of rockfish, are present in relatively large numbers. Redbanded rockfish and shortraker/rougheye rockfish were often associated with gorgonian coral colonies and at least one species of sponge. Also of interest was the presence of a pod of several hundred juvenile golden king crab on acorn barnacle shell hash on a sloping ledge of one pinnacle. We believe this is the first documented observation of juveniles of this species in the Gulf of Alaska. Water currents at the site are generally very strong, but are variable in both direction and strength depending on location. Numerous sections of derelict longline gear were observed on certain areas of the pinnacle, and damage to red tree corals was evident.

In 2001 a series of surveys were completed from the submersible *Delta* in areas of the GOA offshore from Seward southeastward to Yakutat, Alaska. The purpose of the surveys was to determine presence and relative abundance of red tree coral. Choice of survey sites was based on catch of red tree coral brought up in NMFS trawl survey tows. A number of those tows resulted in high catch rates (up to 5800 kg per tow) of coral. In 2001 a total of 18 submersible dives were made at some of these locations. Preliminary analysis of the data reveals that most of these sites were bereft of red tree coral. Three of the sites had small numbers of coral colonies attached to scattered boulders or rock substrates. Most sites were of low-relief with relatively fine substrate and provide relatively low levels of habitat complexity. One such site contained widely scattered boulders, some with attached sponges (*Aphrocallistes* sp.). Numerous juvenile (5-10 cm) rockfish were observed closely associated with the sponges. No juvenile rockfish were found on boulders devoid of sponges. Two dives were made at sites selected based on bathymetric features rather than past trawl survey results. The sites were located along the northwestern and southwestern edges of the Fairweather Grounds, and consisted of high-relief, rocky substrates. One site contained extremely high densities of very large red tree coral. The second site, although similar to the first, was devoid of red tree coral. Observations made during the 2001 survey indicate that red tree coral colonies in the areas studied exhibit patchy distribution and that abundance and distribution estimates of the species based on trawl survey data may be imprecise. In 2002 and 2003 focus was on collection of data from the submersible videos.

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Zooplankton

Bering Sea Zooplankton

Contributed by Jeff Napp,
Alaska Fisheries Science Center

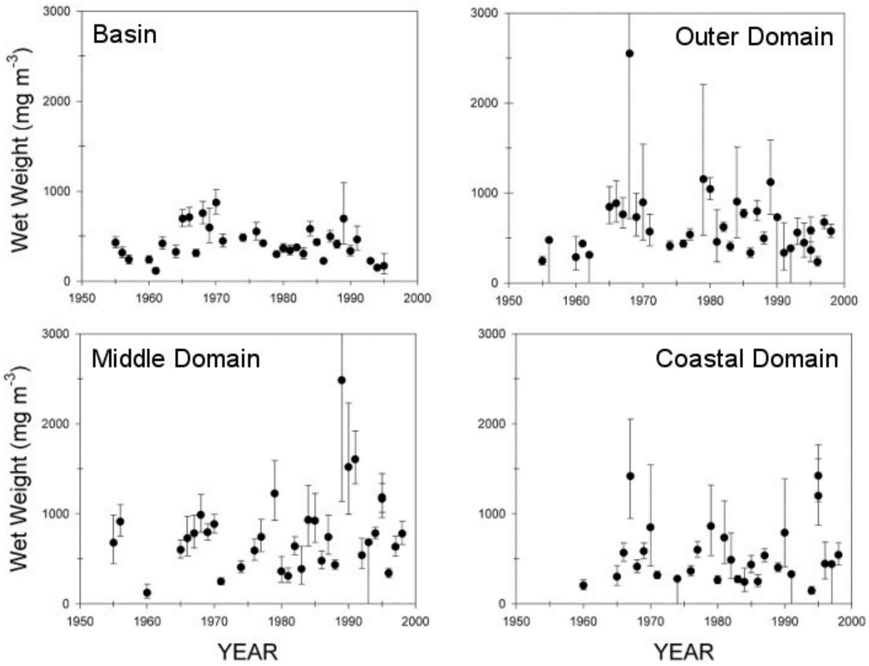

Figure 1. Changes in zooplankton biomass at stations in regions of the deep basin of the Bering Sea and in the outer, middle and coastal domains of the southeastern Bering Sea shelf sampled during the Oshoro Maru Summer Cruises. Data from 1977 to 1994 from Sugimoto and Tadokoro (1998). Data from 1995 to 1999 from Dr. N. Shiga, unpublished. Means with standard errors. This figure is from Hunt et al. 2002.

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 (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).

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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, 1981-2000, 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 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, production and circulation 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.

Preliminary results show unique periodicity and amplitude of interannual variation in abundance among species but some similarities are apparent. Data for pollock, the most abundant species, indicate a 1-3 year cycle of low to high levels of larval abundance (Fig. 1). 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 Pacific cod, northern lampfish, arrowtooth flounder and Pacific halibut. The hypothesis that such a decadal trend in larval abundance may have resulted from a corresponding shift in timing of egg and larval production among species is refuted by statistically insignificant correlations between larval size and abundance over the time-series. Apart from decadal trends in abundance, some similarities in low frequency interranual variation in abundance are evident among species. A consistent pattern of depressed levels of abundance of both eggs and larvae is apparent among diverse species in 1993 (see Fig. 1 for pollock), and to a lesser extent 1997-2000. The implication that a significant across-species similarity exists in the early life history response of fish populations to variation in the northwest Gulf of Alaska oceanographic environment is being explored in this study.

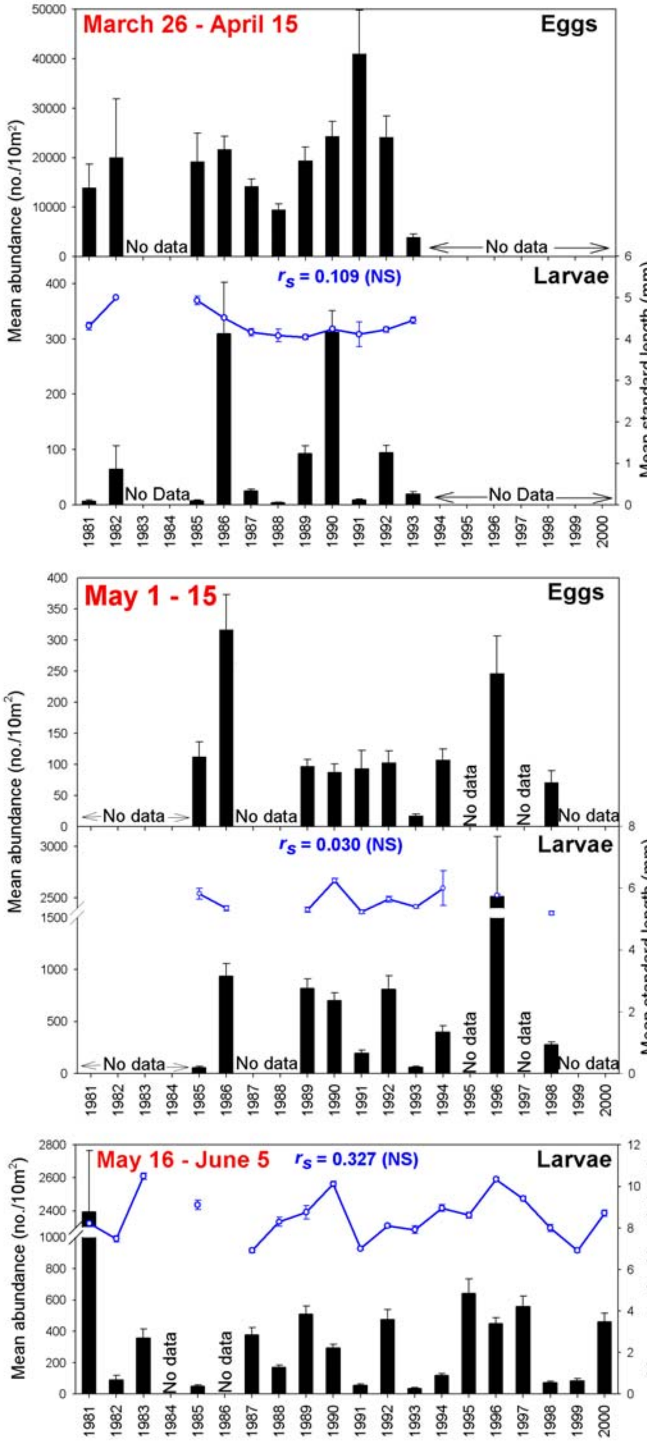


Figure 1. Time series of pollock egg and larval abundance data (mean abundance and standard error) for three spring time-periods in the vicinity of Shelikof Strait, Gulf of Alaska. Line plot shows time series of larval lengths (mean standard length and standard error). r_s = Spearman rank correlation coefficients of mean larval length versus mean larval abundance.

Spatial and temporal patterns among juvenile walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*) in summer on the Eastern Bering Sea shelf 1996-2000

Contributed by: Janet Duffy-Anderson, Recruitment Processes Program, RACE Division, Alaska Fisheries Science Center

Larval and early juvenile fishes were sampled from the Eastern Bering Sea (EBS) shelf during summer (late July) from 1996-2000. Data from these collections were used to examine spatial and temporal patterns in distribution and abundance of larvae and age-0 walleye pollock and Pacific cod. Analyses of distribution revealed a pattern that was generally related to bathymetry and/or geographic feature (e.g. proximity to the Pribilof Islands) in 1996, 1997, 1999, and 2000. Highest catches of pollock were typically noted near the Pribilof Islands, and peak abundances of Pacific cod rarely co-occurred with peak abundances of walleye pollock. Atypical patterns of distribution were noted in 1998. Depressions in abundance were also noted between 1997-1999, though interannual differences in size were not apparent (Figure 1). Preliminary evidence suggests that factors associated with the El Niño event of 1997-1998 in the EBS were sufficient to disrupt established patterns of geographic association of juvenile walleye pollock and Pacific cod, and reduce the abundances of the early life stages. Given concerns over the effects of local-, meso-, and macro-scale perturbations on the structuring of the North Pacific ecosystem, we suggest that larval and juvenile fish data collected in a time series are useful for detecting change and/or determining resilience of North Pacific marine ichthyoplankton assemblages in response to environmental stressors.

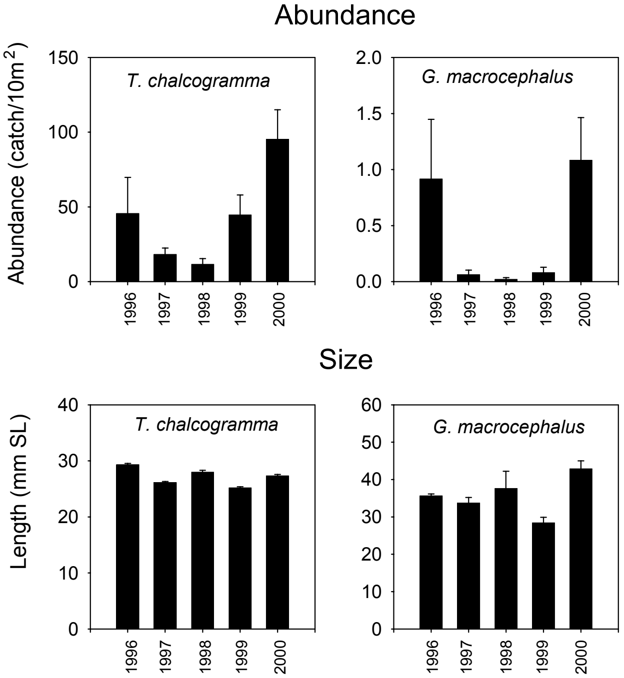


Figure 1. Interannual variations in abundance (top) and length (bottom) (± SE) of walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus marcocephalus*) on the EBS shelf in summer (near the Pribilof Islands).

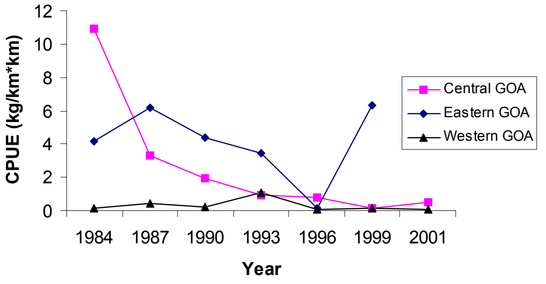
Forage – Gulf of Alaska (not updated for 2003)

Contributed by Eric Brown, Alaska Fisheries Science Center

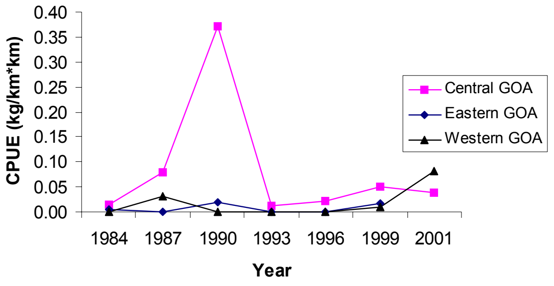
Several groups have been defined as forage species by the North Pacific Fishery Management Council for management purposes. These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Several of these groups are captured incidentally in the RACE bottom trawl survey of the shelf, which may provide an index of abundance (Figure 1). 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. The large spike seen in the central Gulf in 1990 was due to a single catch consisting of 150 individuals. 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, the increases in abundance seen for capelin in the central and eastern Gulf were influenced by a very few and unusually large catches. Of these species, only Pacific sandfish and eulachon exhibit catch rates not unduly influenced by a few large catches.

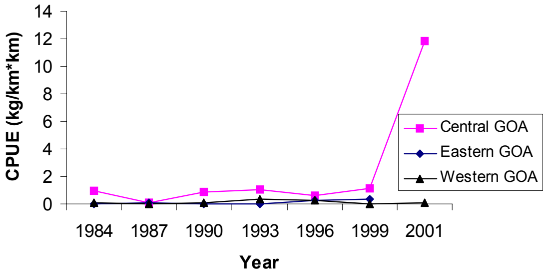
Pacific Sandfish Gulf of Alaska



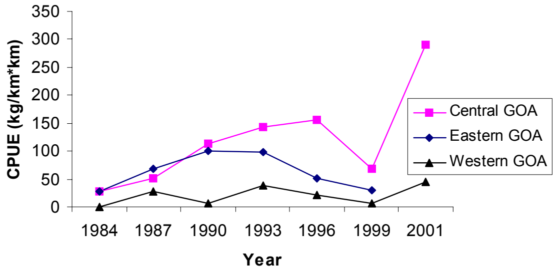
Pacific Sandlance Gulf of Alaska



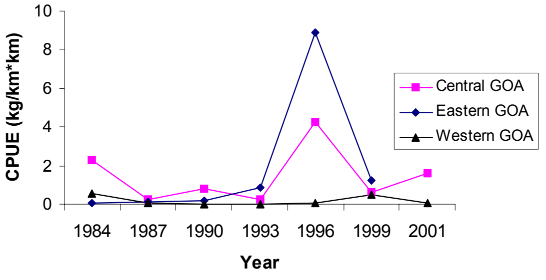
Pricklebacks Gulf of Alaska



Eulachon Gulf of Alaska



Capelin Gulf of Alaska



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 1). 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. 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 biomass index values 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 catch biomass was very high.

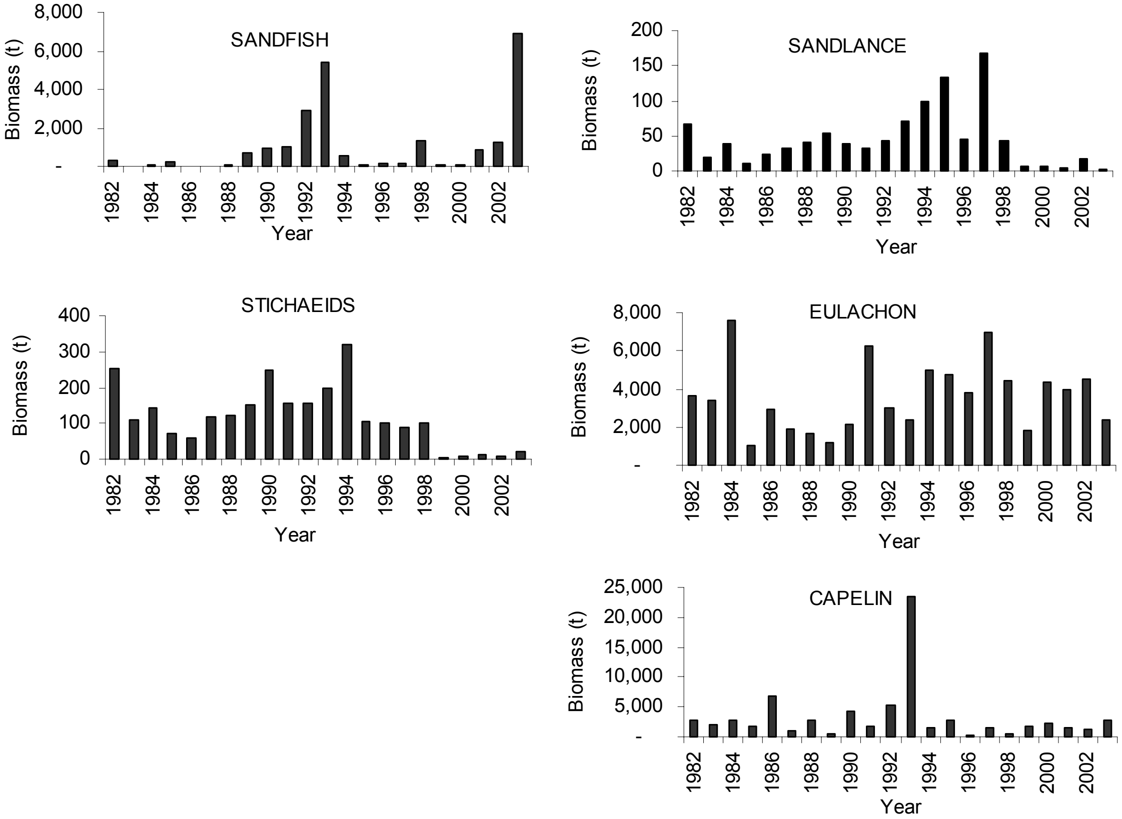


Figure 1. Biomass index values of several forage fish groups from the eastern Bering Sea summer bottom trawl survey, 1982-2003.

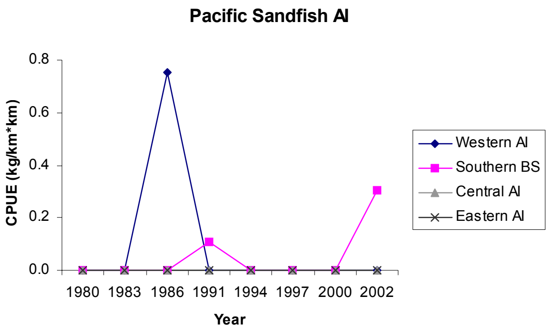
Forage – Aleutian Islands

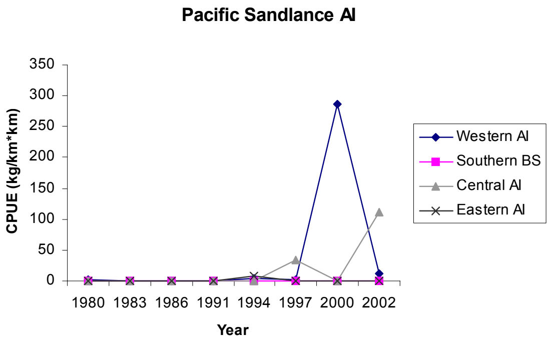
Contributed by Eric Brown, Alaska Fisheries Science Center

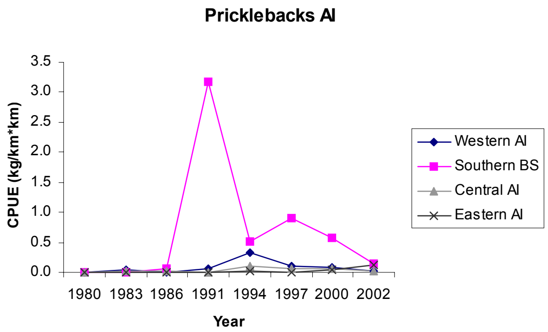
Several groups have been defined as forage species by the North Pacific Fishery Management Council for management purposes. These groups include gunnels, lanternfish, sandfish, sandlance, smelts, stichaeids, and euphausiids. Some of these groups are captured incidentally in the RACE bottom trawl survey of the shelf, which may provide an index of abundance (Figure 1). 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.

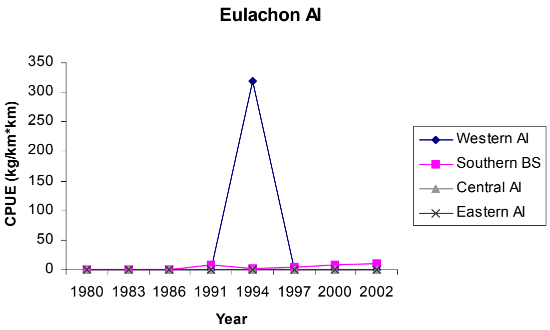
The Aleutian Islands forage species appear only sparingly in survey catches with occasional higher than normal catches. The spike of Pacific sandfish seen in the western Aleutian Islands in 1986 is a result of only 4 individuals appearing in one catch. Similarly, the highest catch rates for pricklebacks, 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.

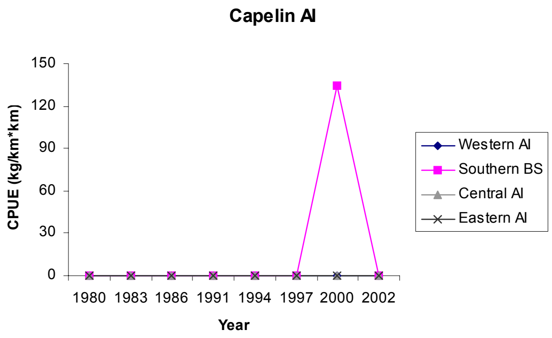
The results of the 2002 survey indicate an apparent three-fold increase in the abundance of Pacific sandfish in the southern Bering Sea. However, over all surveys, Pacific sandfish densities have consistently been low, never exceeding one kg per square kilometer and a frequency of occurrence greater than 2 percent. Other changes include a sharp decrease of Pacific sandlance in the Western Aleutians along with a corresponding increase in the Central Aleutians and a decrease in capelin abundance in the southern Bering Sea to levels consistent with pre-2000 surveys. The abundance of pricklebacks in the southern Bering Sea continues a long downward trend first observed in 1991.


Pacific Sandfish AI
CPUE (kg/km*km)
0.8
0.6
0.4
0.2
0.0
1980
1983
1986
1991
1994
1997
2000
2002
Year
Western AI
Southern BS
Central AI
Eastern AI


Pacific Sandlance AI
CPUE (kg/km*km)
350
300
250
200
150
100
50
0
1980
1983
1986
1991
1994
1997
2000
2002
Year
Western AI
Southern BS
Central AI
Eastern AI


Pricklebacks AI
CPUE (kg/km*km)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1980
1983
1986
1991
1994
1997
2000
2002
Year
Western AI
Southern BS
Central AI
Eastern AI


Eulachon AI
CPUE (kg/km*km)
350
300
250
200
150
100
50
0
1980
1983
1986
1991
1994
1997
2000
2002
Year
Western AI
Southern BS
Central AI
Eastern AI


Capelin AI
CPUE (kg/km*km)
150
120
90
60
30
0
1980
1983
1986
1991
1994
1997
2000
2002
Year
Western AI
Southern BS
Central AI
Eastern AI

Herring

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 1). 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 - 2002 average but fell below in 1989 - 1990, and 1993 - present (Figure 2).

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".

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

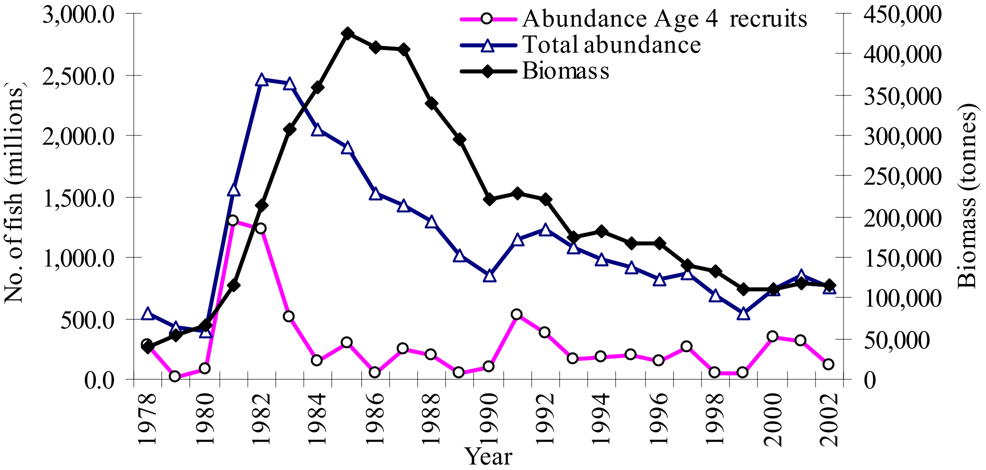


Figure 1. Total population abundance, recruitment, and biomass trends of Pacific herring in the Togiak District of Bristol Bay, 1978 – 2002.

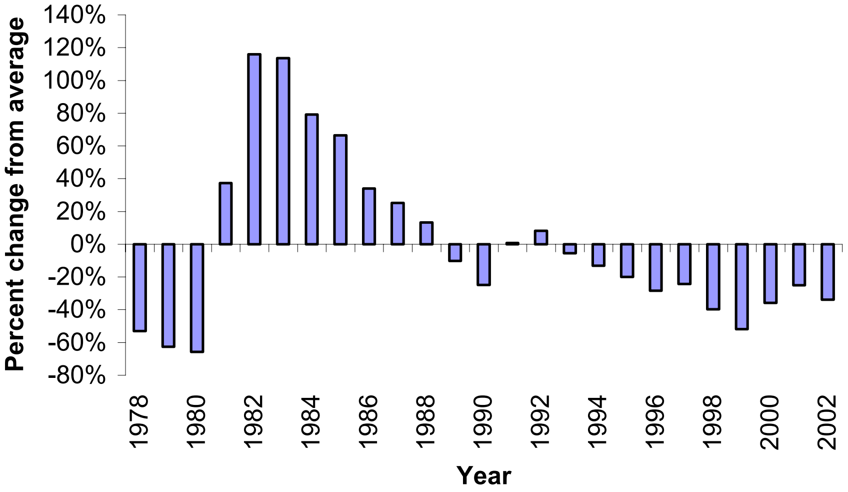


Figure 2. Total abundance trends (percent change from time series average) of Togiak herring from 1978 – 2002.

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Southeast Alaska Herring –

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Herring stock assessments have been conducted 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. Stock status analyses and forecasts for herring in Southeast Alaska are completed during the fall of each year and have not yet been completed for 2003.

Between 2000 and 2001 the combined estimated spawning biomass from the nine areas increased from 101,763 to 116,167 tons and subsequently decreased to 91,073 tons in 2002 (Fig. 1). This estimated 2002 spawning biomass is above the 22-year median biomass of 71,281 tons (Fig. 1, Table 1.). Spawning biomass has been above this median since 1996. 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 been above the 22-year median since 1997.

Herring abundance in S.E. Alaska often changes markedly from year to year, rarely exhibiting consistent, monotonic trends for more than four successive years (Figs. 1 and 2). 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, up or down, and biomass in one area has had a pronounced downward trend (Kah Shakes/Cat Island, Fig. 2). There have been major fluctuations around these long-term trends (Figs. 1 and 2), with periods of both increasing and decreasing trends over the shorter term. The combined S.E. Alaska biomass, both including and excluding Sitka, exhibits a trend of increasing biomass between 1980 and 2002 (Fig. 1).

Fluctuations in herring abundance are probably influenced primarily by localized and regional environmental conditions and, probably to a lesser extent, commercial harvest. 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 that 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 (Fig. 2, Table 2.).

Table 1. Estimated herring spawning biomass (tons) for nine primary spawning areas in Southeast Alaska, 1980-2002.

	Spawning Area										
Year	Kah Shakes - Cat Island	W. Behm Canal	Craig	Ernest Sound	Hobart Bay-Port Houghton	Seymour Canal	Sitka	Hoonah Sound	Tenakee Inlet	TOTAL (including Sitka)	TOTAL (**ex**cluding Sitka)
1980	16,640	1,823	6,011	270	0	5,695	39,396	0	504	70,339	30,943
1981	20,290	700	4,867	410	0	2,015	33,517	750	810	63,359	29,842
1982	17,979	1,250	7,958	160	0	1,340	33,875	398	654	63,614	29,739
1983	17,939	500	7,139	1,640	0	4,015	28,961	265	768	61,227	32,266
1984	17,732	875	2,000	1,000	0	1,950	44,341	540	619	69,057	24,716
1985	11,396	750	2,000	1,000	0	3,000	38,486	928	6,431	63,991	25,504
1986	11,388	625	3,352	1,000	0	4,342	30,455	994	2,040	54,196	23,741
1987	9,840	500	11,481	440	0	4,800	50,226	740	7,875	85,902	35,676
1988	7,237	500	18,364	880	635	3,200	68,084	1,325	7,577	107,802	39,718
1989	3,912	250	21,491	500	768	3,115	39,144	4,000	6,050	79,231	40,087
1990	8,624	283	21,571	1,000	1,202	2,850	26,815	2,462	2,595	67,401	40,587
1991	11,110	1,274	21,073	3,000	2,000	2,100	25,417	2,299	400	68,672	43,255
1992	9,356	1,870	14,666	2,650	4,100	1,780	53,877	5,931	200	94,431	40,553
1993	8,478	3,854	7,624	692	2,238	3,005	45,524	1,200	904	73,519	27,995
1994	5,162	2,621	5,149	2,544	2,554	3,675	18,790	2,757	400	43,651	24,861
1995	7,258	3,659	3,914	2,501	4,850	1,252	43,089	546	200	67,269	24,180
1996	4,534	6,349	4,359	2,885	3,675	1,703	44,526	3,513	4,569	76,113	31,588
1997	6,505	10,022	6,450	6	2,694	4,913	38,284	6,574	10,098	85,545	47,261
1998	12,157	15,346	7,125	5,792	4,938	4,390	41,633	7,278	11,005	109,665	68,031
1999	2,407	14,135	7,229	96	5,350	4,044	53,739	5,247	11,884	104,131	50,392
2000	642	3,478	9,510	920	1,293	4,984	62,888	4,073	9,919	97,706	34,818
2001	819	5,574	8,345	2,052	1,026	9,423	70,816	8,568	9,278	115,900	45,084
2002	0	8,695	7,720	2,406	827	10,489	50,302	6,216	4,220	90,874	40,572

Table 2. Southeast Alaska catch-related herring mortality (tons) for nine primary spawning areas in Southeast Alaska, 1980-2002.

	Spawning Area										
Year	Kah Shakes - Cat Island	W. Behm Canal	Craig	Ernest Sound	Hobart Bay - Port Houghton	Seymour Canal	Sitka	Hoonah Sound	Tenakee Inlet	TOTAL (including Sitka)	TOTAL (excluding Sitka)
1980	1,140	0	261	270	0	0	4,385	0	504	6,560	2,175
1981	1,840	0	467	0	0	618	3,506	0	810	6,623	3,117
1982	2,279	0	608	0	0	0	4,363	0	654	7,904	3,541
1983	3,239	0	139	0	0	0	5,450	0	768	9,596	4,146
1984	2,182	0	0	0	0	518	5,830	0	619	8,631	2,801
1985	2,161	0	0	0	0	0	7,475	0	1,431	11,067	3,592
1986	1,538	0	302	0	0	392	5,443	0	2,040	9,715	4,272
1987	1,440	0	1,231	0	0	302	4,216	0	1,275	8,162	3,946
1988	1,087	0	2,014	0	0	586	9,575	0	1,577	14,253	4,678
1989	592	0	1,691	0	0	547	12,135	0	690	15,108	2,973
1990	0	0	3,221	0	0	361	3,804	112	595	7,731	3,927
1991	660	0	3,273	0	0	0	1,908	124	0	5,965	4,057
1992	1,256	0	2,316	0	0	0	5,368	217	0	9,157	3,789
1993	737	0	668	8	0	0	10,216	101	0	11,730	1,514
1994	749	0	824	0	0	382	4,753	307	0	7,014	2,261
1995	626	0	499	111	140	319	2,908	272	0	4,875	1,967
1996	605	0	739	220	229	0	8,144	0	0	9,937	1,793
1997	1,137	0	892	6	230	0	11,147	609	98	14,119	2,972
1998	616	0	779	0	110	586	6,680	806	586	10,163	3,483
1999	0	0	602	96	0	706	9,118	675	835	12,032	2,914
2000	0	0	346	0	0	426	4,900	344	494	6,510	1,610
2001	0	0	408	0	432	649	12,060	620	775	14,944	2,884
2002	0	0	392	0	33	1,169	9,936	1,281	135	12,945	3,010

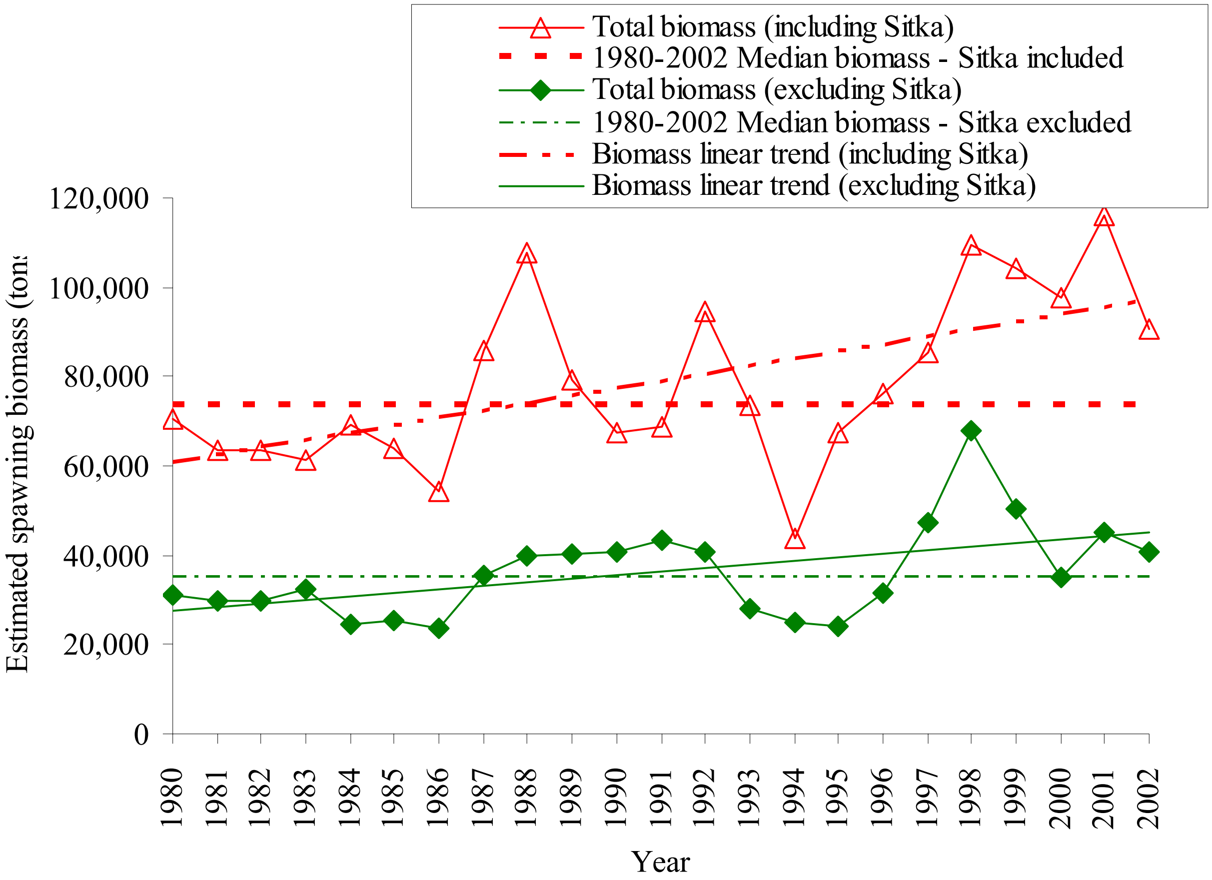

Figure 1. Estimated combined annual herring spawning biomass (including and excluding Sitka) at major Southeast Alaska spawning areas, 1980-2002.

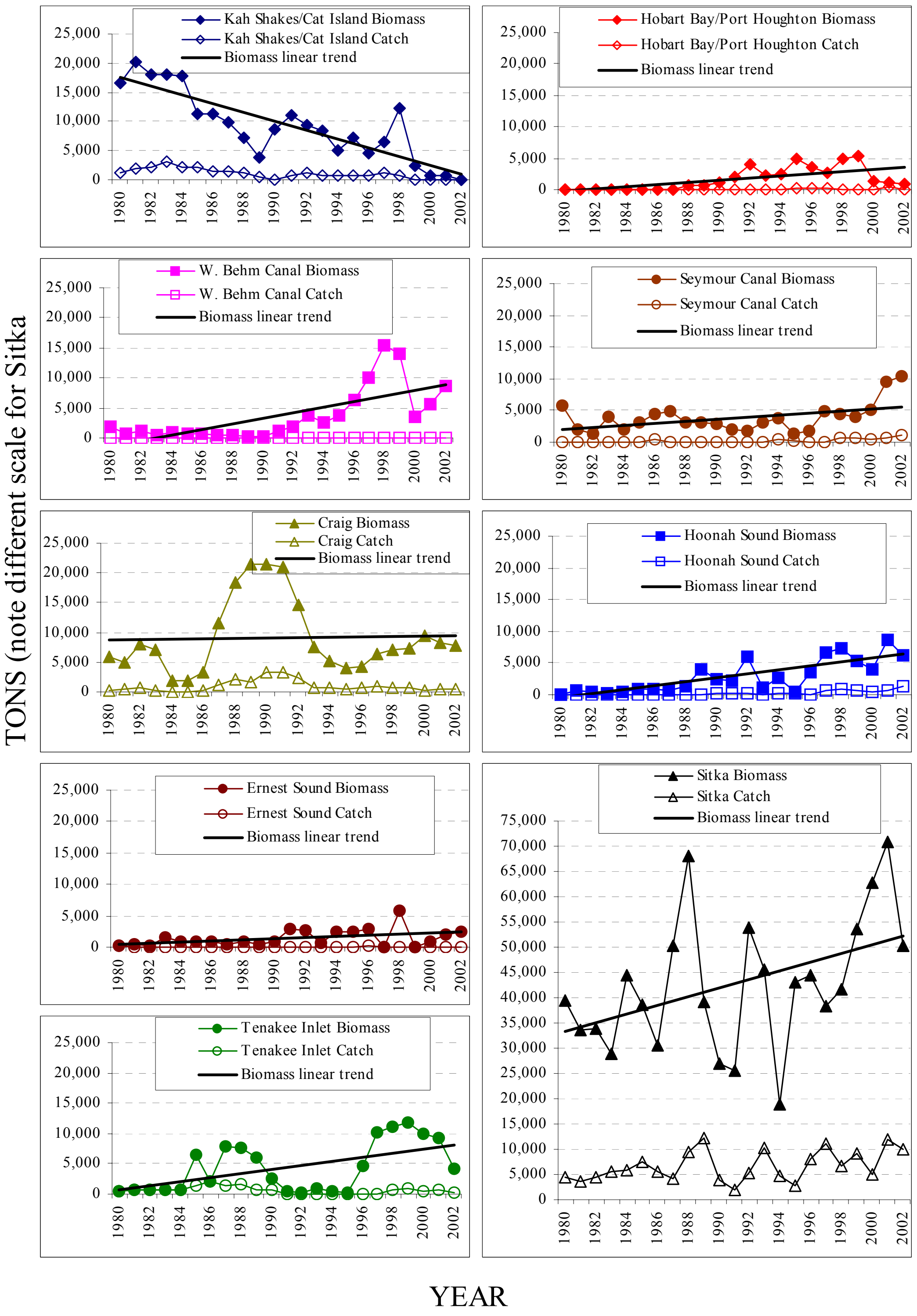

Figure 2. Estimated herring spawning biomass, catch and biomass linear trend at nine major spawning locations in S.E. Alaska, 1980-2002.

Salmon

Historical trends in Alaskan salmon

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Overall Catch Trends

Pacific salmon rear in the Gulf of Alaska (GOA) and Central Bering Sea (BS) and are managed in four regions based on freshwater drainage areas, Southeast, Central, Westward, and Arctic-Yukon-Kuskokwim (Figure 1). Salmon distribution throughout the GOA and BS varies by species and stocks, 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 2-5). Asian stocks have shown similar trends while Pacific Northwest and British Columbia stocks have been at lower levels. 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 (Figures 2 and 3). 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. 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. 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

Overall productivity of salmon in Alaska has been stable and at high levels, despite recent anomalous returns in a few areas. Salmon survival varies among stocks and regions, for example, recruitment for most Bristol Bay stocks has been moderate to strong in the last decade; whereas, recruitment for Kvichak River sockeye in recent brood years has been low. Catch by species data was provided by Doug Eggers (Alaska Department of Fish and Game). A full report (Eggers 2003) of run forecasts and a review of the 2002 season is available on the web at http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmhome.htm#forecasts.

SOCKEYE

Abundance of sockeye salmon in all areas increased from the mid 1970s to the 1980s (Figure 2). Since then the increased abundance has been stable and at high levels. Recruitment for most Bristol Bay sockeye salmon stocks other than Kvichak (Figure 3) has been moderate to strong in the last decade. Catch and escapement data for all Bristol Bay sockeye stocks are available (provided by Lowell Fair, Alaska Department of Fish and Game, Anchorage, Alaska). 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 2000 suggest that returns in 2003 may be more characteristic of the 1978-95 period (Fair 2003).

PINK

Pink salmon catches have generally been high in all regions in the last decade, and appeared to begin increasing in the late 1970’s (Figure 2).

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 4). 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).

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 4). 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. 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 2002 has been lower than the previous decade, but still above catches in the 1960's and 1970's (Figure 5).

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). The overall average weight of chinook salmon in Alaska continued to decline 1995-2000 (Figure 6). Overall average weight of returning chum salmon was higher in 1997-2000 than previously recorded (Figure 6).

Figure 1. The four fishery management regions of the Alaska Department of Fish and Game, Division of Commercial Fisheries.

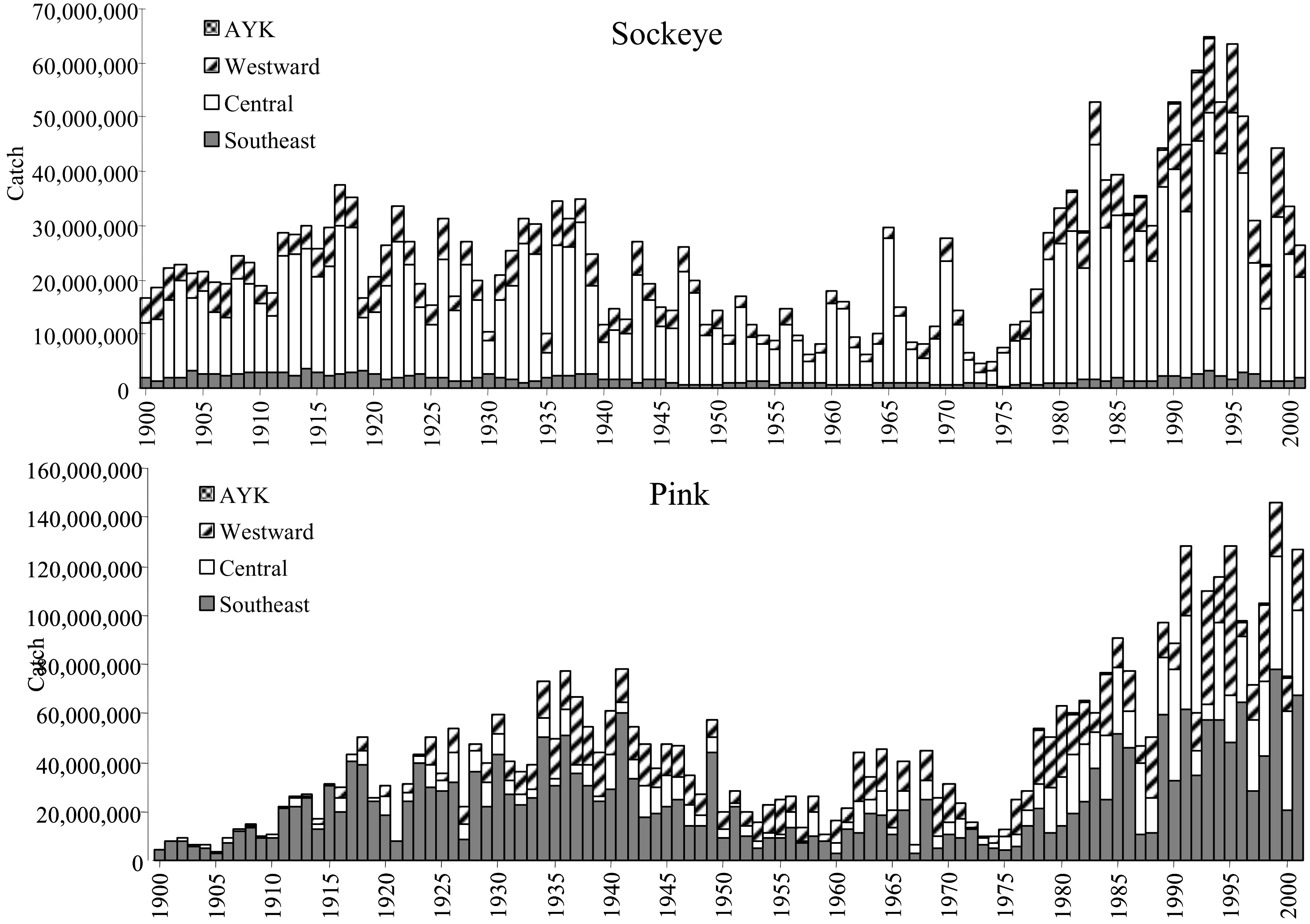

Figure 2. Historical catch of sockeye and pink salmon by area in Alaska.

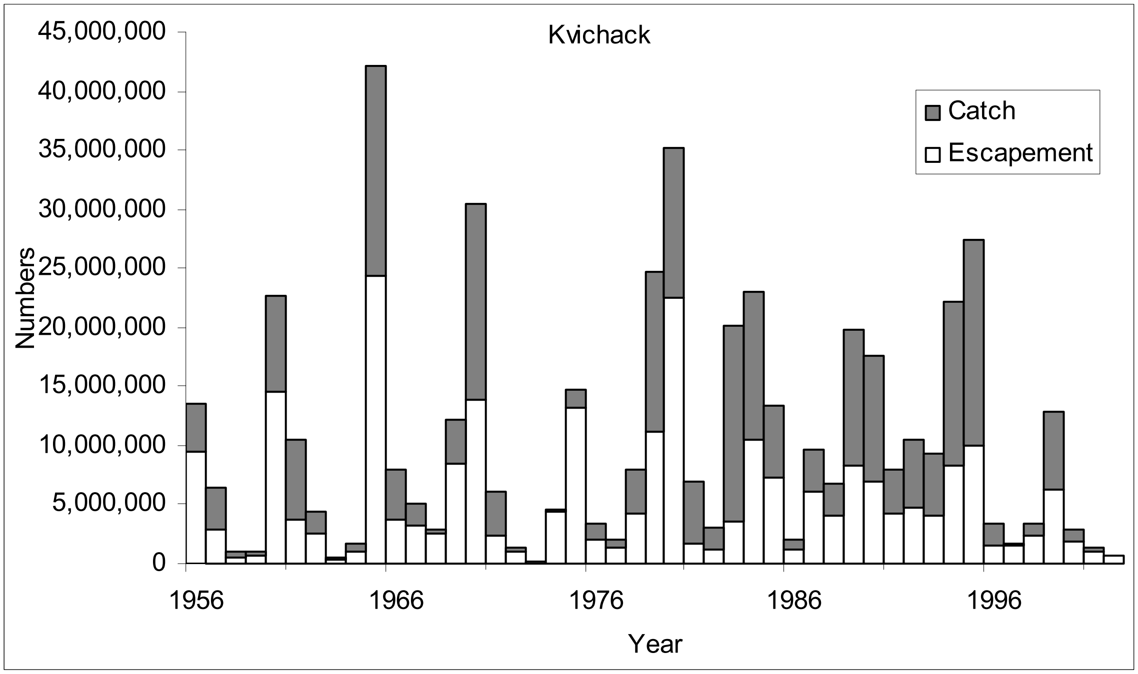

Figure 3. Historical catch and escapement of Kvichack River sockeye salmon, a Bristol Bay stock in the Westward Alaska management region.

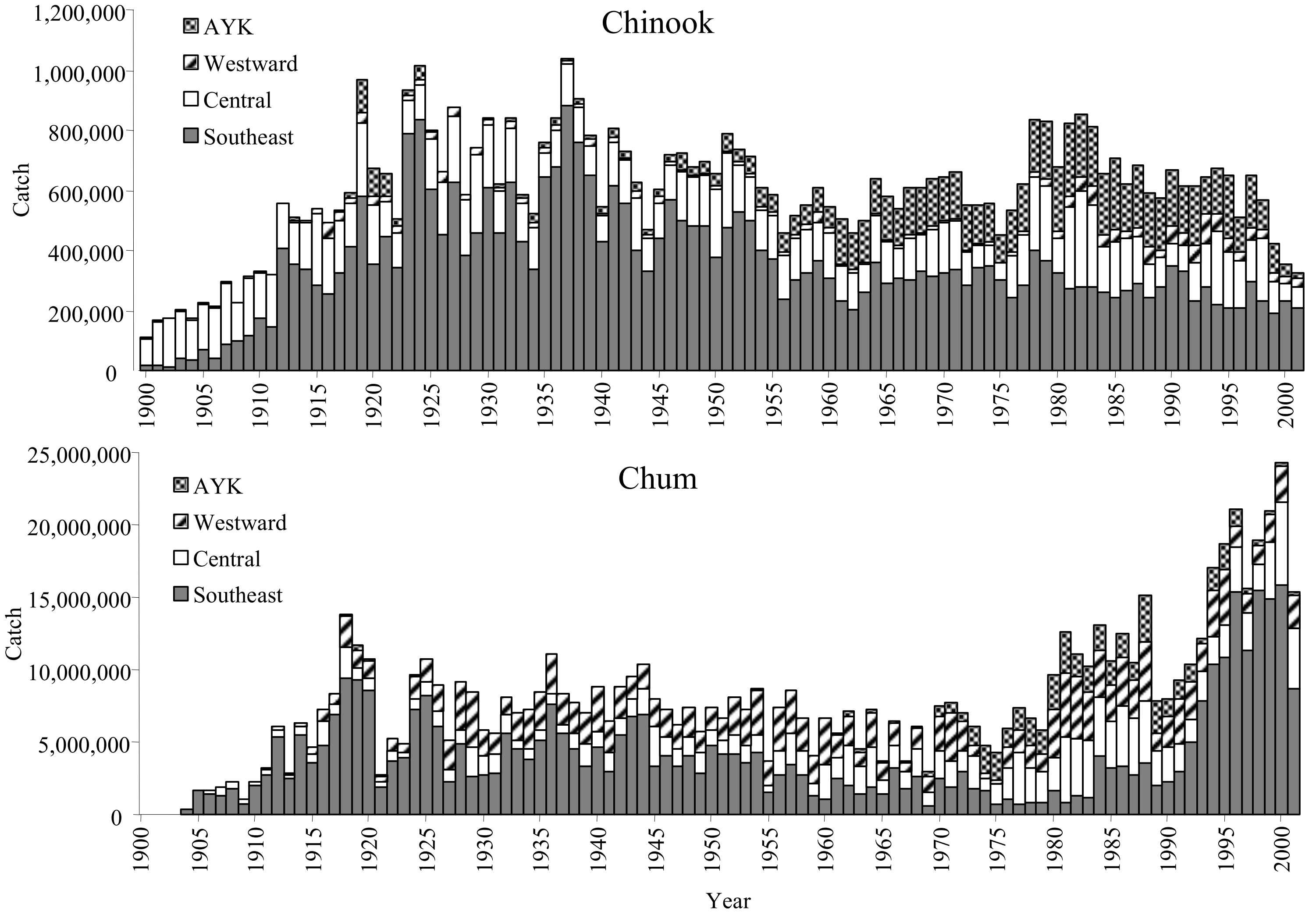

Figure 4. Historical catch of chinook and chum salmon by area in Alaska.

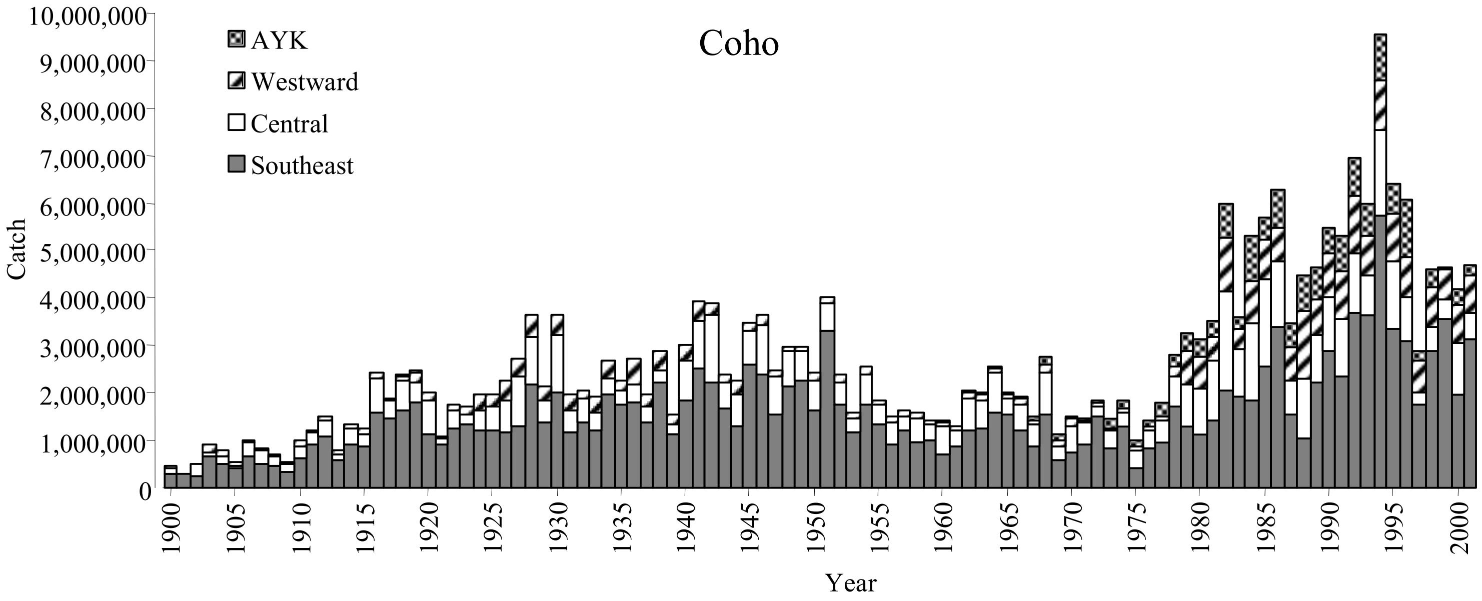

Figure 5. Historical catch of coho salmon by area in Alaska.

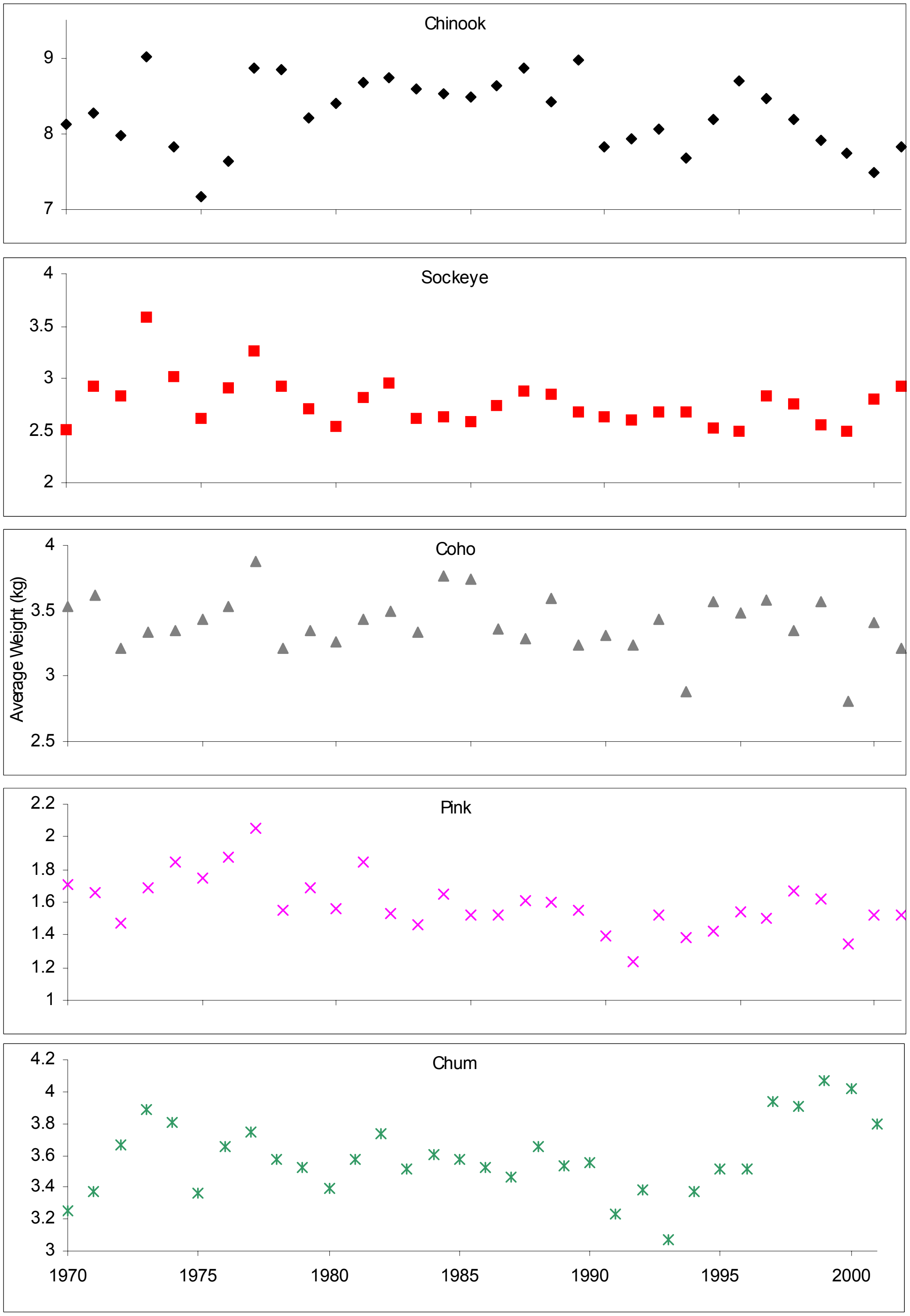

Figure 6. Historical average weight (kg) of salmon caught in Alaska. Data was obtained from the Alaska Department of Fish and Game website (http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/catchval/history/1970-2001s.htm).

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Groundfish Biomass and Recruits per Spawner Trends

By Alaska Fisheries Science Center 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 1). The assessment information is available in the NPFMC stock assessment and fishery evaluation reports (2002 a, b) and on the web, http://www.refm.noaa.gov/stocks/specs/Data%20Tables.htm.

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 1979 to present average occurring in 1990-91, 1997-98, and 2001-02 (Figure 1). Walleye pollock was the dominant species and influenced observed fluctuations in total biomass.

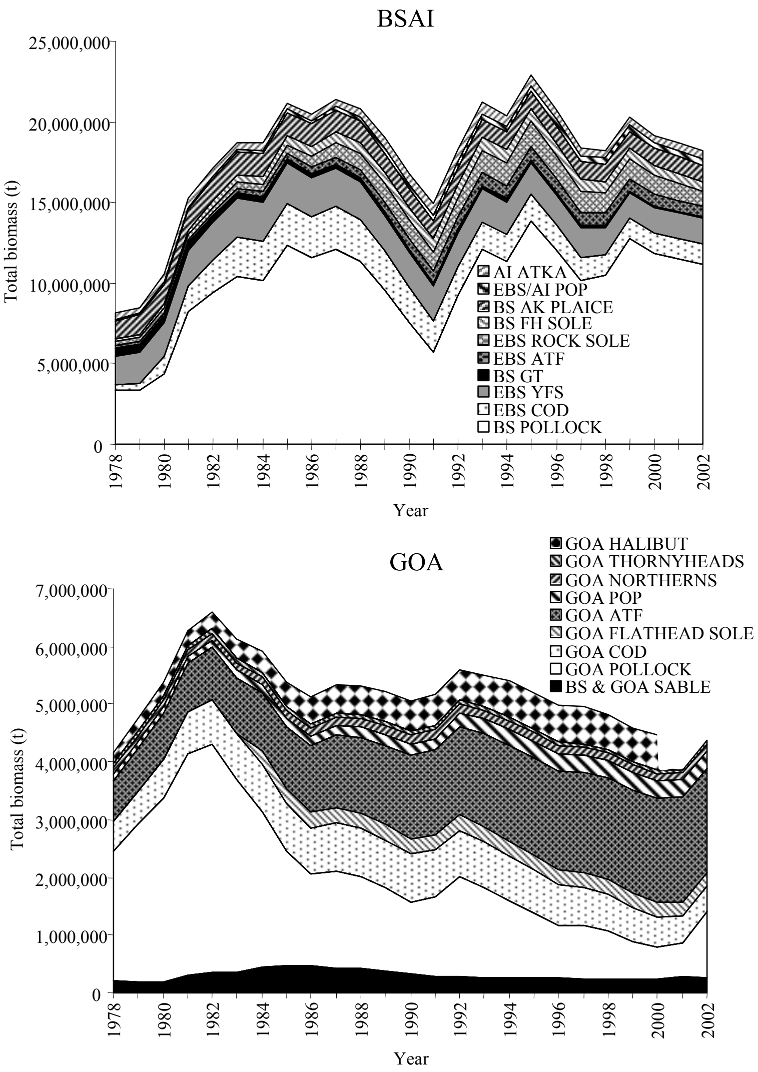

Figure 1. Groundfish and halibut biomass trends (metric tons) in the BSAI and GOA from 1978-2002, as determined from age-structured models of the Alaska Fisheries Science Center reported by NPFMC (2002 a, b) and by IPHC.

Gulf of Alaska groundfish biomass trends (Figure 1) 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 was fairly stable from around 1985-1993, it declined from 1994 to 2000, but has increasd slightly in 2002. Pollock started out as the dominant groundfish species but arrowtooth flounder has increased in biomass and is now dominant. Pacific halibut, assessed by the International Pacific Halibut Commission (IPHC), for areas 2C, 3A, and 3B are included in these biomass trends. IPHC stock assessment in 2000 for the GOA area indicated halibut biomass increased from 1979 to 1986 to almost twice the 1979 level and biomass levels in 2000 were still above the 1979 levels (IPHC 2000). Reliable estimates of halibut biomass from 2001-03 are not available due to a need for reevaluation of the stock assessment model (S. Hare, IPHC, personal communication). Biomass estimates of halibut in the Bering Sea are not available because they are so lightly exploited there.

Recruit per spawner anomalies were calculated using normalized (estimate minus the average of years 1977-2001) values of the logged ratios of recruit abundance per unit mass of spawning biomass (Figures 3 and 4). Anomalies of several groundfish species, such as BS flathead and rock sole, BS and GOA arrowtooth flounder, BSAI and GOA POP, GOA northerns, and GOA thornyheads, changed sign at times of identified "regime changes" (Hare and Francis 1995, Hare and Mantua 2000; Mantua and Hare 2001) (Figures 3 and 4). Anomalies for all of these species except thornyheads changed from positive (high recruit per spawners) to negative (low recruit per spawners) in approximately 1988. Recruit per spawner anomalies for other groundfish species did not seem to follow any known climatic changes. Yearclass strengths for Pacific halibut in GOA IPHC area 3A showed higher recruitment in the 1980s and declining recruitment after around 1987.

Temporal trends in flatfish production in the Eastern Bering Sea are consistent with the hypothesis that decadal scale climate variability influences marine survival during the early life history period. Examination of the recruitment of winter-spawning flatfish in the Bering Sea (rock sole, flathead sole and arrowtooth flounder) in relation to decadal atmospheric forcing indicates favorable recruitment may be linked to wind direction during spring (Wilderbuer et al. 2001). 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 4). The pattern of springtime wind changed to an off-shore direction during the 1990s which coincided with below-average recruitment.

Examination of the average deviations (recruit per spawner anomalies divided by the standard deviation) indicates that both BSAI and GOA groundfish experienced similar trends in survival (Figure 5). For example, BSAI flatfish show similar trends as the GOA flatfish. BSAI pollock survival trends were comparable to those of GOA pollock up until 1991, after which the resemblance ended. When assembled into species groups, survival trends of gadids, flatfish, and rockfish of BSAI and GOA combined, were also similar (Figure 5). This may be another indication that multiple species of more than one ecosystem are responding in similar ways to large-scale climate changes.

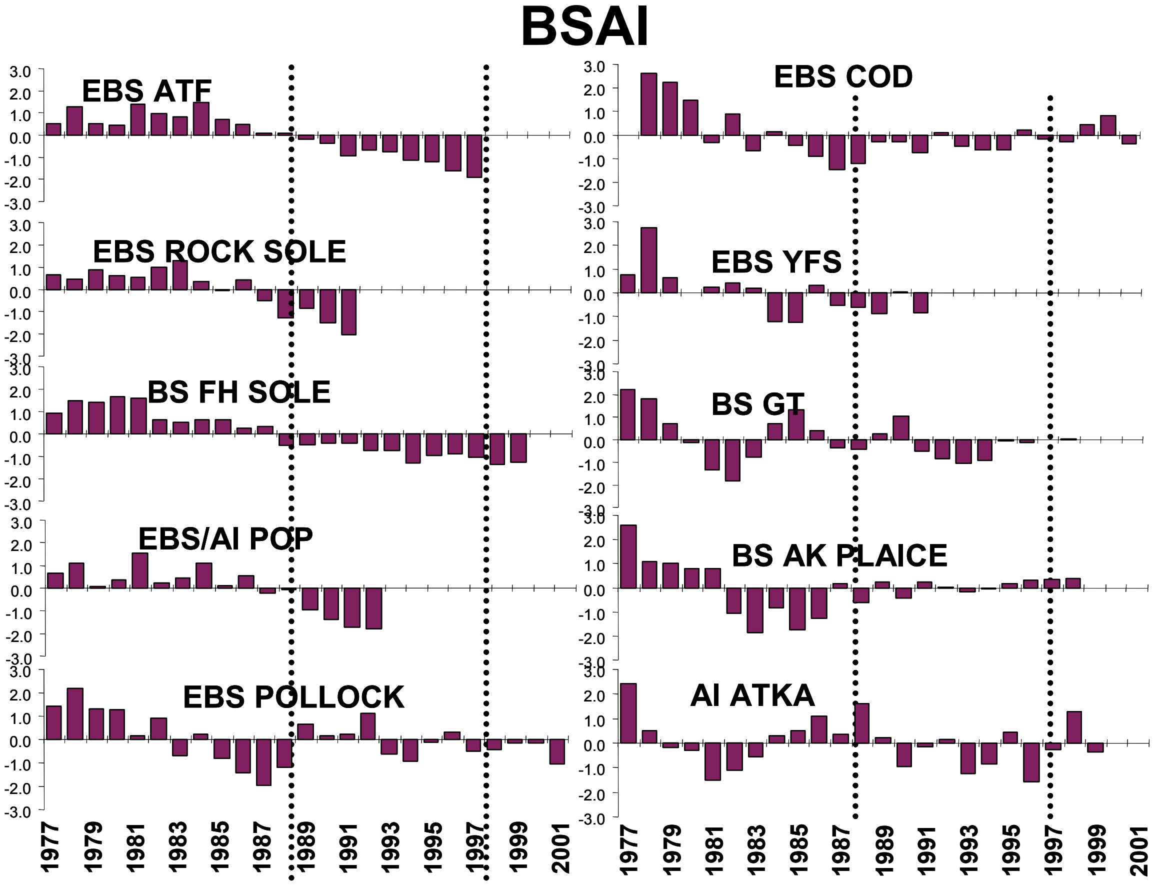

Figure 2. Recruit per spawner anomalies for BSAI groundfish species assessed with age- or size-structured models. Anomalies are normalized (estimate minus the average of years 1977-2001) values of the logged ratios of recruit abundance per unit mass of spawning biomass. Dashed lines represent identified "regime changes" (Hare and Francis 1995, Hare and Mantua 2000; Mantua and Hare 2001).

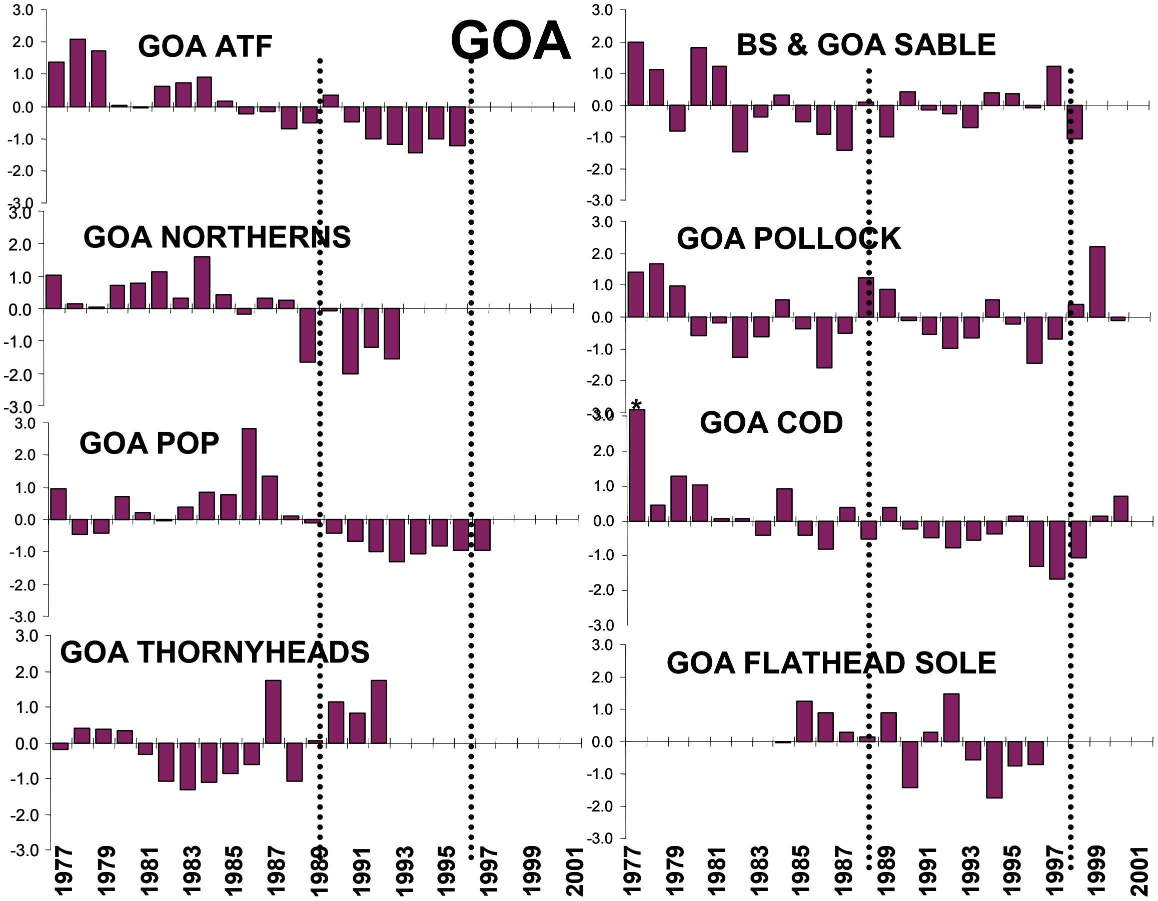

Figure 3. Recruit per spawner anomalies for GOA groundfish species assessed with age- or size-structured models. Anomalies are normalized (estimate minus the average of years 1977-2001) values of the logged ratios of recruit abundance per unit mass of spawning biomass. Dashed lines represent identified "regime changes" (Hare and Francis 1995, Hare and Mantua 2000; Mantua and Hare 2001). * 1978 spawning biomass of GOA Pacific cod was used as a proxy for the 1977 spawning biomass to capture the large yearclass.

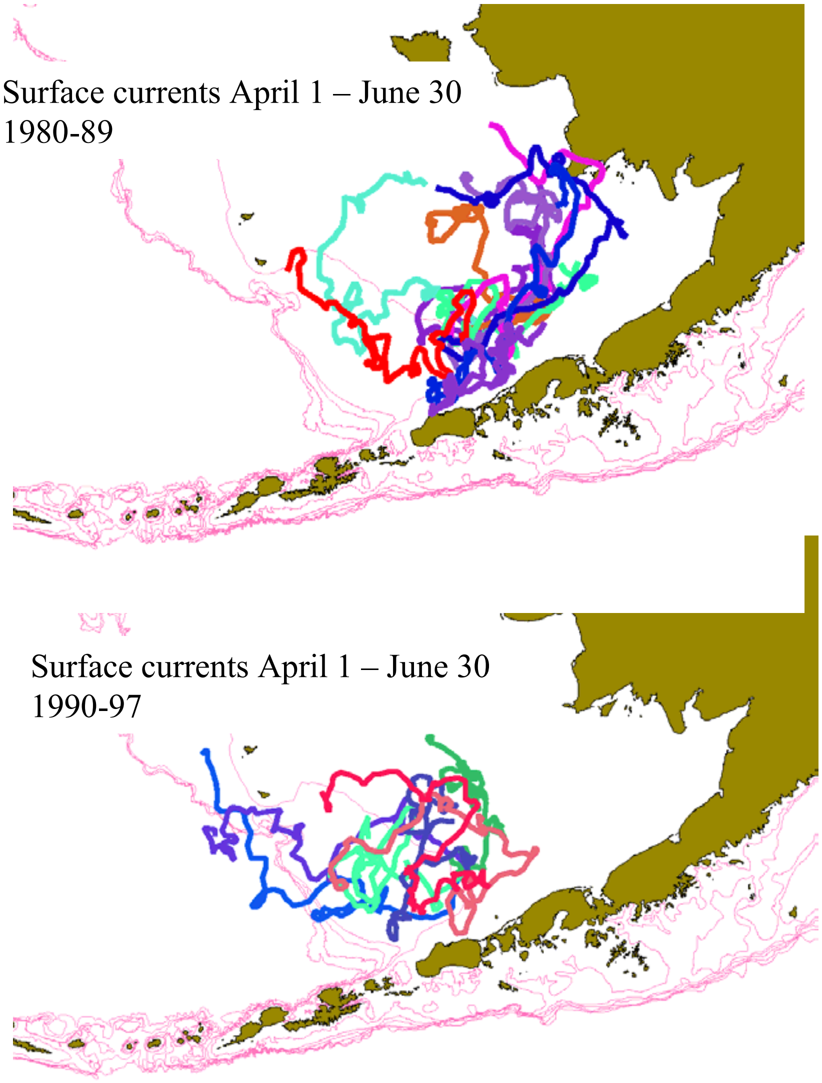

Figure 4. OSCURS (Ocean Surface Current Simulation Model) trajectories from starting point 56° N, 164° W from April 1 – June 30 for the 1980's (upper panel) and 1990-96 (lower panel).

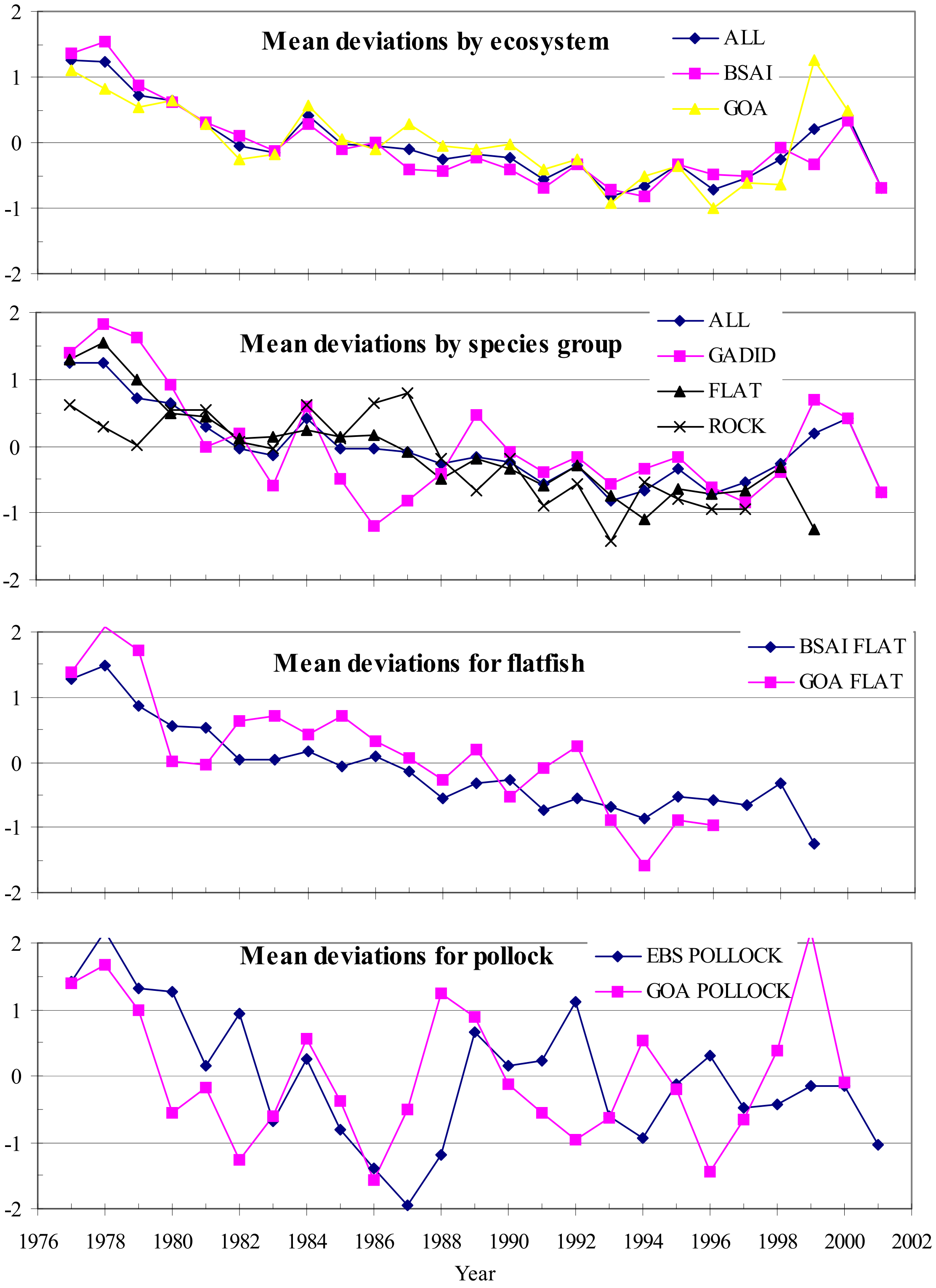

Figure 5. Average deviations (recruit per spawner anomalies divided by the standard deviation) across ecosystem or species groups.

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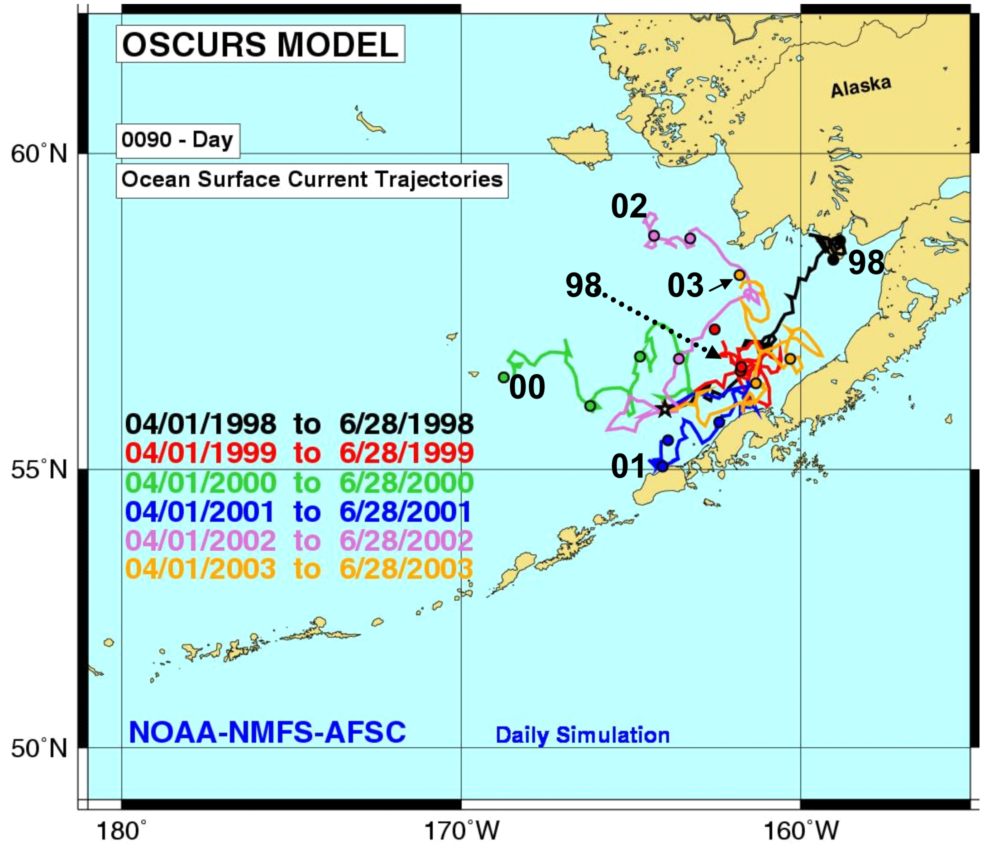
Update on EBS winter spawning flatfish recruitment and wind forcing

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 (1998-2003; Figure 1) for the last 6 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.



Environmental controls of fish growth in the southeastern Bering Sea

Contributed by Michael C. Palmer, University of Alaska Fairbanks

Fish growth rates are important indicators of ecosystem response to environmental and climatic variability. Differential growth affects recruitment and stock abundance through changes to juvenile mortality, age-at-maturation, and fecundity. Such changes in biology can affect management strategies by altering gear selectivity and estimates of biomass and stock recruitment. Growth is a function of food ingestion, assimilation, and metabolism and as such influenced by food availability, which can limit ingestion rates at low prey densities, and temperature, which can influence ingestion and assimilation rates as well as metabolic rates.

Given the importance of sea ice on the regulation of shelf water temperatures (Wyllie-Echeverria and Wooster, 1998) and productivity (Walsh and McRoy, 1986; Hunt et al., 2002) over the southeastern Bering Sea shelf, a sea ice-initiated conceptual model of growth was proposed which differentiated between food and temperature-mediated growth (Fig. 1). Because the timing of sea ice retreat has the potential to inversely affect food delivery to the pelagic and benthic ecosystems (Walsh and McRoy, 1986; Smith, 2003), fish were partitioned into two trophic guilds based on feeding ecology. The pelagic feeding guild was comprised of walleye pollock (Theragra chalcogramma) and the Togiak stock of Pacific herring (Clupea pallasi). The benthic feeding guild included yellowfin sole (Limanda aspera) and northern rock sole (Lepidopsetta polyxystra). Fish growth was estimated over the period 1982 to 2000 from mean length-at-age increments using the following equation:

$$G_x = (L_{x+1} - L_x)/t$$

where G_x is the absolute growth rate (mm/yr) in year X, L_x is the mean length-at-age in year X, L_{x+1} the mean length-at-age in year X + 1 and t is the time interval. Growth rates for each age were standardized and then the annual standardized growth for all age classes were averaged to obtain an annual species-average standardized growth.

Using stepwise linear regression the effects of those variables outlined in the conceptual model on the growth of the study species were assessed. The stepwise selection process produced significant ($p < 0.05$) models for all species with the exception of Pacific herring. Because Togiak herring primarily feed near Unimak pass it could be that the conceptual model does not apply to herring, as it is representative of only shelf production dynamics. The successful models for the remaining species are summarized in Figure 2. Results indicate that (1) the growth rates of Bering Sea fish species are related to environmental conditions and (2) with the exception of rock sole, the species responded to environmental indices as predicted by the conceptual model. Pollock growth increased when ice retreat occurred early (and pelagic production was theorized to be high) and yellowfin sole growth increased when indicators of pelagic production were low. The results for pollock and yellowfin sole suggest that production in the pelagic environment may be inversely related to production in the benthic environment. Examination of the mean length-at-age time series for walleye pollock and yellowfin sole (Fig. 3) supports this conclusion.

While this study did not clearly differentiate between food and temperature controls, it did establish that fish growth is associated with interannual changes in the environment. Such associations are important when considering the effects of large-scale climatic conditions such as regime shifts on fish populations. For example, this study showed the sensitivity of walleye pollock growth to the timing of ice retreat in the region, which changed dramatically after the 1976/77 regime shift (Fig. 4). Thus, the implication of past-shifts, and the potential implications of future shifts on fish growth and stock assessments should be considered.

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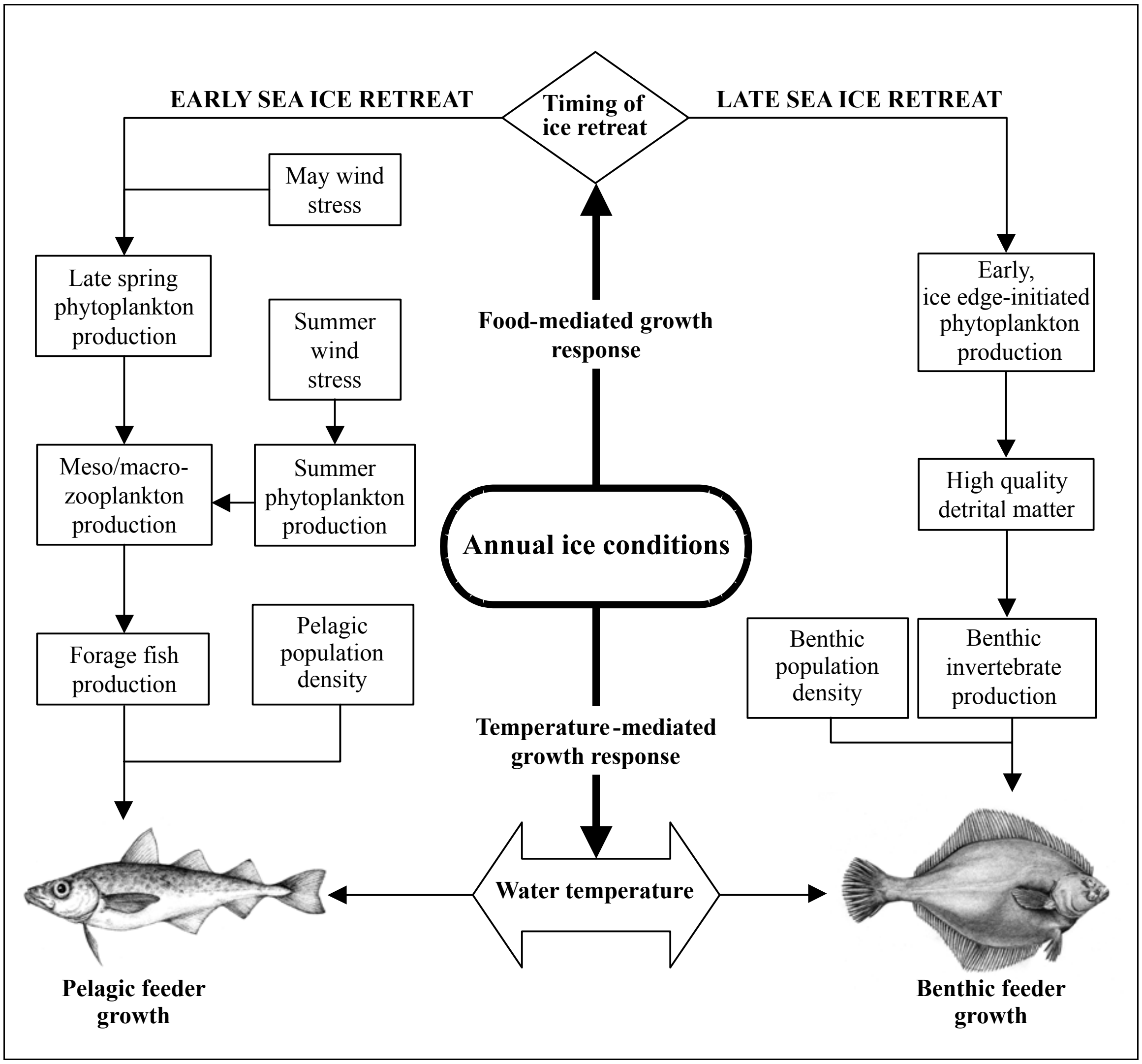

Figure 1. Conceptual model of hypothesized fish growth control factors over the southeastern Bering Sea shelf. The pathways of the two growth hypotheses, food availability and temperature, are shown. Food availability is tied to phytoplankton-zooplankton coupling and supports growth in either pelagic or benthic feeders dependent on the timing of ice retreat, resulting in an inverse growth response between pelagic and benthic feeders.

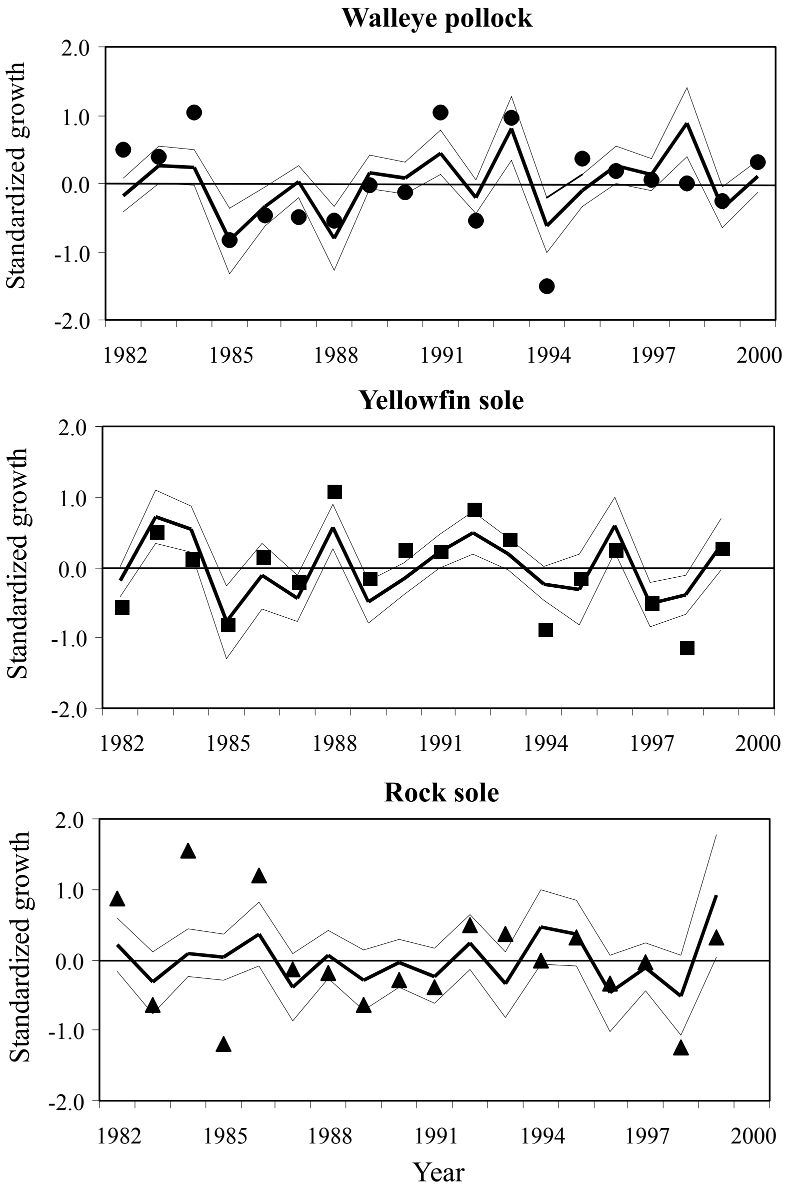

Figure 2. Stepwise selection model fits for the standardized average growth compared to actual observed growth for pollock (●), yellowfin sole (■) and rock sole (▲). Thin lines represent 95% confidence intervals and heavy lines represent the average standardized growth over the time period. Models for the three species were as follows: $G_{walleye\ pollock} = -0.0001 + 0.0278TSI$ $G_{yellowfin\ sole} = 2.7823 - 17.2017W_{May} - 0.0018Z$, $G_{rock\ sole} = 1.0665 - 0.4634BT$, where G is the annual average standardized growth for the species, TSI is an index of the timing of ice retreat from the region (+ values indicate early ice retreat and – values are late), W_{May} is annual average May wind stress, Z is an estimate of the annual zooplankton biomass and BT is the average shelf bottom temperature.

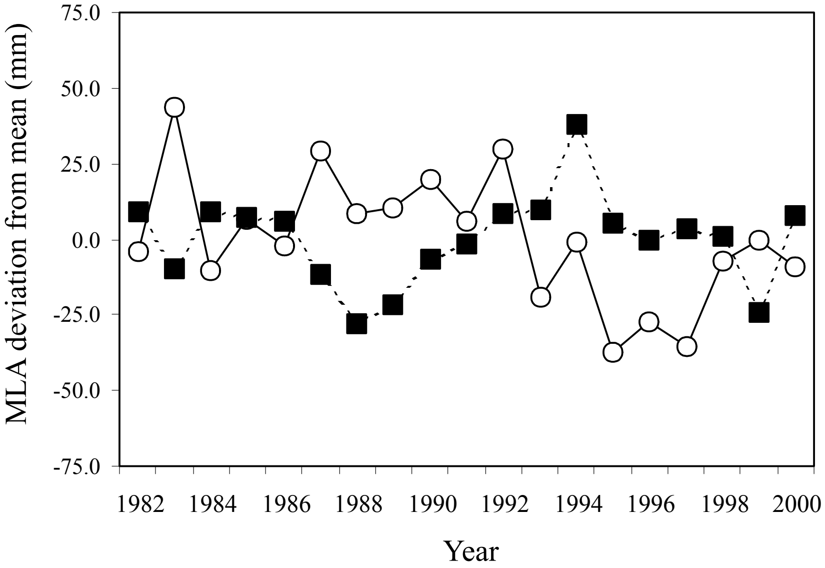

Figure 3. Plot comparing annual mean length-at-age anomalies of age-2 walleye pollock (○) to age-3 yellowfin sole (■).

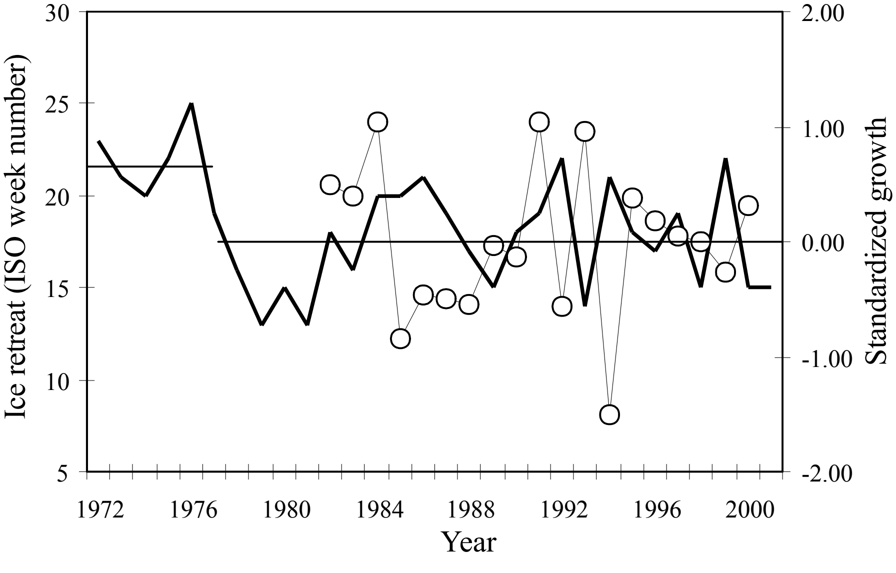

Figure 4. Comparison of timing of ice retreat (bold line) to annual standardized pollock growth (○). Average dates of ice retreat prior to and after the 1976/77regime shift are shown as horizontal dashed lines.

Other Species

Shark bycatch in Alaska State and Federal waters

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Kenneth J. Goldman, Jackson State University,
Bill Bechtol, Alaska Department of Fish and Game,
Claude Dykstra, International Pacific Halibut Commission,
Sarah Gaichas, Alaska Fisheries Science Center, and
Tom Kong, International Pacific Halibut Commission.

Introduction

Sharks exhibit a life history strategy characterized by slow growth, late maturity, low fecundity and, therefore, extremely low intrinsic rates of population increase (Holden 1974 and 1977, Hoenig and Gruber 1990). This fact, in combination with heavy exploitation rates, has led to rapid stock declines and fishery failures worldwide (Compagno 1990, Hoff and Musick 1990, Castro et al. 1999). Successful conservation and management of sharks in Alaska waters begins with knowledge of basic life history parameters such as growth rates, age at maturity and longevity (Goldman 2002). The three main species of sharks caught in Alaska state and federal waters are spiny dogfish (*Squalus acanthias*), Pacific sleeper sharks (*Somniosus pacificus*), and salmon sharks (*Lamna ditropis*).

Sources of Data

This report uses fisheries dependent and independent shark bycatch data collected by the National Marine Fisheries Service (NMFS) observer database, the International Pacific Halibut Commission (IPHC), and the Alaska Department of Fish and Game (ADFG). Seven shark species appear in the bycatch data, however catch of blue (*Prionace glauca*), sixgill (*Hexanchus griseus*), soupfin (*Galeorhinus galeus*) and brown catsharks (*Apristurus brunneus*) are nominal. As such, this report will focus on the spiny dogfish (*Squalus acanthias*), the Pacific sleeper shark (*Somniosus pacificus*) and the salmon shark (*Lamna ditropis*).

The NMFS data are currently being summarized by NMFS as two data series (1990-1996 and 1997-2002) because of differences in how data were assigned to a groundfish target fishery, which determines how observed catch is scaled up to estimate total catch (catches presented herein represent total bycatch). Gear used by target fisheries includes longlines, pots, and pelagic and bottom trawls. Although catch is summed across gear types in this report, it should be noted that bottom trawls and longlines were responsible for the majority of sleeper shark and spiny dogfish bycatch while pelagic trawls caught most of the salmon sharks (Table 1). The 1990-1996 data were assigned to a target fishery based on total catch weight of allocated species in individual hauls, while 1997-2002 observer data were assigned to a target fishery based on the retained catch weight of allocated species for an entire week on an individual vessel, gear type and area combination. The latter method is how the Regional NMFS Office assigns target species and is believed to be more accurate. Therefore, these data sets are cautiously comparable; one potential problem being that mismatches in target fisheries may result in inappropriate estimates (S. Gaichas, Alaska Fishery Sciences Center, personal communication). Additionally, trends in catch may not necessarily reflect trends in catch per unit effort (CPUE). These data, however, are worth examining in their current form (tons). Effort is currently being estimated for the various target fisheries, gear types, and areas so that CPUE can be calculated, allowing a better look at shark bycatch and relative abundance. It is important to remember that differences in catch can be driven by numerous factors including changes in target fishery effort within and across statistical areas, gear types used in different target fisheries and areas, and the selectivity of different gear types and vessels.

Table 1. NMFS observer data records of total catch of Salmon sharks, Spiny dogfish, and Sleeper sharks with three gear types: hook and line, pot, and trawl.

		Total catch (tons)		
	Year	Hook and line	Pot	Trawl
Salmon shark	1997	0.00	0.00	123.77
	1998	0.00	0.00	70.96
	1999	18.37	0.70	112.51
	2000	0.61	0.00	37.21
	2001	0.00	0.00	32.78
	2002	1.06	0.00	57.11
Spiny dogfish	1997	475.66	0.04	181.77
	1998	163.28	0.00	701.57
	1999	231.97	0.25	81.35
	2000	283.80	0.38	113.42
	2001	252.48	0.59	240.91
	2002	81.21	0.21	35.62
Sleeper shark	1997	50.73	0.00	85.14
	1998	25.38	0.00	48.65
	1999	509.72	0.00	47.94
	2000	382.71	0.42	225.06
	2001	96.09	0.00	152.91
	2002	45.27	0.00	180.29

The IPHC conducts an annual halibut longline survey (5-7 skates per set, 67-106 hooks per skate) at standard index stations. The timing of the survey varies among years between the end of May and early September, which may affect shark bycatch. The 9 years of bycatch data are summarized herein as 2 data sets, 1994-1996 and 1997-2002, and expressed as number of sharks per 100 hooks. Comparison problems stem from changes in the method of data collection and in the identification of sharks to species vs. non-species specific identification as a “shark” or “unidentified shark” category. From 1994 to 1996, every hook was observed as they came from the water, whereas, from 1997 to the present, 20 hooks per skate were sub-sampled in a non-random manner. For subsampling, the first 20 hooks from each skate were observed, although at times the 20-hook subsample began at a haphazard point in the skate. Methods are likely not comparable even if it is assumed that catchability is equal for all hooks on all skates. For example, non-random sub-sampling may result in an underestimate of the true variance. The IPHC is currently conducting field studies and statistical analyses to examine this question (H. Gilroy, IPHC, personal communication). The geographical area surveyed also expanded during the time series. In addition to the change in sampling methods, 18.5% of the sharks caught between 1994 and 1996 were categorized as “unidentified shark” compared to only 0.4% between 1997 and 2000. Therefore, average catch per unit effort (ACPUE) by species underestimates actual ACPUE during 1994 to 1996. As with the NMFS data set, the 1994 to 1996 IPHC data are cautiously comparable to data from 1997 to 2002. IPHC shark bycatch reported here is likely underestimated because stations with high halibut predation, by sharks or other animals, or high shark bycatch were excluded from the IPHC data set for halibut stock assessment. Future analyses of shark bycatch will include these stations and may result in higher bycatch of sharks in some areas, such as Sleeper sharks in PWS and Cook Inlet, and Spiny dogfish in PWS and Southeast Alaska. IPHC Areas 210, 220 and 230 cover virtually the same area as NMFS Area 640 and IPHC Areas 185, 190 and 200 are encompassed by NMFS Area 650.

The ADF&G sablefish longline survey has been conducted, and bycatch recorded (number of sharks per 100 hooks), in Prince William Sound (PWS) since 1996 and in the North GOA in 1999, 2000, and 2002. While the survey methods have not changed (~675 hooks per set), the areas sampled within PWS are not the same for every year of the survey. In 1996 and 2002, only the northwest area of the Sound was surveyed. In 1997, 1999, and 2001, the northwest and southwest areas of the sound were surveyed, while in 1998 and 2000 the northwest and eastern areas of PWS were surveyed. The northwest area was examined separately since it provided a continuous time series and could be compared to IPHC catch data. Bycatch in the North GOA is negligible.

Results

SPINY DOGFISH

Gulf of Alaska

NMFS Observer catch data
Spiny dogfish appear to be most abundant in areas 630-650 of the GOA (Figure 1). Catches of spiny dogfish were consistently higher in area 630 (104-396 t) compared to all other areas in most years, except area 640 in 1998 (575 t) and area 650 in 1997 (335 t) (Figure 1). Low catch in the eastern GOA may be an artifact of a trawl exclusion zone in that area. There is no apparent temporal pattern in the catches which is not uncommon for a mobile species with a patchy distribution. Catches in 1998 and 2001 are particularly high in most areas for both NMFS observer and IPHC survey data (Figures 1 and 2).

IPHC Survey bycatch

IPHC survey areas 185-260 are encompassed by NMFS observer areas 630-650, where dogfish catches were highest. From 1997-2002, the average catch per 100 hooks (ACPUE) was generally higher in areas 185-240 than in areas 250 and 260 (Figure 2). ACPUE ranged from 7 to 38 across areas 185-240 and from 4-16 in areas 250 and 260. In most areas, peak ACPUE, 19-38, occurred in 1998 and 2001 (Figure 2). No IPHC survey data was available for 1994-95 in areas 185-230; therefore, comparisons among areas during the 1994-96 time series are limited.

Prince William Sound

IPHC Survey bycatch

Since 1998, average catch per 100 hooks (ACPUE) of spiny dogfish has been generally lower (0.7-8.0) in IPHC survey area 242 of PWS compared to area 232 (2.1-28.0) (Figure 3). Within PWS areas, ACPUE was highest in 2002. If IPHC data are evaluated according to the ADFG-defined northwest area, the highest ACPUE (3.8) was in 1998 (Figure 3).

ADFG Sablefish longline survey bycatch

Catch per 100 hooks (CPUE) of spiny dogfish in the ADFG sablefish longline survey have typically been low (0.1-0.4) (Figure 3). The highest CPUE occurred in 1998 in NW and E PWS (7.6); this was also observed in the IPHC survey. The second highest CPUE occurred in 2001 (1.4) in the NW and SW areas, also a year of high CPUE in the IPHC survey (Figure 3).

Bering Sea and Aleutian Islands

NMFS observer catch data

Catches of spiny dogfish in the Bering Sea appeared to be highest in NMFS observer areas 509 and 517, at the end of the Alaskan Peninsula (Figure 4). Catches ranged from 1.0 to 5.8 t in these areas and from 0.1 to 2.4 t in other areas. In all areas, catches of spiny dogfish were highest in 2001.

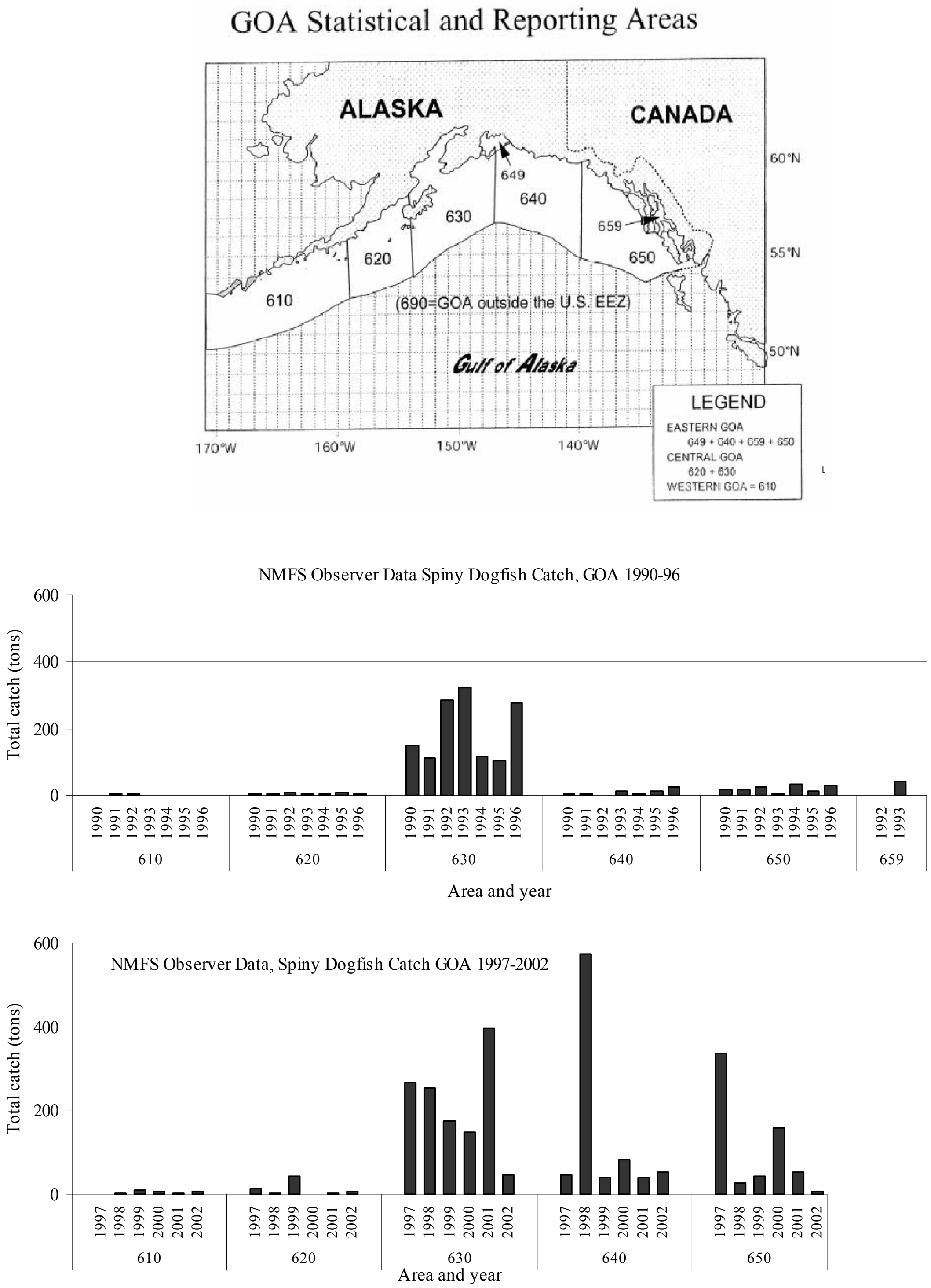


Figure 1. The statistical areas for NMFS observer data in the Gulf of Alaska and spiny dogfish bycatch in the GOA as recorded in the NMFS observer catch data from 1990 to 1996 and from 1997-2001.

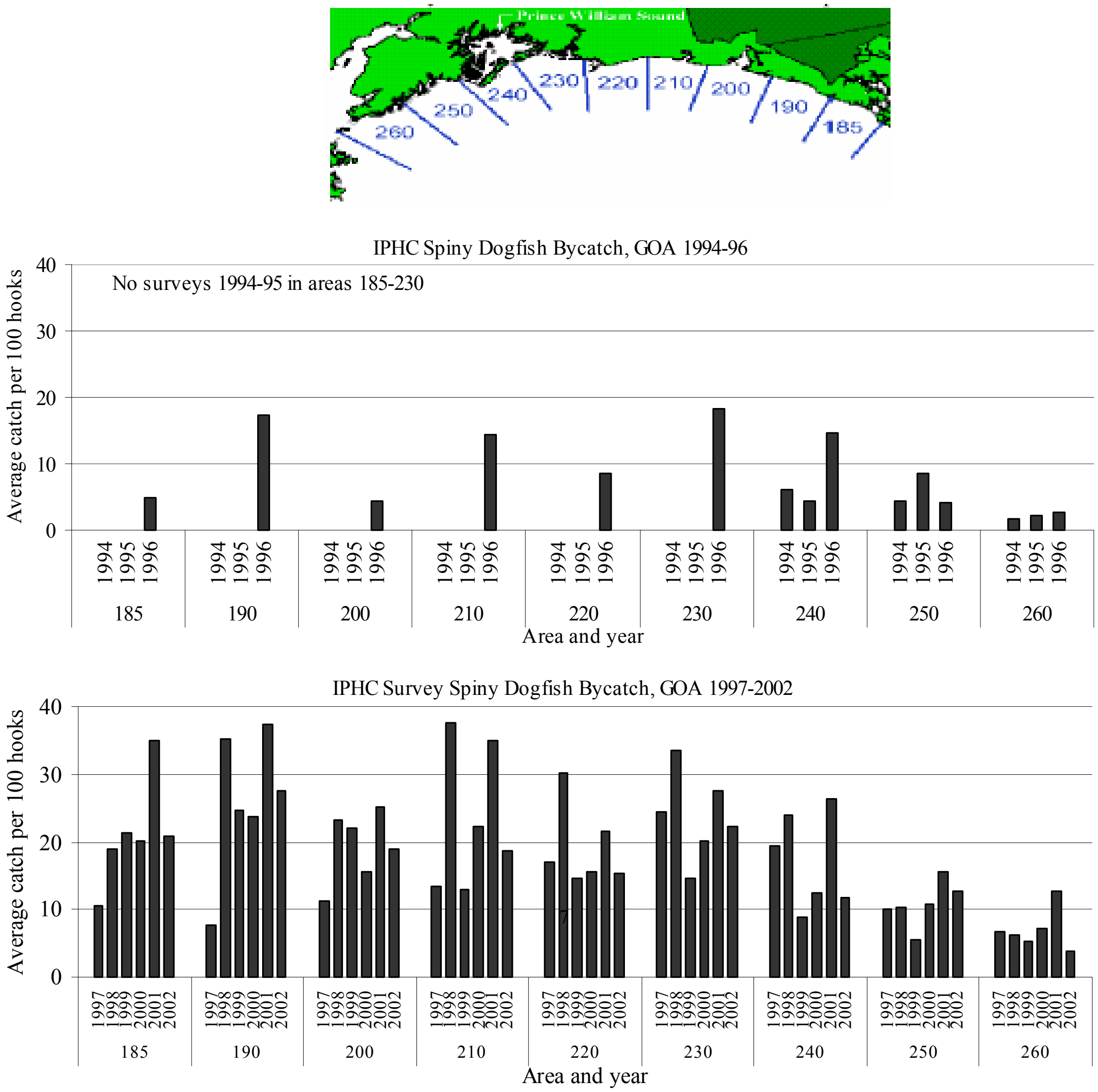


Figure 2. The statistical areas for IPHC survey data in the Gulf of Alaska and spiny dogfish bycatch in the GOA as recorded in the IPHC survey data from 1990 to 1996 and from 1997-2002.

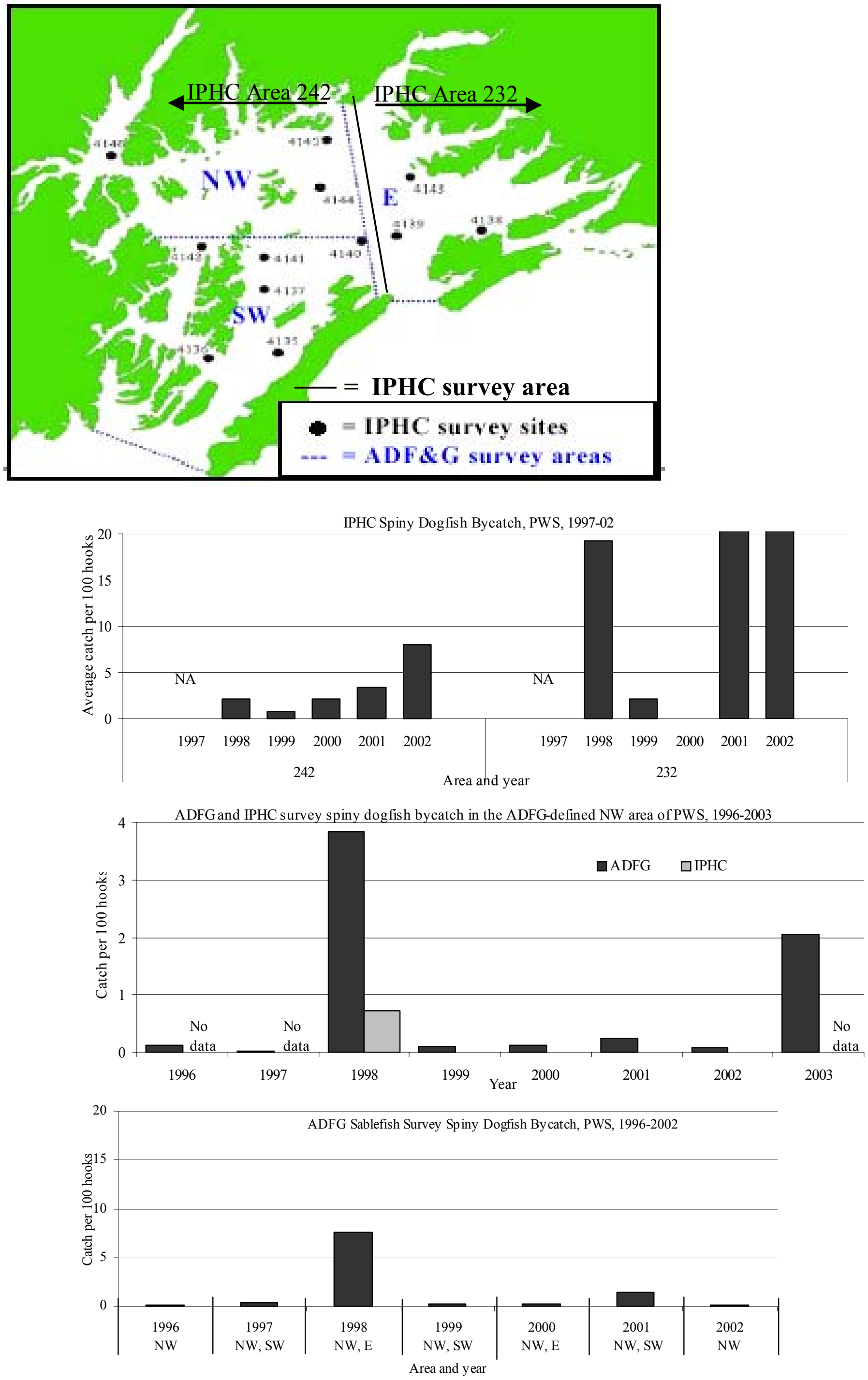


Figure 3. The statistical areas for IPHC survey data and ADFG survey data in Prince William Sound and spiny dogfish bycatch in PWS as recorded in the IPHC and ADFG surveys from 1996 to 2003.

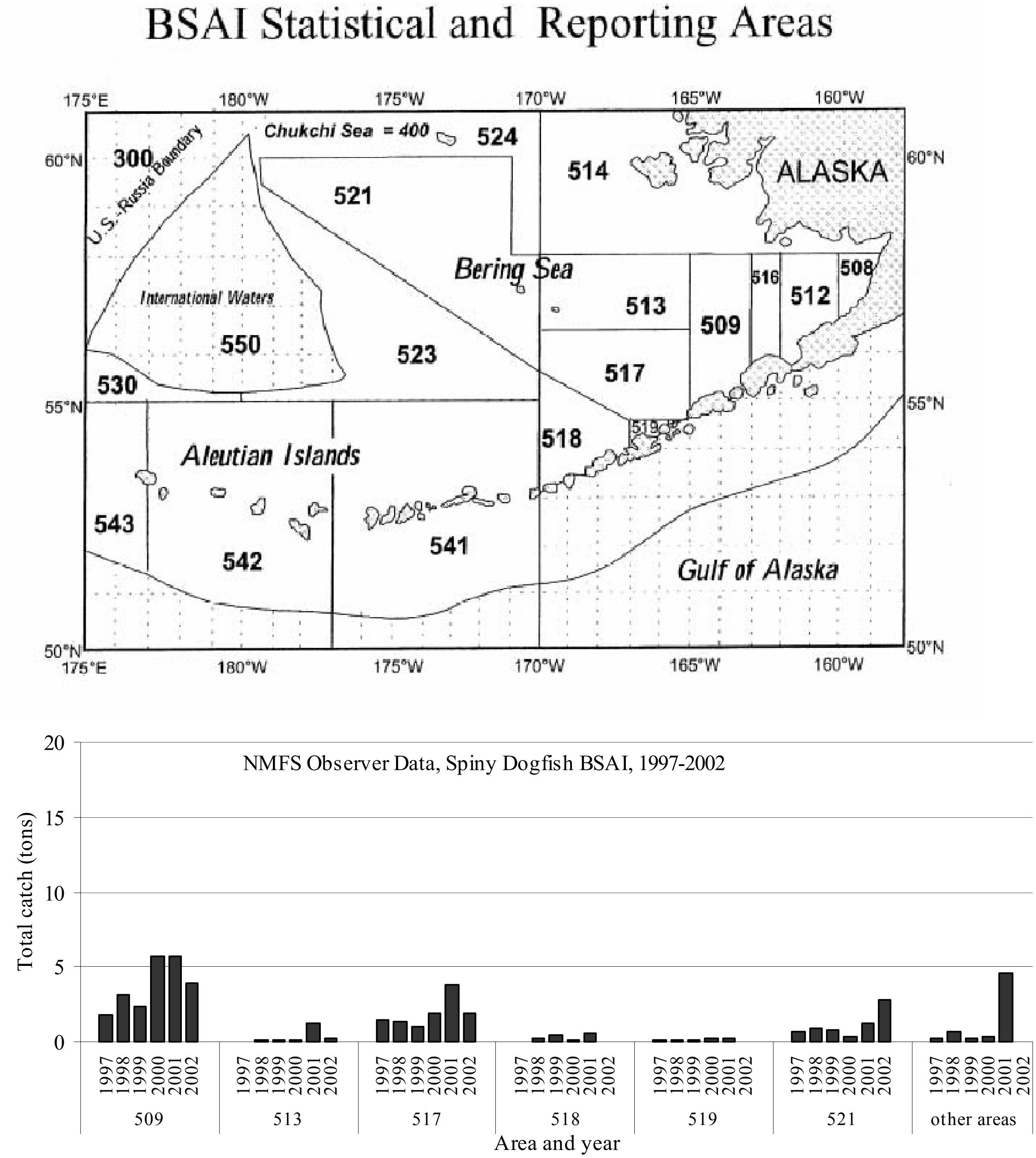


Figure 4. The statistical areas for NMFS observer data in the Bering Sea and Aleutian Islands, and spiny dogfish bycatch as recorded in the NMFS observer catch data from 1997 to 2002.

SLEEPER SHARKS

Gulf of Alaska

NMFS Observer catch data
Catch of sleeper sharks was highest in central and western GOA, NMFS observer areas 610, 620, and 630 in all years (Figure 5). Gear types used in the eastern, central, and western GOA could affect the number of sleeper sharks caught. The highest catches occurred in 1999 (454.7 t) and 2000 (415.4 t) in area 630 (Figure 5). No temporal trend in catches was observed.

IPHC Survey bycatch
Records of sleeper sharks are virtually absent in the 1993 to 1996 IPHC data set. This could easily be due to the high number of unidentified sharks in that data series. The highest average catch per 100 hooks (ACPUE) was in area 220 in 1998 (6.4), 2000 (8.6), and 2001 (6.0), and in area 240 in 1996 (6.8); otherwise, ACPUE was relatively consistent and below 4.0 (Figure 6).

Prince William Sound

IPHC Survey bycatch
Bycatch of sleeper sharks in PWS during the IPHC surveys has been relatively consistent in both areas surveyed and in all years, 1998-2002 (Figure 7). Average catch per 100 hooks (ACPUE) ranged from 1.7 to 10.0. If IPHC data are examined by the ADFG-defined northwest area, ACPUE is relatively consistent across years and areas, ranging from 3.9 to 11.2.

ADFG Sablefish longline survey bycatch
Bycatch of sleeper sharks in the ADFG sablefish longline survey was lower (0.2-0.6 dogfish per 100 hooks) than that of the IPHC survey, but was also consistent across years and areas (Figure 7).

Bering Sea and Aleutian Islands

NMFS Observer catch data
Sleeper shark bycatch in the Bering Sea was highest in areas 521 and 517, which are along the middle front of the shelf to the shelf break (Figure 8). From 1997-2002, catches increased from 44.0 t (1998) to 172.0 t (2002) in area 517, and from 108.5 t (1997) to 601.8 t (2002) in area 521.

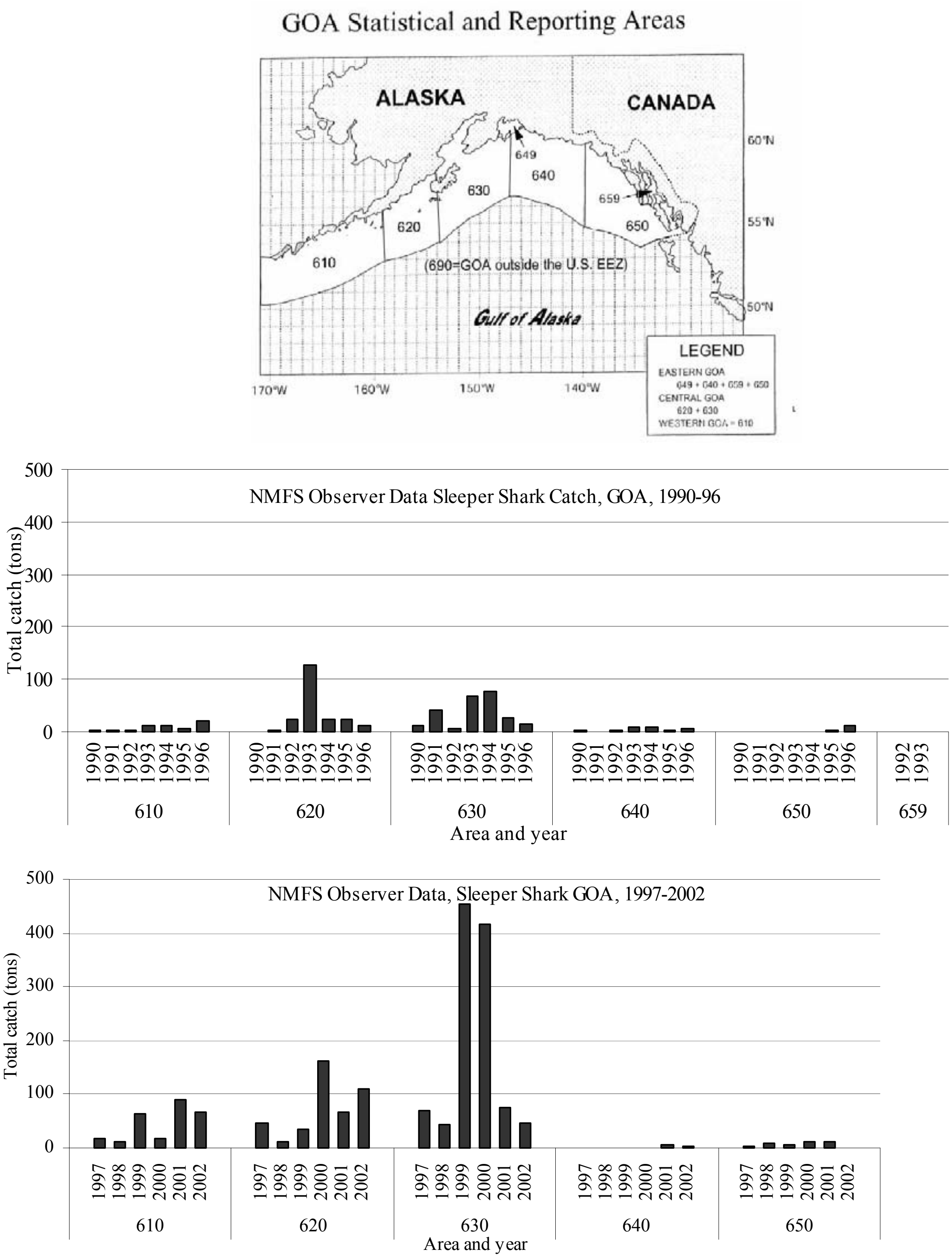
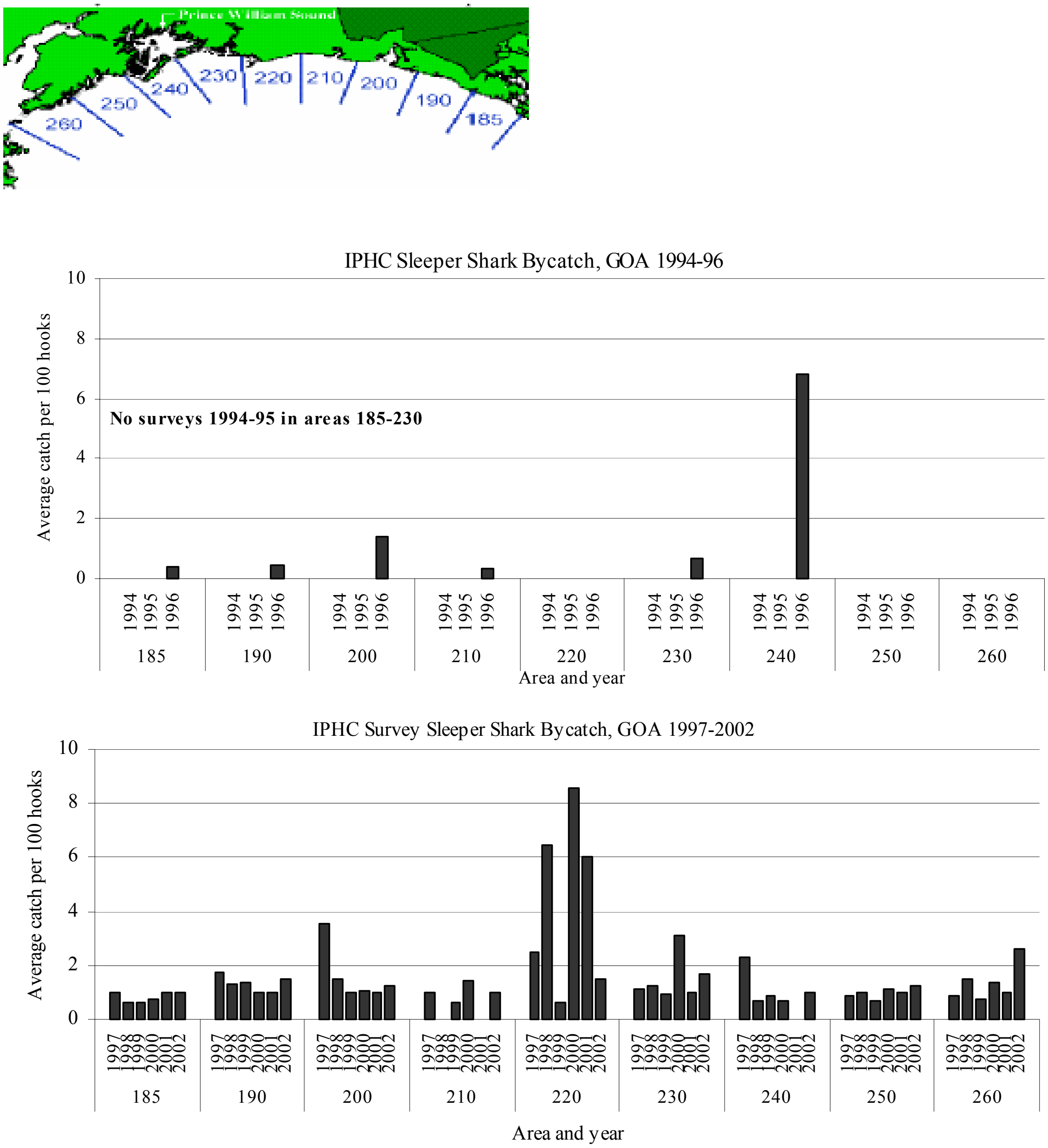


Figure 5. The statistical areas for NMFS observer data in the Gulf of Alaska and sleeper shark bycatch in the GOA as recorded in the NMFS observer catch data from 1990 to 1996 and from 1997-2002.



IPHC Sleeper Shark Bycatch, GOA 1994-96

IPHC Survey Sleeper Shark Bycatch, GOA 1997-2002

Figure 6. The statistical areas for IPHC survey data in the Gulf of Alaska and sleeper shark bycatch in the GOA as recorded in the IPHC survey data from 1994 to 1996 and from 1997-2002.

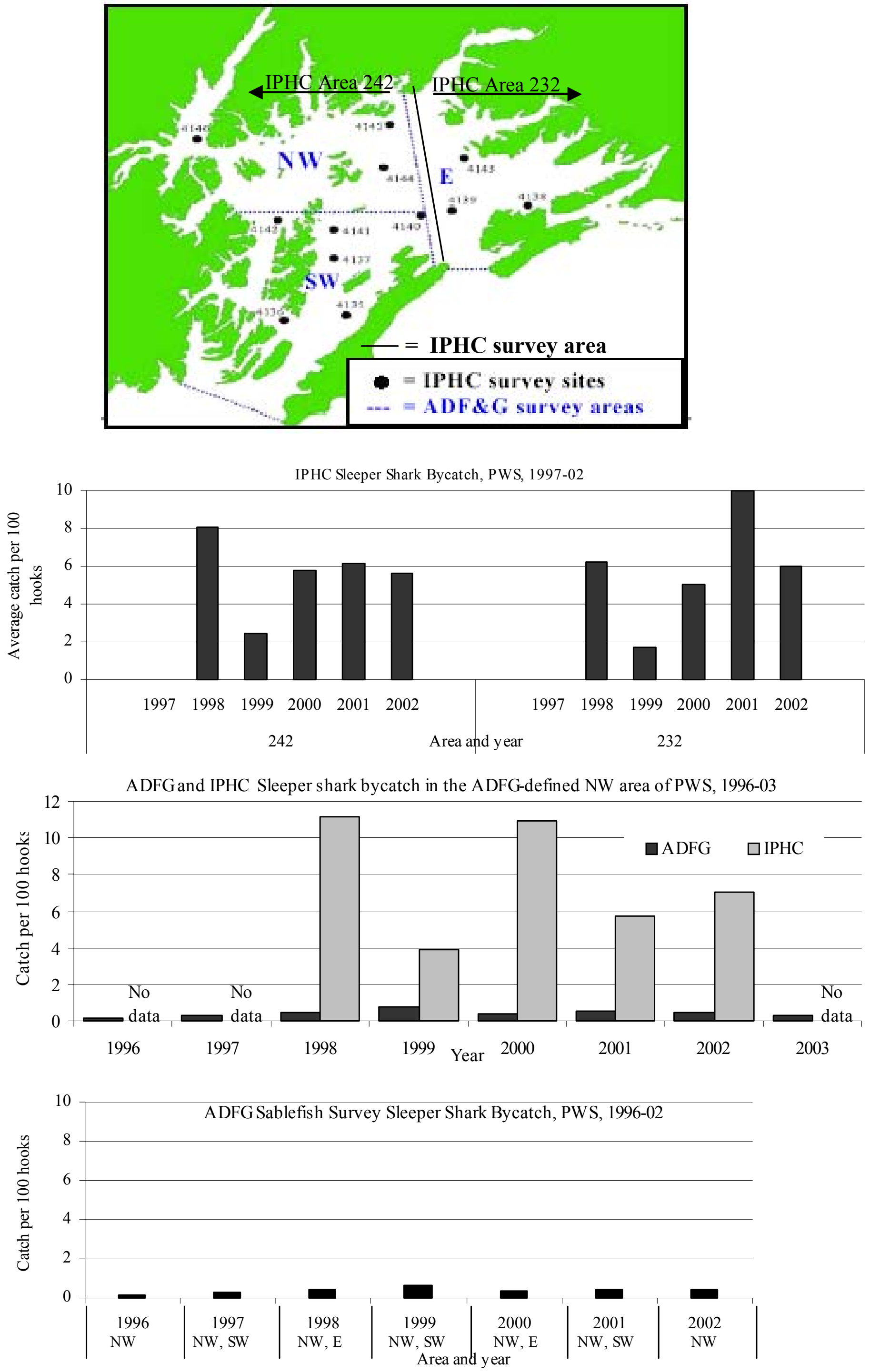


Figure 7. The statistical areas for IPHC survey data and ADFG survey data in Prince William Sound and sleeper shark bycatch in PWS as recorded in the IPHC and ADFG surveys from 1996 to 2003.

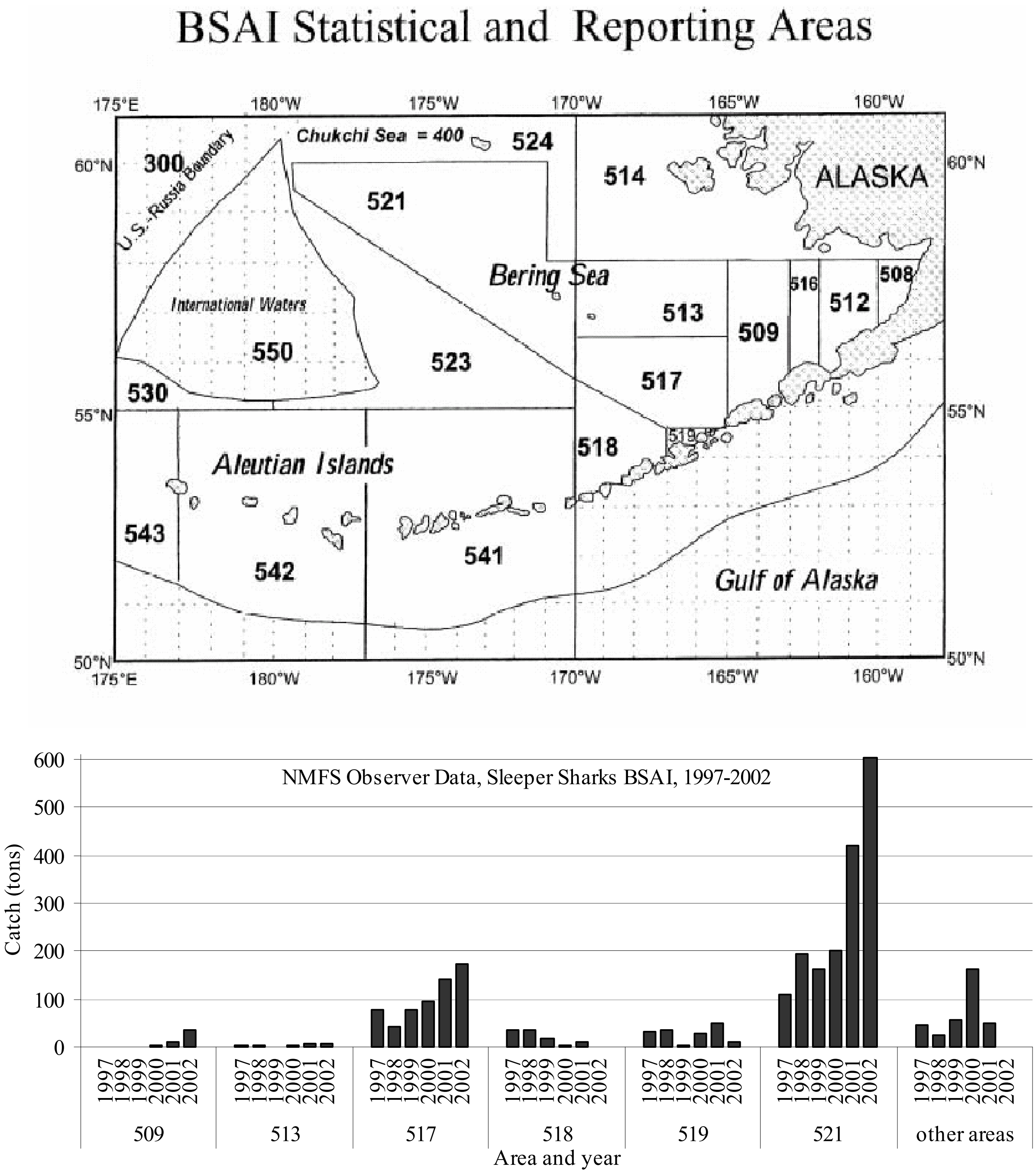


Figure 8. The statistical areas for NMFS observer data in the Bering Sea and Aleutian Islands, and sleeper shark bycatch as recorded in the NMFS observer catch data from 1997 to 2002.

SALMON SHARKS

Gulf of Alaska

NMFS Observer catch data
Salmon sharks catch was observed in areas 610, 620, and 630 in the NMFS observer surveys (Figure 9). The vast majority of salmon shark are caught in mid-water trawls. The highest catches of salmon sharks were in areas 620 and 630, with catches ranging from 1.7 t to 130.3 t (Figure 9). The highest catches occurred in area 620 in 1992 (130.3 t) and in area 630 in 1997 (107.4 t). No temporal pattern was apparent. No salmon sharks were caught on IPHC surveys in PWS, and the ADF&G survey has only taken 6 salmon sharks since 1996. This is likely a result of longline gear that is primarily fishing the bottom.

Bering Sea and Aleutian Islands

NMFS Observer catch data
In the Bering Sea, Salmon shark bycatch, like Sleeper shark bycatch, was highest in areas 521 and 517, which are along the middle front of the shelf to the shelf break (Figure 10). There was no apparent temporal pattern, but catches were highest in 1999 in area 517 (18.9 t) and in 2002 in area 521 (26.9 t).

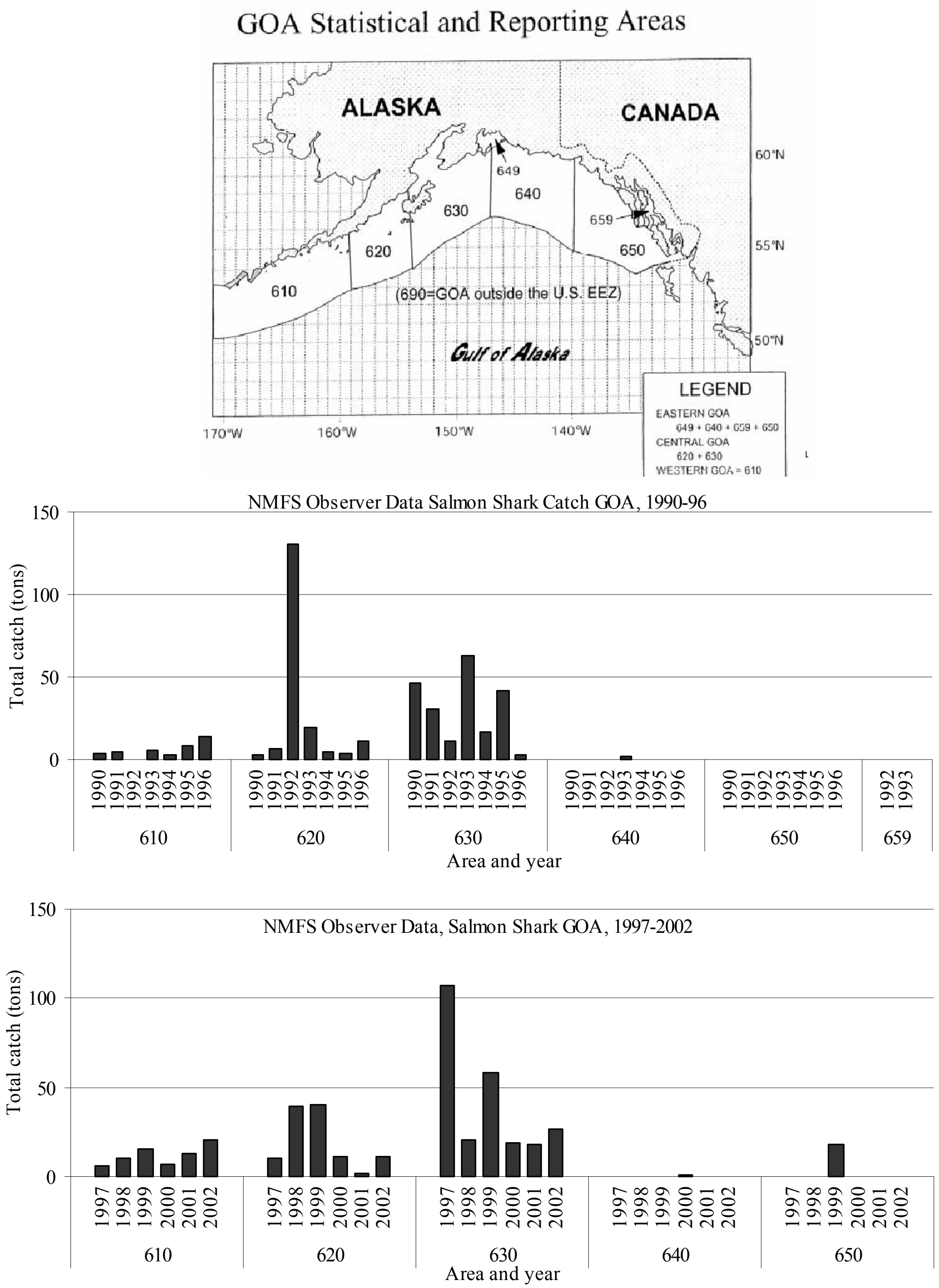


Figure 9. The statistical areas for NMFS observer data in the Gulf of Alaska and salmon shark bycatch in the GOA as recorded in the NMFS observer catch data from 1997-2002.

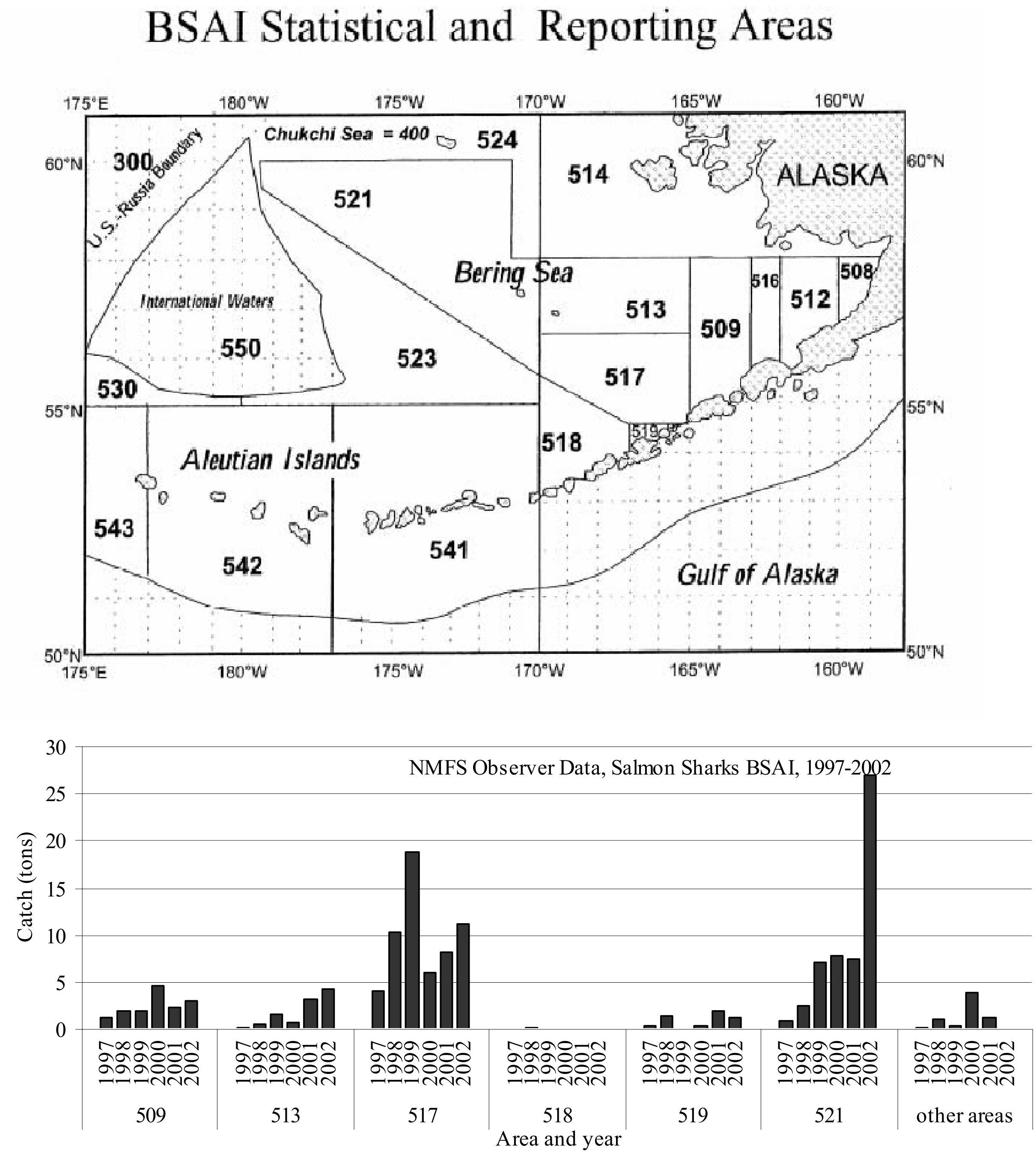


Figure 10. The statistical areas for NMFS observer data in the Bering Sea and Aleutian Islands, and Salmon shark bycatch as recorded in the NMFS observer catch data from 1997 to 2002.

Conclusions

It is difficult to assess whether the amount of shark bycatch represents a threat to the status of shark stocks in Alaska waters at this point in time. The cause of the 1998 and 2001 'spikes' in spiny dogfish catches that was seen in virtually all data sets is unknown. Shark bycatch is currently a topic of major concern around the world. Stevens et al. (2000) estimate that around 50% of the estimated global catch of chondrichthyan fishes (sharks, skates, rays and chimaeras) is taken as bycatch. As a result, species of skate, sawfish and some deep-sea dogfish have been virtually extirpated from large areas. With the depleted status of numerous shark populations worldwide (Compagno 1990), it is even more crucial that any approach to assessing shark bycatch levels and relative abundance in Alaska be carried out using the best available data. As further analyses of these data and the sampling of shark bycatch continue, we will begin to better understand the relative abundance and overall status of sharks in Alaskan waters, and determine the impact of current levels of shark bycatch. Careful analysis of the available data and knowledge of life history parameters, demographics and movements will allow fishery managers to better understand the biology and overall ecology of sharks in the GOA, PWS, BS and AI.

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Analysis of Pacific Sleeper Shark (*Somniosus pacificus*) Abundance Trends from Sablefish Longline Surveys 1979 - 2003

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Pacific sleeper sharks (*Somniosus pacificus*) are a deepwater shark of the North Pacific. Some information suggests their abundance is increasing. Analysis of National Marine Fisheries Service (NMFS) fisheries independent trawl survey data from the Gulf of Alaska found that Pacific sleeper shark abundance has significantly increased in the central Gulf of Alaska during 1984 - 1996 (Mueter and Norcross 2002). NMFS internal analyses of commercial fisheries dependent and independent shark bycatch data from the Gulf of Alaska, and Bering Sea has indicated that Pacific sleeper shark abundance is either stable or increasing (Gaichas et al. 1999; Gaichas 2000; Hulbert 2000; Goldman 2001; Courtney and Sigler 2002, Boldt et al. this document).

Pacific sleeper sharks are occasionally caught during sablefish longline surveys of the upper continental slope and continental shelf break in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska and of deepwater gullies on the Gulf of Alaska continental shelf. In this paper we analyzed sablefish longline surveys from 1979-2003 for Pacific sleeper shark bycatch. We examined the sleeper shark bycatch to determine the relative abundance trend and to ascertain if the trend was statistically significant.

Survey methods

NMFS sablefish longline surveys have sampled the upper continental slope and deepwater gullies of the Gulf of Alaska, eastern Bering Sea, and Aleutian Islands region annually since 1979. The survey time series consists of two surveys, the Japan-U.S. cooperative longline survey, which ran from 1979-1994, and the domestic longline survey, which ran from 1988-present. The surveys sampled the same locations (stations), with the same bait (squid), the same hook spacing (2 meters), and with standardized effort. Currently, a standard station in the Gulf of Alaska and Aleutian Islands consists of 160 hachis with 45 hooks per hachi for a total of 7,200 hooks per station. A standard station in the Bering Sea consists of 180 hachis with 45 hooks per hachi for a total of 8,100 hooks per station. The surveys differed in two principal ways. The domestic longline survey gear consists of heavier-weight beckets and ganions than the cooperative longline survey, so that a shark is more likely to escape from the cooperative longline survey gear. The domestic longline survey gear uses a circle hook, whereas the cooperative longline survey used a type of J-hook called a tara hook.

Analytical methods

Relative population numbers (RPN's, an index of relative abundance in numbers) were calculated by station for the Japan-U.S. cooperative survey and for the domestic survey (Sasaki 1985; Gulland 1969; Quinn et al. 1982). The number of Pacific sleeper sharks captured per hachi (catch per unit effort or CPUE) was calculated for each depth stratum within a station. RPN's were computed from CPUE by multiplying the CPUE of each depth stratum with the area (km^2) of the depth stratum (e.g., the 201 – 300 m depth stratum of the Shelikof Trough sampling region of the central Gulf of Alaska has an area of 13,076 km^2). RPN's for each depth stratum within a station were summed to obtain an independent RPN estimate by station. RPN estimates from all stations within a sampling region (e.g., 4 standard survey stations within Shelikof Trough) were averaged to obtain an RPN estimate for the sampling region. RPN estimates from sampling regions were summed to obtain RPN's for broader management units (e.g., RPN estimates for the central Gulf of Alaska INPFC management area were obtained by adding RPN's from the Chirikof [slope], Shelikof Trough, Kodiak [slope], and Amatuli Gully sampling regions).

95 % bootstrap confidence intervals were calculated for the domestic survey. The bootstrap method (Efron and Tibshirani 1986) was applied to estimate the variability of the abundance estimates (Sigler and Fujioka 1988). A station was randomly chosen with replacement and the resultant station RPN's were averaged for the sampling region. The regions were summed and the resultant value is termed the bootstrap replicate. A confidence interval for the abundance estimate was created from a distribution of 1,000 bootstrap replicates by the percentile method (Efron and Tibshirani 1986).

Results

A total of 1,565 Pacific sleeper sharks were captured during sablefish longline surveys from 1979-2003 (Table 1). Pacific sleeper shark catches have increased during the survey from a low of 0 in 1979 and 1983 to a high of 176 in 2001 (Table 1). The most recent available catch is 129 Pacific sleeper sharks in 2003. Pacific sleeper shark CPUE (catch per standard station - 7,200 hooks) has ranged from a low of 0 in 1979 and 1983 to a high of 2.3 in the year 2002 (Table 1). The most recent available CPUE is 1.7 in the year 2003 (Table 1).

Most Pacific sleeper sharks (67%) were captured in the 201 - 300 m depth stratum (Table 2). Most Pacific sleeper sharks (850 [54%] of 1,565) were captured in one gully - Shelikof Trough (Table 3).

CPUE and RPN of Pacific sleeper sharks were calculated separately for the Japan-U.S. cooperative survey and the domestic survey because their effectiveness for capturing Pacific sleeper sharks likely differ. CPUE and RPN analysis was limited to standard survey stations and to effective hachis (defined as less than or equal to 5 ineffective hooks within a hachi). For statistical analysis, CPUE and RPN estimation was further limited to the years 1982-1994 for the Japan-U.S. cooperative survey and to the years 1989-2003 for the domestic survey, which were considered standard survey years for each survey.

A total of 1,362 Pacific sleeper sharks were captured with effective hachis at standard stations during the years 1979-2003 (Table 4). The catch of Pacific sleeper sharks in the Japan-U.S. cooperative survey fluctuated during the years 1982-1994 ranging from 0 in 1979 and 1983 to 50 in 1994 (Table 4), and CPUE (catch per standard station – 7,200 hooks) ranged from 0 in 1979 and 1983 to 0.8 in 1994 (Table 5). Catch of Pacific sleeper sharks in the domestic survey ranged from a low of 3 in 1988 to a high of 142 in 2001 (Table 4), and CPUE (catch per standard station – 7,200 hooks) ranged from a low of 0.1 in 1988 to a high of 2.3 in 2001 (Table 5). The most recent available CPUE is 1.6 in the year 2003 (Table 5).

The relative population numbers (RPN's) of Pacific sleeper sharks captured in the Japan-U.S. cooperative longline survey also fluctuated during the years 1979-1994 ranging from 0 in 1979 and 1983 to 354 in 1994 (Tables 6 and 7, Figure 1). RPN's of Pacific sleeper sharks captured in the domestic survey increased from a low of 79 in 1988 to a high of 2,980 in 2001 (Table 6, Figure 1). The increase in RPN's of the domestic survey was most pronounced between the years 1992 and 1993 and has remained high after 1993 (Figure 1). The most recent available RPN is 1,693 in the year 2003 (Table 6). The increase in the domestic longline survey RPN was driven largely by the high Pacific sleeper shark RPN's in the Shelikof Trough sampling region (Table 8).

95% bootstrap confidence intervals were calculated for the domestic longline survey between the years 1989 - 2003. The confidence intervals did not overlap for all years suggesting that there may have been a significant increase in Pacific sleeper shark RPN's between some years from 1989 through 2003 (at the 95 % confidence level, Figure 1).

Discussion

Pacific sleeper shark bycatch in the sablefish longline surveys was relatively rare (less than 1 shark per standard station, Table 1). Most Pacific sleeper shark bycatch from the sablefish longline surveys occurred in the 201 – 300 m depth stratum in Shelikof Trough, a deepwater gully in the central Gulf of Alaska, and Pacific sleeper sharks appeared to be relatively abundant in this area (13 sharks per standard station, Table 3). Pacific sleeper sharks may be relatively abundant in other areas of the continental shelf not effectively sampled by sablefish longline surveys. In particular, the sablefish longline survey stations are located along the continental shelf break and deepwater gullies and are designed to effectively sample the shelf break and upper continental slope from depths of 200 to 1000 m. Most of the 100 – 200 m depth stratum of the continental shelf away from the shelf break is not effectively sampled by the sablefish longline survey.

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Table 1. Catch (in numbers) and CPUE (catch per standard survey station - 7,200 hooks) of Pacific sleeper sharks from the sablefish longline survey during the years 1979-2003 in the Gulf of Alaska, Aleutian islands and Bering Sea.

Year[a]	Number of sleeper sharks	Hachis	% of Total	Hooks	Catch per 7,200 hooks	% of Total
1979	0	8069	1.84%	363105	0.00	0.00%
1980	1	11153	2.54%	501885	0.01	0.09%
1981	1	11469	2.61%	516105	0.01	0.08%
1982	1	16950	3.86%	762750	0.01	0.06%
1983	0	16344	3.72%	735480	0.00	0.00%
1984	5	17139	3.91%	771255	0.05	0.28%
1985	10	17062	3.89%	767790	0.09	0.57%
1986	9	16959	3.86%	763155	0.08	0.51%
1987	27	16844	3.84%	757980	0.26	1.55%
1988	21	25909	5.90%	1165905	0.13	0.78%
1989	45	26980	6.15%	1214100	0.27	1.61%
1990	33	28572	6.51%	1285740	0.18	1.11%
1991	34	28192	6.42%	1268640	0.19	1.16%
1992	74	28728	6.55%	1292760	0.41	2.49%
1993	110	28749	6.55%	1293705	0.61	3.69%
1994	175	29415	6.70%	1323675	0.95	5.74%
1995	61	11176	2.55%	502920	0.87	5.27%
1996	86	12281	2.80%	552645	1.12	6.76%
1997	103	13920	3.17%	626400	1.18	7.14%
1998	91	12030	2.74%	541350	1.21	7.30%
1999	93	12475	2.84%	561375	1.19	7.20%
2000	111	11895	2.71%	535275	1.49	9.01%
2001	176	12423	2.83%	559035	2.27	13.68%
2002	169	11761	2.68%	529245	2.30	13.87%
2003	129	12403	2.83%	558135	1.66	10.04%
Total	**1,565**	**438,898**		**19,750,410**	**0.57**	

[a] NMFS sablefish longline survey timeline.
1979 First year of NMFS cooperative (Japanese) sablefish longline survey.
1982 First year of NMFS cooperative (Japanese) sablefish longline survey in the Bering Sea .
1987 First year of NMFS experimental domestic sablefish longline survey in Gulf of Alaska (using herring as bait), but not included in database.
1988 First year of NMFS experimental domestic sablefish longline survey in Gulf of Alaska (using squid as bait), and first year of NMFS domestic sablefish longline survey in database.
1990 First year of standardized NMFS domestic sablefish longline survey in Gulf of Alaska.
1994 Last year of NMFS cooperative (Japanese) sablefish longline survey.
1996 First year of standardized NMFS domestic sablefish longline survey in the Aleutian Islands.
1997 First year of standardized NMFS domestic sablefish longline survey and in the Bering Sea and experimental fishing along side a submersible in the Gulf of Alaska.
1998, 2000, 2002 Standardized NMFS domestic sablefish longline survey in Gulf of Alaska and Aleutian Islands.
1999, 2001, 2003 Standardized NMFS domestic sablefish longline survey in Gulf of Alaska and Bering Sea.

Table 2. Catch (in numbers) and CPUE (catch per standard survey station - 7,200 hooks) of Pacific sleeper sharks grouped by depth stratum from the sablefish longline survey during the years 1979-2003 in the Gulf of Alaska, Aleutian islands and Bering Sea.

Depth Stratum[a]	Min depth	Max depth	Number	% of Total	Hachis	% of Total	Hooks	Catch per 7,200 hooks	% of Total
NA			3	0.19%				NA	
1	0	100	0	0.00%	1550	0.35%	69750	0.00	0.00%
2	101	200	115	7.35%	84704	19.30%	3811680	0.22	6.72%
3	**201**	**300**	**1042**	**66.58%**	**80313**	**18.30%**	**3614085**	**2.08**	**64.24%**
4	301	400	89	5.69%	50833	11.58%	2287485	0.28	8.67%
5	401	600	152	9.71%	103353	23.55%	4650885	0.24	7.28%
6	601	800	133	8.50%	90053	20.52%	4052385	0.24	7.31%
7	801	1000	31	1.98%	26604	6.06%	1197180	0.19	5.77%
8	1001	1200	0	0.00%	1429	0.33%	64305	0.00	0.00%
9	1200	Greater	0	0.00%	59	0.01%	2655	0.00	0.00%
Total			**1,565**		**438,898**		**19,750,410**	**0.57**	

[a] Depth stratum details.
Depth stratum 1 not intentionally sampled in survey
Depth stratum 2 not effectively sampled away from the continental shelf break

Table 3. Catch (in numbers) and CPUE (catch per standard survey station - 7,200 hooks) of Pacific sleeper sharks grouped by sampling region from the sablefish longline survey during the years 1979-2003 in the Gulf of Alaska, Aleutian islands and Bering Sea.

Sampling Region	Number	% of Total	Min Lon	Max Lon	Hachis	% of Total	Hooks	Catch per 7,200 hooks	% of Total
NA	1				640	0.15%	28800	0.25	0.82%
Bering 5	51	3.26%	-178.85501	-177.38001	7400	1.69%	333000	1.10	3.64%
SE Aleutians	12	0.77%	-178.60999	-173.50501	25828	5.88%	1162260	0.07	0.25%
NE Aleutians	11	0.70%	-177.58333	-170.14167	20941	4.77%	942345	0.08	0.28%
Bering 4	77	4.92%	-177.5818333	-174.3	15468	3.52%	696060	0.80	2.63%
Bering 3	61	3.90%	-174.2316667	-170.57167	22454	5.12%	1010430	0.43	1.43%
Bering 2	75	4.79%	-169.95	-166.03001	32333	7.37%	1454985	0.37	1.22%
Bering 1	62	3.96%	-169.25	-165.66667	13963	3.18%	628335	0.71	2.34%
Shumagin slope	35	2.24%	-169.09867	-159.879	50562	11.52%	2275290	0.11	0.37%
Chirikof slope	44	2.81%	-158.55667	-154.79666	35551	8.10%	1599795	0.20	0.65%
Shumagin Gully	2	0.13%	-158.50667	-158.00617	1453	0.33%	65385	0.22	0.73%
West Semidi	0	0.00%	-157.50534	-157.50534	160	0.04%	7200	0.00	0.00%
Shelikof Trough	**850**	**54.31%**	**-156.2281667**	**-155.0406667**	**10313**	**2.35%**	**464085**	**13.19**	**43.49%**
Kodiak slope	6	0.38%	-153.0813333	-148.34017	45985	10.48%	2069325	0.02	0.07%
Chiniak Gully	0	0.00%	-151.698	-151.698	159	0.04%	7155	0.00	0.00%
Amatuli gully	71	4.54%	-149.9116667	-146.976	11994	2.73%	539730	0.95	3.12%
W Yakutat slope	13	0.83%	-146.8548333	-141.33333	41209	9.39%	1854405	0.05	0.17%
W-grounds	5	0.32%	-143.59551	-143.389	2418	0.55%	108810	0.33	1.09%
Yakutat Valley	**104**	**6.65%**	**-141.27051**	**-140.9366667**	**2416**	**0.55%**	**108720**	**6.89**	**22.71%**
E Yakutat slope	20	1.28%	-139.48333	-137.37334	14841	3.38%	667845	0.22	0.71%
Alsek Strath	13	0.83%	-139.33483	-139.08416	960	0.22%	43200	2.17	7.15%
Spencer Gully	1	0.06%	-137.08867	-137.08867	2578	0.59%	116010	0.06	0.20%
Southeastern slope	19	1.21%	-136.5395	-133.9181667	43535	9.92%	1959075	0.07	0.23%
Southeastern shelf	1	0.06%	-135.4	-135.4	4910	1.12%	220950	0.03	0.11%
Southeastern	0	0.00%	-136.29733	-136.11033	1440	0.33%	64800	0.00	0.00%
Ommaney Trench	21	1.34%	-134.9773333	-134.9003333	2417	0.55%	108765	1.39	4.58%
Iphigenia Gully	0	0.00%	-134.66966	-134.407	966	0.22%	43470	0.00	0.00%
Dixon Entrance	9	0.58%	-133.153	-132.8381667	2416	0.55%	108720	0.60	1.97%
NW Aleutians	0	0.00%	172.71667	179.91667	9687	2.21%	435915	0.00	0.00%
SW Aleutians	1	0.06%	172.95667	179.56667	13901	3.17%	625545	0.01	0.04%
Total	**1,565**				**438,898**		**19,750,410**	**0.57**	

Table 4. Catch of Pacific sleeper sharks from the combined sablefish longline survey, the domestic sablefish survey, and Japan-U.S. cooperative sablefish survey in the Gulf of Alaska, Aleutian Islands and Bering Sea during the years 1979-2003.

Year	All effective hachis	All effective[1] hachis, All standard[2] hauls	Domestic survey	Cooperative survey
1979	0	0		0
1980	1	1		1
1981	1	1		1
1982	1	1		1
1983	0	0		0
1984	5	5		5
1985	6	6		6
1986	5	5		5
1987	25	25		25
1988	20	15	3	12
1989	26	23	15	8
1990	29	26	25	1
1991	29	28	27	1
1992	71	40	26	14
1993	103	88	69	19
1994	155	117	67	50
1995	61	53	53	
1996	83	83	83	
1997	95	88	88	
1998	84	79	79	
1999	84	78	78	
2000	107	103	103	
2001	147	142	142	
2002	130	120	120	
2003	94	90	90	
Total	**1,362**	**1,217**	**1,068**	**149**

[1] Effective hachis have less than or equal to 5 ineffective hooks.
[2] Standard hauls do not include experimental stations.

Table 5. CPUE (catch per standard survey station - 7,200 hooks) of Pacific sleeper sharks from the combined sablefish longline survey, the domestic sablefish survey, and Japan-U.S. cooperative sablefish survey in the Gulf of Alaska, Aleutian islands and Bering Sea during the years 1979-2003.

Year	All effective hachis	All effective[1] hachis, All standard[2] hauls	Domestic survey	Cooperative survey
1979	0.00	0.00		0.00
1980	0.01	0.02		0.02
1981	0.01	0.02		0.02
1982	0.01	0.01		0.01
1983	0.00	0.00		0.00
1984	0.05	0.06		0.06
1985	0.09	0.12		0.12
1986	0.07	0.10		0.10
1987	0.31	0.41		0.41
1988	0.13	0.13	0.07	0.15
1989	0.20	0.22	0.30	0.15
1990	0.22	0.25	0.49	0.02
1991	0.26	0.31	0.53	0.03
1992	0.45	0.34	0.50	0.22
1993	0.61	0.71	1.34	0.26
1994	0.95	1.01	1.31	0.77
1995	0.89	0.94	0.94	
1996	1.10	1.37	1.37	
1997	1.12	1.30	1.30	
1998	1.14	1.24	1.24	
1999	1.20	1.28	1.28	
2000	1.51	1.66	1.66	
2001	2.09	2.32	2.32	
2002	1.91	2.01	2.01	
2003	1.44	1.57	1.57	

[1] Effective hachis have less than or equal to 5 ineffective hooks.
[2] Standard hauls do not include experimental stations.

Table 6. Relative population numbers (RPN's) of Pacific sleeper sharks from the combined sablefish longline survey, the domestic sablefish survey, and the Japan-U.S. cooperative sablefish survey in the Gulf of Alaska, Aleutian islands and Bering Sea during the years 1979-2003.

Year	All effective[1] hachis, All standard[2] hauls	Domestic survey	Cooperative survey
1979	0.00		0.00
1980	6.89		6.89
1981	3.92		3.92
1982	6.20		6.20
1983	0.00		0.00
1984	47.39		47.39
1985	92.10		92.10
1986	206.50		206.50
1987	186.61		186.61
1988	152.61	78.67	101.75
1989	216.12	136.07	164.72
1990	307.54	361.13	4.78
1991	362.23	405.80	5.30
1992	521.04	462.14	85.29
1993	1,477.41	1,371.52	148.38
1994	1,728.08	1,532.47	353.68
1995	908.90	908.90	
1996	1,445.18	1,445.18	
1997	929.61	929.61	
1998	1,405.24	1,405.24	
1999	1,443.26	1,443.26	
2000	1,778.93	1,778.93	
2001	2,979.75	2,979.75	
2002	2,660.54	2,660.54	
2003	1,693.35	1,693.35	

[1] Effective hachis have less than or equal to 5 ineffective hooks.
[2] Standard hauls do not include experimental stations.

Table 7. Relative population numbers (RPN's) of Pacific sleeper sharks captured by the cooperative sablefish longline survey during the years 1982-1994 in the Gulf of Alaska, Aleutian islands and Bering Sea.

Pacific Sleeper Shark Relative Population Numbers (RPN)

Cooperative sablefish longline survey Sampling regions	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Bering Sea													
Bering 4	0	0	0	0	0	7	5	17	0	0	11	0	165
Bering 3	0	0	0	0	0	9	21	21	0	0	16	55	49
Bering 2	0	0	15	0	30	44	19	0	0	0	19	16	45
Bering 1	6	0	4	0	0	0	7	18	0	0	14	73	59
Aleutian Islands													
NW Aleutians	0	0	0	0	0	0	0	0	0	0	0	0	0
SW Aleutians	0	0	0	19	0	0	0	0	0	0	0	0	0
NE Aleutians	0	0	21	25	28	23	35	11	0	0	0	0	0
SE Aleutians	0	0	6	41	0	8	12	0	0	5	0	0	0
Gulf of Alaska Slope													
Shumagin [1]	0	0	0	6	8	58	0	0	0	0	0	0	0
Chirikof [2]	0	0	2	0	0	14	3	0	0	0	5	0	3
Kodiak [3]	0	0	0	0	0	0	0	0	0	0	0	0	0
W Yakutat [4]	0	0	0	0	0	10	0	2	0	0	21	0	0
E Yakutat [5]	0	0	0	0	0	14	0	3	5	0	0	5	33
Southeast [6]	0	0	0	0	0	0	0	0	0	0	0	0	0
Gulf of Alaska Gully													
Amatuli Gully [3]	0	0	0	0	141	0	0	93	0	0	0	0	0

[1] Western Gulf stations (Shumagin)
[2] Central Gulf stations (Chirikof))
[3] Central Gulf Stations (Kodiak)
[4] Eastern Gulf stations (West Yakutat)
[5] Eastern Gulf stations (East Yakutat)
[6] Eastern Gulf stations (Southeast Outside)

Table 7. Continued.

Pacific Sleeper Shark Relative Population Numbers (RPN)

Aggregated regions	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Eastern Bering Sea slope	6	0	19	0	30	59	52	56	0	0	60	144	318
Aleutian Islands slope	0	0	27	86	28	30	46	11	0	5	0	0	0
Western Gulf of Alaska slope	0	0	0	6	8	58	0	0	0	0	0	0	0
Central Gulf of Alaska													
Slope	0	0	2	0	0	14	3	0	0	0	5	0	3
Gully	0	0	0	0	141	0	0	93	0	0	0	0	0
Eastern Gulf of Alaska slope	0	0	0	0	0	25	0	4	5	0	21	5	33
Total	6	0	47	92	206	187	102	165	5	5	85	148	354

Table 8. Relative population numbers (RPN's) of Pacific sleeper sharks captured by the domestic sablefish longline survey during the years 1989-2003 in the Gulf of Alaska, Aleutian islands and Bering Sea.

	Pacific Sleeper Shark Relative Population Numbers (RPN)														
NMFS Domestic sablefish longline survey Sampling regions	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Bering Sea															
Bering 5															
Bering 4									73		35		22		6
Bering 3									37		12		13		4
Bering 2									159		10		0		30
Bering 1									102		8		6		86
Aleutian Islands															
NW Aleutians															
SW Aleutians															
NE Aleutians										0		0		0	
SE Aleutians								0		0		0		0	
Gulf of Alaska															
Shumagin [1]	0	34	38	0	17	6	0	0	0	17	0	0	0	0	0
Shumagin Gully [2,5]	7	0	0	0	0	0	0								
Chirikof [2]	8	0	5	0	0	6	0	6	2	4	2	1	7	18	0
Shelikof Trough [2]	61	102	227	371	1,181	973	809	1,314	387	1,181	1,320	1,635	2,847	2,489	1,391
Kodiak [2]	0	0	0	0	0	0	6	0	0	0	0	29	21	0	0
Amatuli Gully [2]	0	157	81	53	124	532	69	0	37	106	42	16	0	0	0
W Yakutat [3]	11	0	10	0	0	0	3	5	2	0	0	11	0	0	0
E Yakutat [4]	0	0	4	1	1	0	0	0	28	1	0	10	0	1	0
W-grounds [3]	0	0	0	12	12	0	0	0	0	0	0	4	0	0	0
Yakutat Valley [3]	43	65	35	8	16	0	12	121	65	36	5	47	58	76	103
Alsek Strath [4,5]	0	4	6	17	20	8									
Southeast [4]	6	0	0	0	0	3	0	0	37	3	0	0	0	0	30
Spencer Gully [4]	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Ommaney Trench [4]	0	0	0	0	0	6	0	0	0	12	8	26	4	13	43
Iphigenia Trench [4,5]	0	0	0	0	0	0									
Dixon Entrance [4]	0	0	0	0	0	0	8	0	1	44	0	0	0	63	0

Table 8. Continued.

Pacific Sleeper Shark Relative Population Numbers (RPN)

Gulf of Alaska INPFC areas		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Western		0	34	38	0	17	6	0	0	0	17	0	0	0	0	0
Central		69	259	313	424	1,306	1,510	884	1,319	426	1,291	1,364	1,682	2,875	2,507	1,391
Eastern	West Yakutat	54	65	45	21	28	0	15	125	67	36	5	61	58	76	103
	East Yakutat / Southeast Outside	6	0	4	1	1	9	10	0	66	61	8	36	4	78	73

Pacific Sleeper Shark Relative Population Numbers (RPN)

Gulf of Alaska totals	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Gulf of Alaska total	129	358	400	446	1,352	1,525	909	1,445	559	1,405	1,377	1,779	2,938	2,661	1,567
Difference in totals by year		177%	12%	11%	203%	13%	-40%	59%	-61%	151%	-2%	29%	65%	-9%	-41%

Pacific Sleeper Shark Relative Population Numbers (RPN)

Gulf of Alaska gully station[6] totals	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Gulf of Alaska gully stations	104	324	342	445	1,333	1,511	900	1,435	490	1,379	1,375	1,728	2,910	2,642	1,537
Percent of total in gullies	81%	91%	86%	100%	99%	99%	99%	99%	88%	98%	100%	97%	99%	99%	98%

[1] Western Gulf stations
[2] Central Gulf stations
[3] Eastern Gulf stations (West Yakutat)
[4] Eastern Gulf stations (East Yakutat / Southeast Outside)
[5] Discontinued stations, not included in Gulf of Alaska Summary
[6] Continuously sampled gully stations include: Shelikof Trough, Amatuli Gully, W-grounds, Yakutat Valley, Spencer Gully, Ommaney Trench, and Dixon entrance

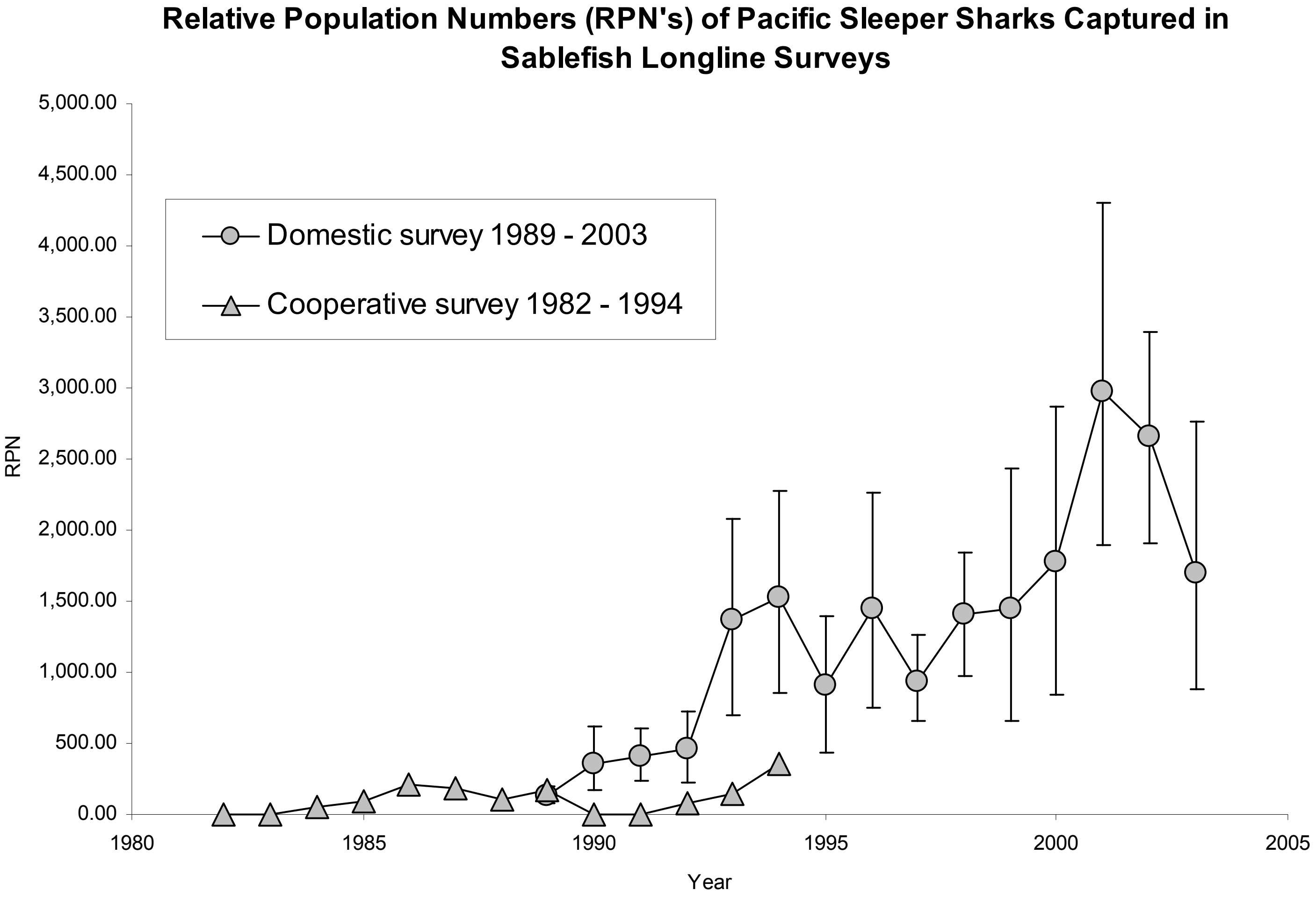

Figure 1. Relative population numbers (RPN's) of Pacific sleeper sharks captured in the Gulf of Alaska, Aleutian islands, and Bering Sea during the years 1982-1994 by the Japan-U.S. cooperative sablefish longline survey, and in the Gulf of Alaska during the years 1989-2003 by the domestic sablefish longline survey (with 95% bootstrap confidence intervals for the domestic survey).

Benthic Communities and Non-target Fish Species

ADF&G Gulf of Alaska Trawl Survey

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The Alaska Department of Fish and Game began using a 400 Eastern trawl for crab surveys in the late 1960s. By the late 1980s, the trawl had become the primary survey device, replacing pot gear for crab surveys around Kodiak Island, the Alaska Peninsula, and the Eastern Aleutians. Survey stations target areas of soft substrate known to be prime crab habitat. Since 1984 the same vessel and captain have been used for these surveys which follow a fairly consistent schedule and survey route from mid-June through September.

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 1) 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). This area is typically surveyed during the third and fourth weeks of June.

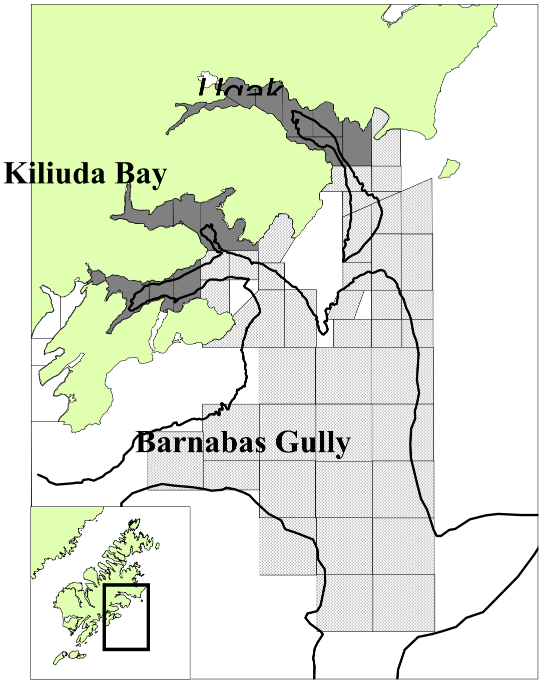

Figure 1. Adjoining trawl stations on the east side of Kodiak Island used to characterize nearshore (dark gray) and offshore (light gray) trawl survey results with the 100m contour indicated.

The change in catch rates of a number of species in Ugak Bay from 1976 to the present is striking (Table 1) and doubtlessly related to the well documented regime shift. King crab went from being a main component of the catch to being nearly non-existent, while Tanner crab catch rates dramatically increased. Walleye pollock and flathead sole catch rates also greatly increased.

Table 1. Comparison of catch rates (kg/km) of selected species from trawl surveys in Ugak Bay on the east side of Kodiak Island.

Species	**1976**	**1990**	**2003**
Red king crab	25.5	0.0	1.5
Tanner crab	22.5	97.8	141.4
Yellow Irish Lord	6.7	0.0	0.0
Flathead sole	13.7	288.4	268.1
Walleye pollock	0.4	29.7	90.9
Pacific cod	18.6	24.6	16.6

Arrowtooth flounder continue to dominate the offshore catch, increasing in recent years to roughly double the catch rates during 1986-2000 (Figure 2). Flathead sole dominate the inshore bay areas, although not to the extent of the early 1990s. Tanner crabs remain a common component of the catch although the commercial fishery during the past two winters probably contributed to the recent decrease in catch. The overall total catch is increasing in recent years in both areas, largely driven by increases in arrowtooth flounder and flathead sole catches. The cause of these increases is unknown.

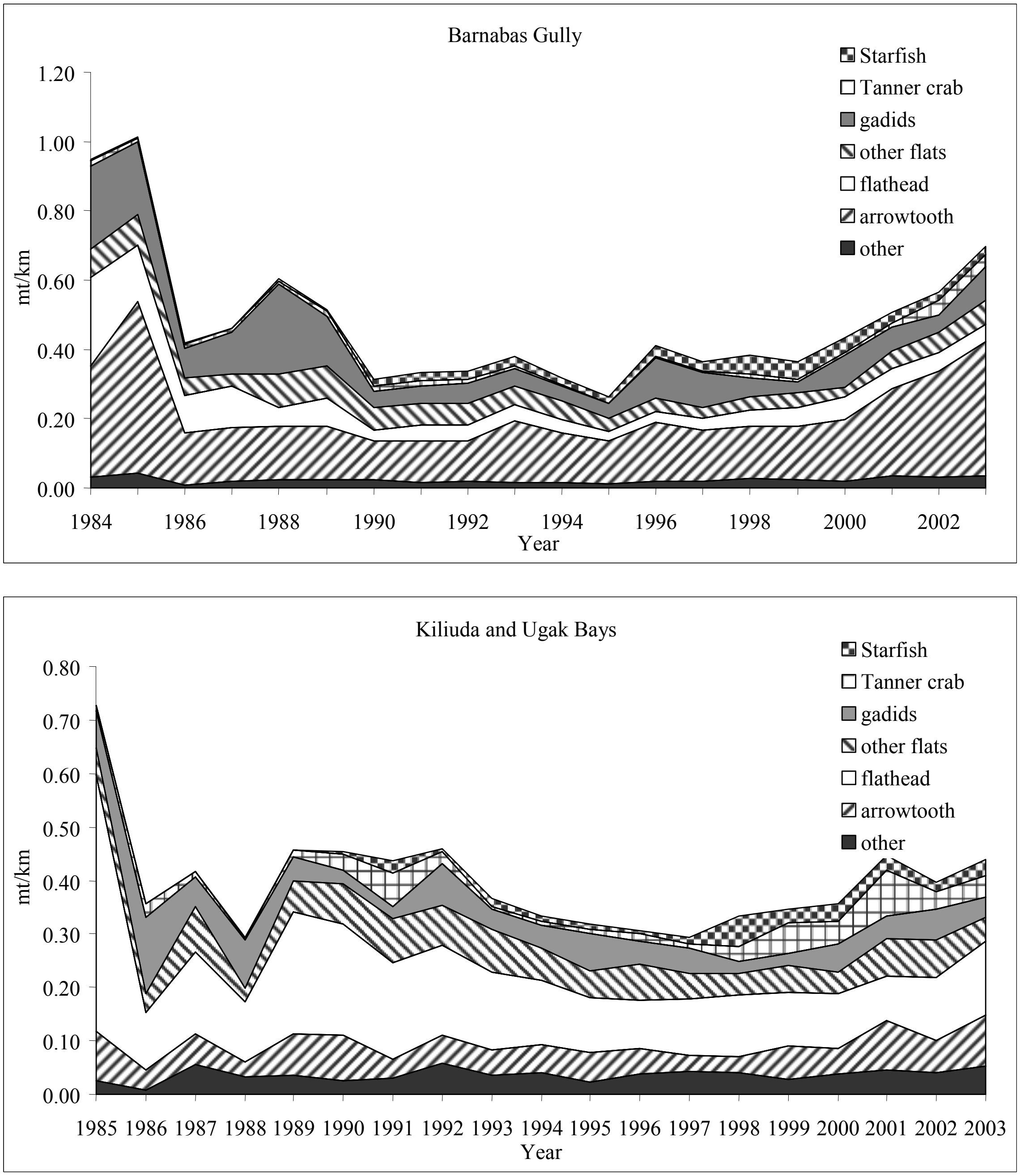

Figure 2. Metric tons per kilometer caught during the ADF&G large mesh trawl survey from adjacent areas off the east side of Kodiak Island.

Bottom temperatures for each haul have been consistently recorded since 1990 (Figure 3). Temperatures have shown a regular oscillation with a period and direction of change roughly corresponding to the sea surface temperatures of the Niño Region of the tropical eastern Pacific. The 2003 bottom temperatures appear to have begun another period of increase.

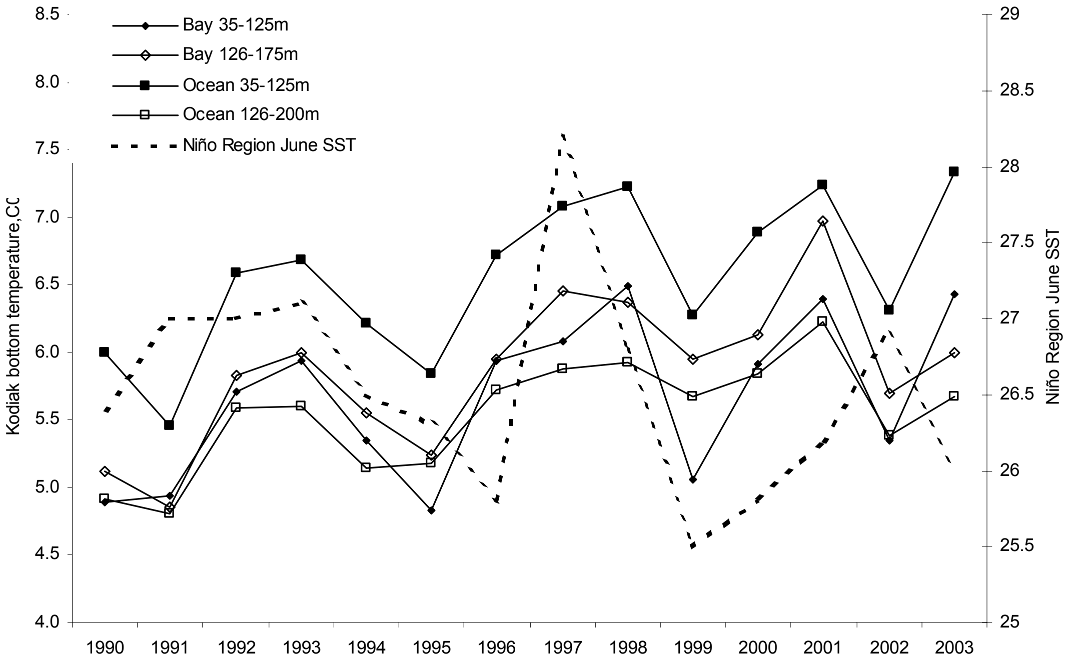

Figure 3. June ocean bottom temperatures from the east side of Kodiak Island, and the average Niño Region June sea surface temperature from 1990-2003. Niño Region SST found at the following site: http://www.cpc.ncep.noaa.gov/data/indices/index.html

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Gulf of Alaska Small Mesh Trawl Survey Trends

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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 2002. 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 2002, 9356 trawls covering 17,804 km were conducted. Annual effort averaged 259 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 epi-benthic fish and invertebrates from 1953 to the present.

Recent data indicate the GOA may be in an early stage of a significant shift in community composition. However, I believe it would be misleading to characterize this preliminary data analysis in this way. Most of the data which have recently been added to the database came from the ADF&G small mesh survey in 2001 (96 tows) and 2002 (108 tows) (Ruccio 2003; Jackson 2003). 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. However additional surveys conducted by NMFS to the west along the Alaska Peninsula (Pavlof Bay in 2001) 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 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 2003. It is anticipated that results will be useful in determining the strength of recent species abundance trends.

Selected Species Index

Pandalid Shrimp

Abundance of Pandalid shrimp has increased since 1998 in the GOA (Figure 1). Average catch per tow for all pandalids combined increased to over 75 kg/km in 2001 and was 38.5 kg/km in 2002. Relative Pandalid shrimp abundance at this level last occurred in survey results nearly twenty years ago in the early 1980s. The years 1995 and 1998 (the most comparable sampling effort to recent surveys) indicated only 20 and 13 kg/km respectively for pandalid shrimp abundance. The lower abundance observed in 2002 is probably the result of the extended survey area west of 158° W longitude, an area with relative low shrimp abundance (Jackson 2003).

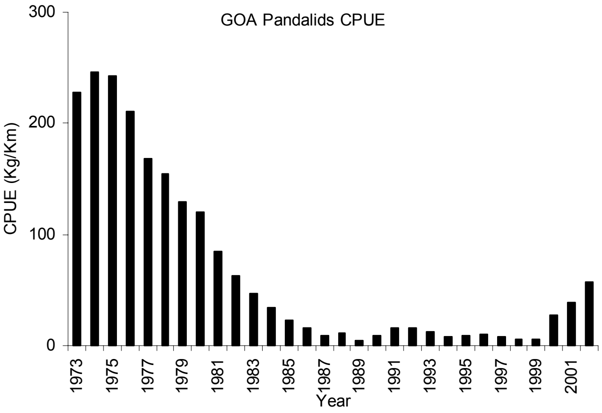

Figure 1. Three year average CPUE (kg per km trawled) of Pandalid shrimp in the GOA small mesh survey, 1973-2002.

The most significant recovery, among pandalid species, has occurred with *Pandalus goniurus*. This species had become almost functionally extinct in GOA shallow nearshore locations where formerly it was locally abundant during the 1970s (Figure 2). Overall abundance was 7.9 kg/km in 2001and 5.6 kg/km in 2002, the highest CPUE recorded for this species since 1984 (10.3 kg/km). Other pandalids showed high relative abundance in 2001 and 2002; *P. borealis* (61.2 kg/km; 30.5 kg/km), *P. hypsinotus* (1.3 kg/km; 1.4 kg/km), and *Pandalopsis dispar* (3.5 kg/km; 1 kg/km) (Figure 2). All of these values approach the abundance of the early 1980s for the survey series. Therefore, recent survey results support the notion that pandalid shrimp, as a group, are showing signs of regaining importance in the community structure of the GOA.

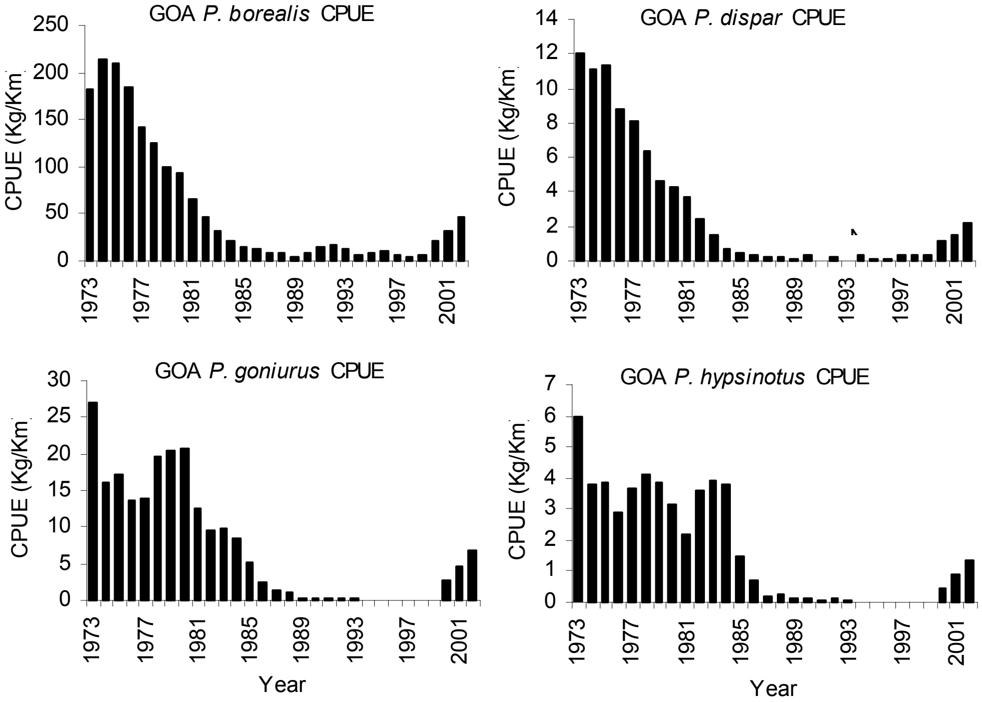

Figure 2. Three year average CPUE (kg per km trawled) of 4 Pandalid shrimp species in the GOA small mesh survey, 1973-2002.

Analysis of length-frequency data from the various shrimp populations sampled may give important clues to the mechanism responsible for the apparent population recovery. Strong size modes at approximately 15 mm of carapace length (CL) (1+ or 2+ age class; Anderson, 1991) for *P. borealis* in almost all areas sampled indicates favorable recruitment conditions in 1999 through 2001. A mode at 7 to 9 mm of CL (0+ age class) in the Marmot Island strata indicates locally favorable production of juvenile shrimp in 2002 in this area (Jackson 2003).

Recent increases in shrimp populations are directly linked to colder conditions as indicated by the PDO (http://tao.atmos.washington.edu/pdo) since 1998. Sustained high population abundance of Pandalid shrimp as a group 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 are important in determining future pandalid population trends and possibly trends in other species abundance as well.

Gadids

Relative abundance of all gadids (codes 21700 through 21749) has declined since 1998 to the lowest abundance in this survey series since 1990. All gadids combined declined to 111.8 and 87.5 kg/km in 2001 and 2002 respectively (Figure 3). In contrast, juvenile walleye pollock (code 21741), fish less than 20 cm in length, are at high relative abundance 11.4 and 2.6 kg/km in 2001 and 2002. 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 declined to12.3 and 7.8 kg/km in 2001 and 2002. Only 7 cod were captured in the juvenile category (< 20 cm FL) sizes ranged from 5 to 11 cm FL. Most cod were in the 49 to 74 cm FL size range. Gadids and particularly Pacific cod are major predators of pandalid shrimp (Albers and Anderson 1985) and forage fish. Declines in these species is probably responsible for at least a part of the species abundance changes that have recently occurred.

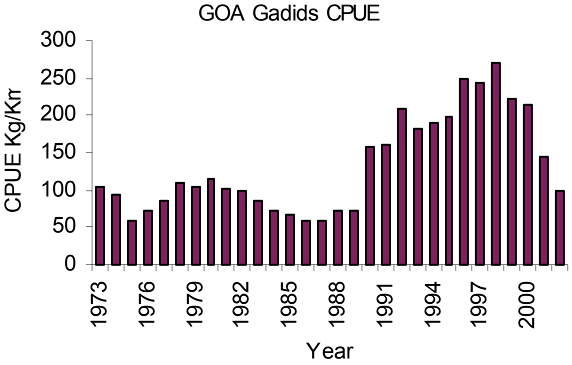

Figure 3. Three year average CPUE (kg per km trawled) of all gadid species in the GOA small mesh survey, 1973-2002.

Pleuronectids

Flatfish abundance, as a group, did not vary significantly from recent surveys (Figure 4). The abundance of all flatfish combined was 121 and 94 kg/km in the 2001 and 2002 surveys. Arrowtooth did show moderate increases in abundance to 44.8 and 31.4 kg/km in 2001 and 2002, the highest CPUE recorded for this species in the last thirty years. Mean lengths for arrowtooth were 35.8 and 35.4 cm FL for the two surveys. Since arrowtooth flounder, especially those less than 40 cm FL, are known predators of pandalid shrimp (Yang and Nelson 2000) these observations are important in determining future species abundance trends. Flathead sole

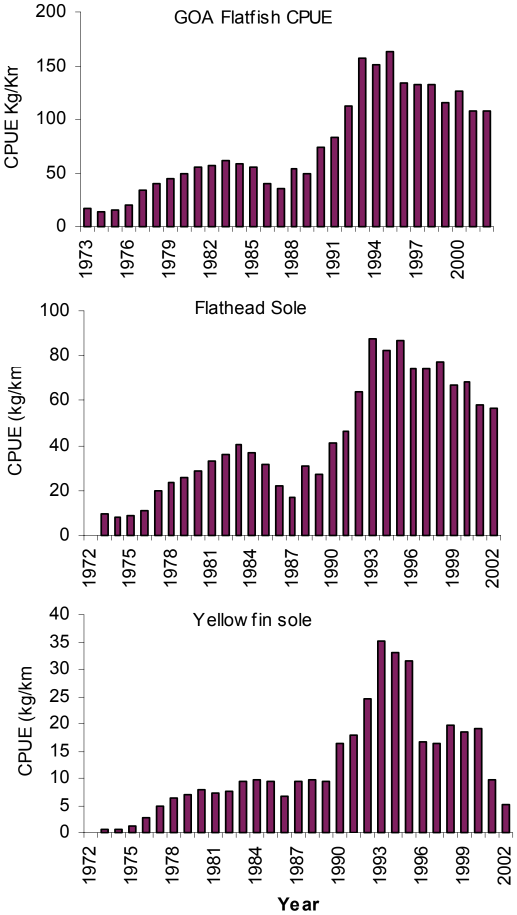

Figure 4. Three year average CPUE (kg per km trawled) of all flatfish species and of flathead and yellowfin sole in the GOA small mesh survey, 1973-2002.

abundance has generally decreased since 1993, but was still above the 1973-to-present average in 2002 (Figure 4). Abundance of yellowfin sole in 2002 was low and was similar to estimates in years prior to 1978 (Figure 4).

Osmerids

Osmerids as a group (species codes 23000 through 23099) increased to 2 and 6 kg/km in 2001 and 2002 (Figure 5). This is the highest relative level of abundance measured since 1980 when 19 kg/km was caught. Average eulachon catch was 1.9 and 6.7 kg/km during the 2001 and 2002 surveys. 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 was evident in many sampling locations (Jackson 2003). This size mode of eulachon in small-mesh trawl survey catches is 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 5).

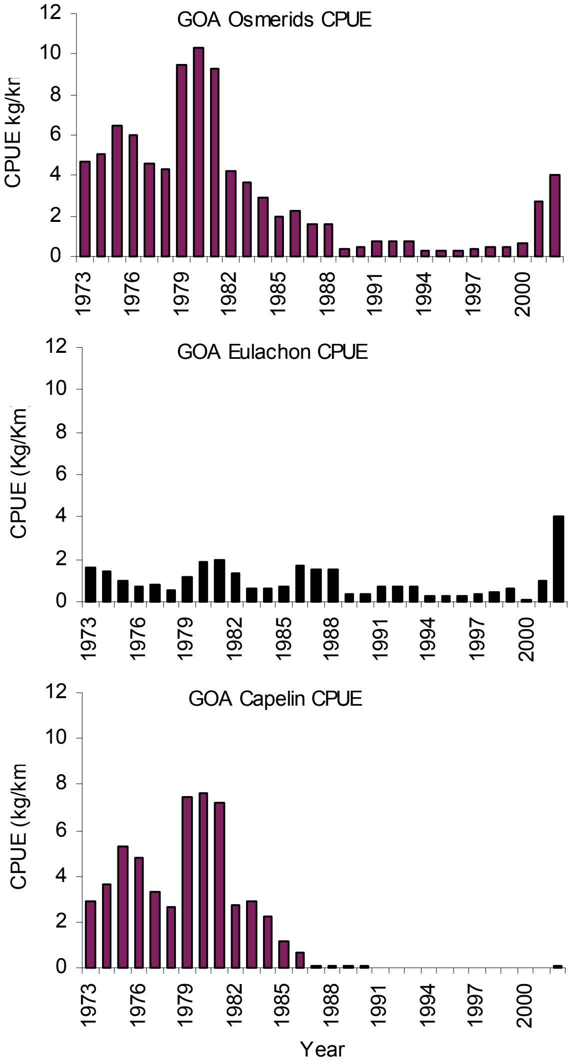

Figure 5. Three year average CPUE (kg per km trawled) of all osmerids and of eulachon and capelin in the GOA small mesh survey, 1973-2002.

Other Forage Species

Other forage species such as Pacific sandfish have shown recovery in recent surveys in the GOA (Figure 6). Pacific sandfish are locally abundant in some bays, the species was present in 18% of survey tows in 2002 (Jackson 2003). Overall the abundance was measured as 3.4 and 2.3 kg/km in the 2001 and 2002 surveys. These are some of the highest observed abundance values of this species during the last 30 years. There appears to be locally strong recruitment in this species since 1999.

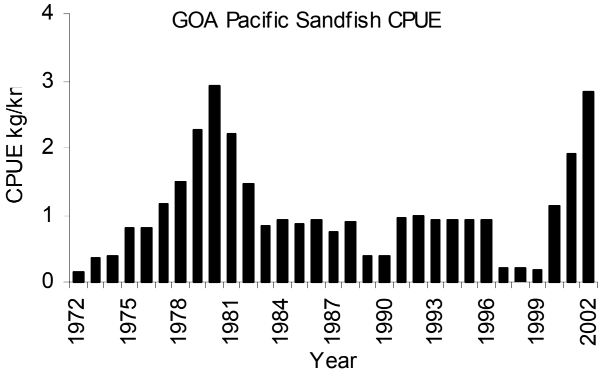

Figure 6. Three year average CPUE (kg per km trawled) of Pacific sandfish in the GOA small mesh survey, 1972-2002.

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Bering Sea Crabs

Contributed by Bob Otto and Brad Stevens, Alaska Fisheries Science Center

A trawl survey is conducted annually in the Eastern Bering Sea to determine the distribution and abundance of crab and groundfish. Population abundance indices are determined using an 'area-swept' method and a stratified systematic sampling design. Precision of crab abundance indices are low because crabs have a patchy distribution, females often prefer rocky, untrawlable areas, and small crabs are not well represented in the samples. Crab abundances are generally low, and of the 7 crab fisheries, 2 are open, 5 are closed, and 4 are considered overfished. Rebuilding plans have been developed or are under development for the overfished stocks. The full report (Stevens et al. 2002) from which this and the following information has been taken is available on the web at http://www.afsc.noaa.gov/kodiak/shellfish/crabEBS/crabsurvey.htm.

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 (Figure 1). The total mature biomass of crabs has remained above 50% of the MSY biomass and, therefore, the stock is not considered overfished. The abundance of both legal and pre-recruit males increased considerably in 2002, whereas, the number of mature females decreased slightly.

PRIBILOF ISLAND RED KING CRAB

Mature biomass of Pribilof Island red king crab was well below 50% MSY in the 1980's. Since 1991, the mature biomass has been higher than the 50% MSY with peaks in 1993 and 2001 and is not considered overfished (Figure 1). No change in abundance of large male crabs was observed, and estimates of both pre-recruit males and mature females are too imprecise to detect trends. The fishery for Pribilof Island red king crab is closed because there is no apparent recruitment to the population and due to concerns of unacceptable levels of incidental catch of blue king crab.

PRIBILOF ISLANDS BLUE KING CRAB

Blue king crab in the Pribilof Islands area are considered overfished since the reproductive population estimate fell below the 50% MSY in 2002. Abundances of legal and pre-recruit males and mature females decreased in 2002 (Figure 1). Little or no recruitment is apparent in the population which has been at low levels since the early 1980's.

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 (Figure 1). Both legal and pre-recruit male abundances decreased. Indices of female crab abundances are affected by their preference for inshore, rocky, and untrawlable habitat.

WHOLE EASTERN BERING SEA TANNER CRAB

The Eastern Bering Sea tanner crab population was high in the early 1980's and from 1988-1992 (Figure 1). 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.

WHOLE 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 (Figure 1). Recently the biomass has declined and is currently below 50% MSY and is considered overfished. The abundance of mature females has declined and there has been a lack of recruitment to the female reproductive stock, substantiated by the increasing prevalence of old shelled crab. Small male and female crabs are also decreasing in abundance.

ALL DISTRICTS HAIR CRAB

The population of hair crabs has been declining for several years and the fishery has been closed since 2000. Recruitment trends are unclear due to poor representation of small crabs in survey tows.

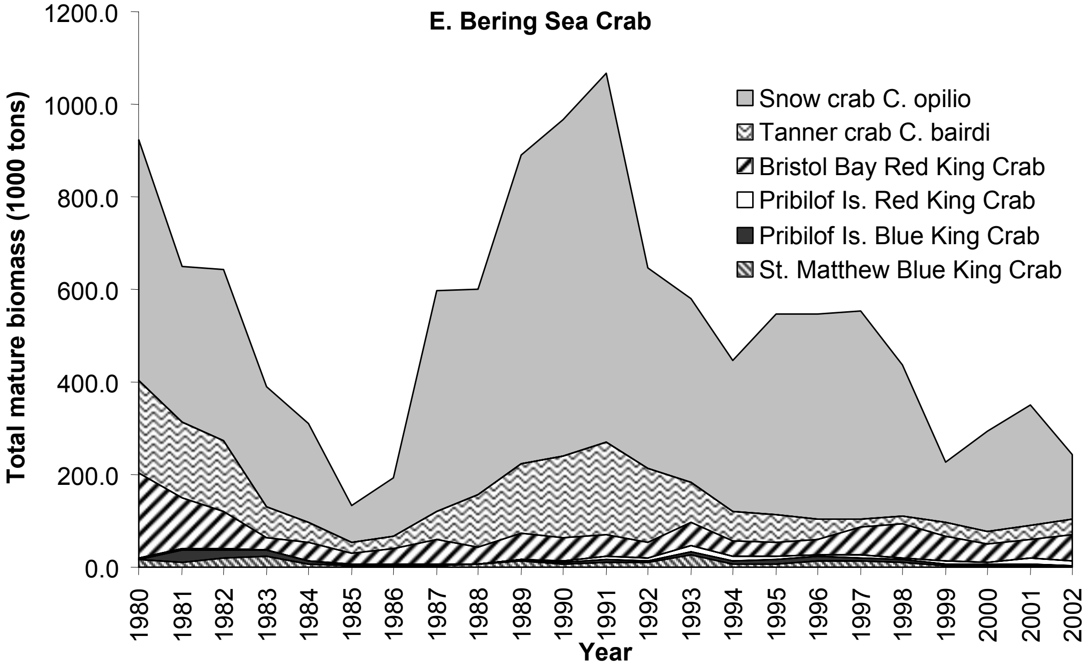

Figure 1. Total mature biomass of Eastern Bering Sea crab populations.

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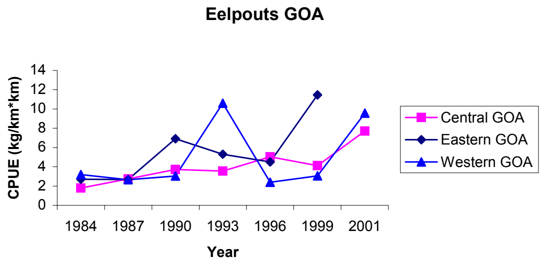
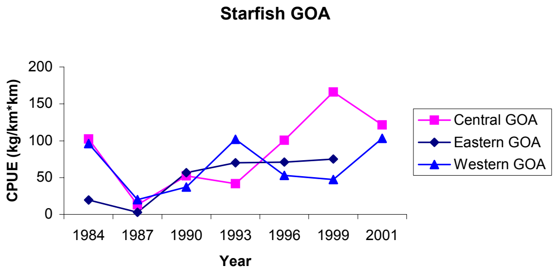
Miscellaneous Species – Gulf of Alaska - not updated for 2003

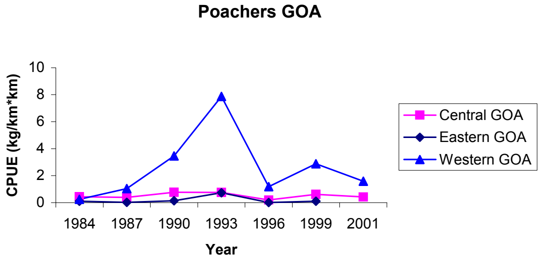
Contributed by Eric Brown, Alaska Fisheries Science Center

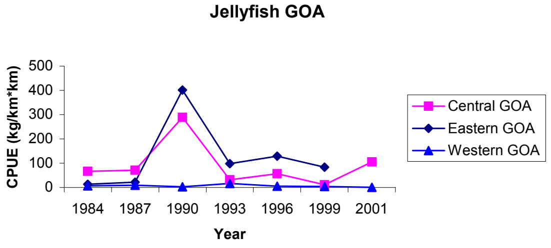
A variety of non-target species are seen in the RACE bottom trawl survey in the Gulf of Alaska. It is possible that the survey may provide information about possible relative abundance changes for some of these species. Some initial results at summarizing these trends are shown (Figure 1). This survey 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. Poachers occur occasionally at very low abundance levels. Their apparent large increase in abundance observed in 1993 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.


Eelpouts GOA


Starfish GOA


Poachers GOA


Jellyfish GOA

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 2003 (Figure 1). The trend for increasing abundance that began around 1989 reported by Brodeur et al. (1999) did not continue in 2001-2003. In fact, the 2001-2003 catches decreased dramatically and were close to levels seen in the 1980's and early 1990's. The overall area biomass index for 2003 is 55,296 t. It is unknown whether this decline is due to a change in availability or actual abundance.

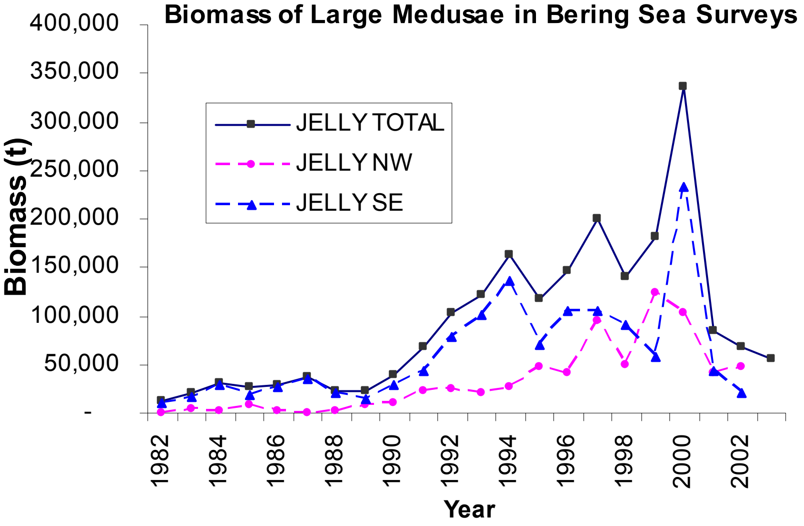


Figure 1. Index of large medusae biomass during the summer in the eastern Bering Sea from the NMFS bottom trawl survey, 1982-2003.

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 biomass of this group appeared higher in the early 1980's than in the late 1980's to the present. Although lower, biomass appears to be relatively stable in the recent time period. Further analyses are needed to examine biomass trends at the species level. The biomass of poachers, likely dominated by sturgeon poacher (*Podothecus acipenserinus*), was low in the early 1980's but increased e in the late 1980's to the mid-1990's. Biomass appears to be lower in recent years and may be returning to levels seen in the early 1980's. 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. Total biomass index 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 biomass trends.

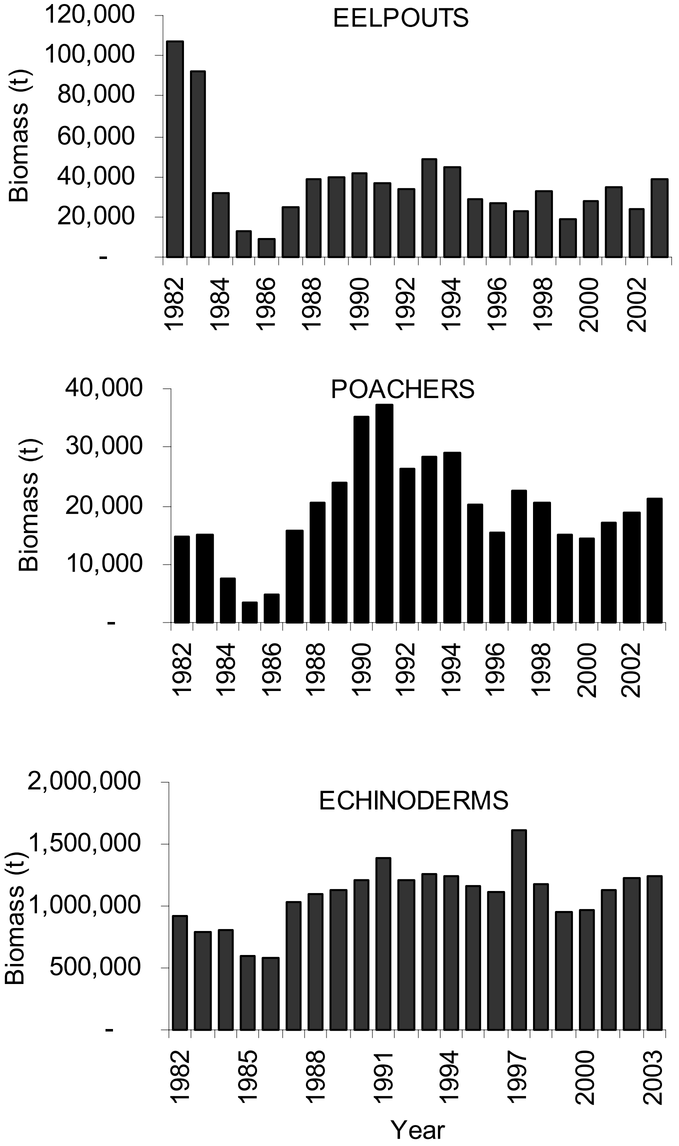


Figure 1. Biomass index values of miscellaneous species caught in the eastern Bering Sea summer bottom trawl survey, 1982-2003.

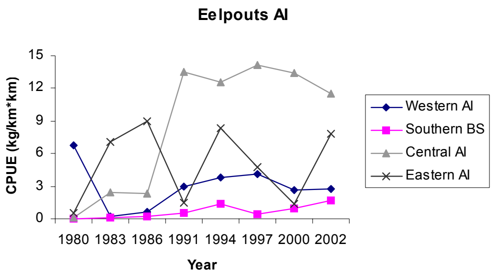
Miscellaneous Species – Aleutian Islands

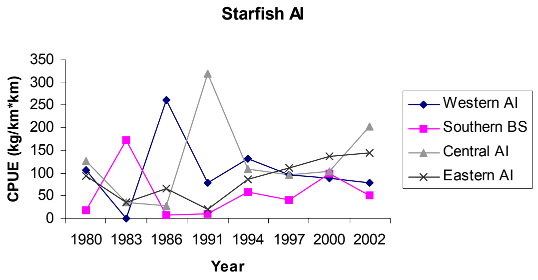
Contributed by Eric Brown, Alaska Fisheries Science Center

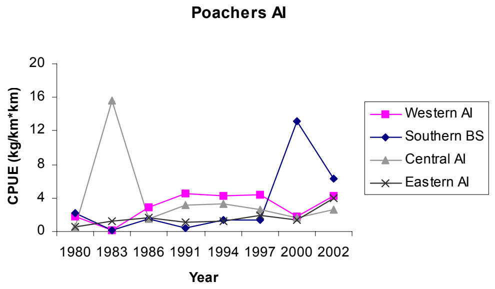
A variety of non-target species are seen in the RACE bottom trawl survey in the Aleutian Islands. It is possible that this survey may provide information about possible relative abundance changes in some of these species. Some initial results at summarizing these trends are shown (Figure 1). This survey is not designed to assess these organisms and further detailed examinations of these results are needed to assess whether there are meaningful trends.

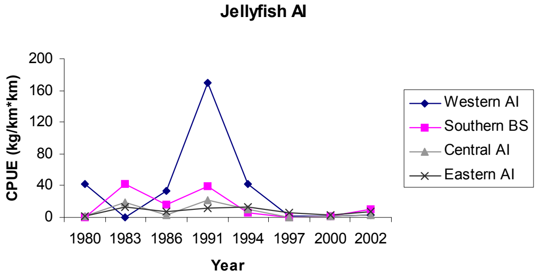
Eelpouts and poachers are relatively common in trawl catches but generally occur at very low catch rates so that any apparent increases in abundance may be driven by one or two catches of only a few fish. Starfish and jellyfish are also quite common but exhibit much higher apparent abundance levels.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

The 2002 survey shows the highest abundance of poachers occurring in the southern Bering Sea however abundance levels in this area have declined from the unusually high catch rates observed in the 2000 survey. The survey results also indicate that the dramatic increase in eelpout abundance first observed in the central Aleutians during the 1991 survey has remained relatively level in subsequent surveys. Starfish abundance increased fairly sharply in the central and eastern Aleutians while jellyfish catch rates were relatively unchanged from the previous two surveys.









Marine Mammals

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Note: the material that follows has been directly excerpted from published literature and the Stock Assessment Report published annually by the National Marine Mammal Laboratory (Angliss and Lodge 2002). Research summaries and data are available electronically on: http://nmml.afsc.noaa.gov and ***http://www.nmfs.noaa.gov/prot_res/PR2/Stock_Assessment_Program/sars.html***
Slides and posters of recent research efforts into the causes of Steller sea lion decline can be found at: http://www.afsc.noaa.gov/stellers/symposium2003.htm

The Bering Sea and Gulf of Alaska support one of the richest assemblages of marine mammals in the world. Twenty-six species are present from the orders Pinnipedia (seals, sea lion, and walrus), Carnivora (sea otter and polar bear), and Cetacea (whales, dolphins, and porpoises) in areas fished by commercial groundfish fleets (Lowry and Frost, 1985; Springer et al., 1999). Most species are resident throughout the year, while others migrate into or out of the management areas seasonally. Marine mammals occur in diverse habitats, including deep oceanic waters, the continental slope, and the continental shelf (Lowry et al., 1982). Descriptions of the range, habitat, diet, abundance, and population status for species thought to have the most significant interactions with commercial fisheries, either because of direct takes or diet overlap, were provided in previous Ecosystem Considerations Chapters (Livingston, 2001; 2002). Marine mammal stock status, fishery mortality through direct takes, and subsistence harvest levels relative to potential biological removals are summarized in Table 5. Below is an update of the status and trends for species currently of particular concern, as well as direct fisheries take information for all monitored marine mammals in the Gulf of Alaska and Bering Sea.

PINNIPEDIA

Steller sea lion (*Eumetopias jubatus*)

Steller sea lions range along the North Pacific Ocean rim from northern Japan to California (Loughlin et al., 1984), with centers of abundance and distribution in the GOA and Aleutian Islands, respectively. The northernmost breeding colony in the Bering Sea is on Walrus Island in the Pribilof Islands and in the Gulf of Alaska on Seal Rocks in Prince William Sound (Kenyon and Rice, 1961). Habitat includes both marine waters and terrestrial rookeries (breeding sites) and haulouts (resting sites). Although most often within the continental shelf region, they may be found in pelagic waters as well (Bonnell et al., 1983, Fiscus and Baines, 1966; Fiscus et al., 1976; Kenyon and Rice, 1961).

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. Prior to the 1970s surveys were conducted using a number of different techniques throughout portions of the species range. Therefore, reconstruction of population trends for Steller sea lions includes a patchwork of regional surveys conducted over many years.

Population – Western Stock

Aerial surveys conducted from 1953 through 1960 resulted in combined counts of 170,000 to 180,000 Steller sea lions in what is now defined as the Western Stock in Alaska (Mathisen, 1959; Kenyon and Rice, 1961). Braham *et al*. (1980) documented declines of at least 50% from 1957 to 1977 in the eastern Aleutian Islands, the center of what now is the Western Stock. Merrick *et al.* (1987) estimated a population decline of about 50% from the late 1950s to 1985 over a much larger geographical area, the central Gulf of Alaska through the central Aleutian Islands. The population in the Gulf of Alaska and Aleutian Islands declined by about 50% again from 1985 to 1989, or an overall decline of about 70% from 1960 to 1989 (Loughlin *et al*., 1992).

Much of the population trend analyses during recent years have focused on "trend sites" (NMFS 1992, NMFS 1995). Trend sites are those rookeries and haul-out sites surveyed consistently from the mid-1980s to the present, thus allowing analysis of population trends on a decadal scale. Trend sites include about 64%-75% of animals observed in recent surveys (Strick *et al*., 1997; Sease *et al.*, 1999; Sease and Loughlin, 1999; Sease and Gudmundson, 2003) of the Western Stock. From 1991 to 2002, the population declined by an average of 4.1% per year ($P < 0.001$: 95% C.I.= -2.8% to -5.5%) for all trend sites (Figure 1; Table 1) and 3.9% per year ($P= 0.002$: 95% C.I.= -2.3% to -5.6%) at the trend rookeries (Strick *et al*., 1997; Sease *et al.,* 1999; Sease and Loughlin, 1999; Sease *et al*., 2002) (Figure 1). The June 2002 survey resulted in a total count of 26,602 non-pup Steller sea lions on all surveyed sites (n=259) in the Western Stock in Alaska (Figure 1; Table 2). This represents the first

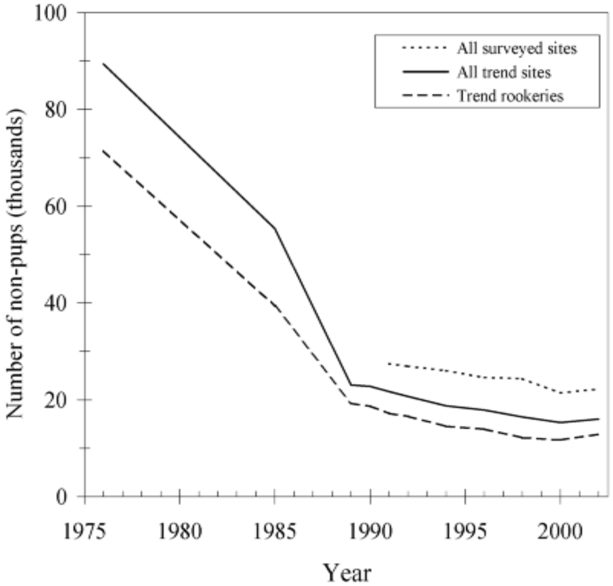

Figure 1.-- Historical trends of various regional components of the Western and Eastern stocks.

region-wide increase observed since standardized aerial surveys began in the 1970s, an increase of 5.5% for all trend sites and 6.8% for trend rookeries from June 2000. Counts were still down compared to 1998 (-5.4% for all trend sites and -1.2% for trend rookeries) and down more than 34% since 1991 (Table 1).

Importantly, the observed increase in 2002 counts of Steller sea lions was not the result of a large increase at a few sites in one region, but rather a geographically broad-based increase from the eastern Gulf of Alaska through the central Aleutian Islands (Sease and Gudmundson, 2002). Although it represents a favorable change, it is premature to conclude that the decades-long decline is over.

Population – Eastern Stock

Despite observed declines in southern and central California of as much as 10% per year since 1990 (NMFS, 1995; Calkins *et al.*, 1999; Ferrero *et al.*, 2000, Angliss and Lodge, 2002), the Eastern Stock as a whole is stable or increasing slowly. Calkins *et al.* (1999) estimated that the Steller sea lion population in southeast Alaska increased by an average of 5.9% per year from 1979 to 1997, based on counts of pups at the three rookeries in the region. Counts of non-pup sea lions at the three rookeries and ten haul-outs sites showed an overall increase of 29.3% from 1990 to 2000, or an average annual increase of 1.9% (Sease *et al.*, 2001). The number of non-pup sea lions in British Columbia is similar to the number in southeast Alaska, and increasing by about 2.5% per year during the last decade.

Table 1.-- Counts of adult and juvenile (non-pup) Steller sea lions observed at **rookery and haul-out trend sites** in seven subareas of Alaska during June and July aerial surveys from 1991 to 2002, including overall percent change from between 1991, 1998, and 2000 to 2002 and estimated annual rates of change from 1991 to 2002.

	Gulf of Alaska			Aleutian Islands			Kenai to Kiska	Western stock
Year	Eastern (n=10)	Central (n=15)	Western (n=9)	Eastern (n=11)	Central (n=35)	Western (n=4)	(n=70)	(n=84)
1991	4,596	6,270	3,732	4,228	7,496	3,083	21,726	29,405
1992	3,738	5,739	3,716	4,839	6,398	2,869	20,692	27,299
1994	3,365	4,516	3,981	4,419	5,820	2,035	18,736	24,136
1996	2,132	3,913	3,739	4,715	5,524	2,187	17,891	22,210
1998	2,110 *	3,467	3,360	3,841	5,749	1,911	16,417	20,438 *
2000	1,975	3,180	2,840	3,840	5,419	1,071	15,279	18,325
2002	2,500	3,366	3,221	3,956	5,480	817	16,023	19,340
Percent change								
2000-2002	26.6	5.8	13.4	3	1.1	-23.7	4.87	5.54
1998-2002	18.5	-2.9	-4.1	3	-4.7	-57.2	-2.4	-5.37
1991-2002	-45.6	-46.3	-13.7	-6.4	-26.9	-73.5	-26.25	-34.23
Estimated annual rates of change: 1991 to 2002								
Annual change	-6.6	-6.2	-2.2	-1.6	-2.3	-11.4	-3.1	-4.1
Upper 95%	-1.3	-3.7	-0.2	0.4	-0.4	-7.1	-2	-2.8
Lower 95%	-11.9	-8.7	-4.2	-3.6	-4.2	-15.7	-4.2	-5.5
P	0.024	0.001	0.038	0.09	0.025	0.001	< 0.001	< 0.001

* 1999 counts substituted for sites in the eastern Gulf of Alaska not surveyed in 1998.

Table 2.--Counts of adult and juvenile (non-pup) Steller sea lions observed at **all surveyed rookery and haul-out sites** for seven subareas of Alaska during June and July aerial surveys from 1991 to 2002, including overall percent change from 1991, 1998, and 2000 to 2002 and estimated annual rates of change from 1991 to 2002.

	Gulf of Alaska			Aleutian Islands			Kenai to Kiska	Western stock
Year	Eastern (n=27)	Central (n=52)	Western (n=35)	Eastern (n=55)	Central (n=78)	Western (n=12)	(n=220)	(n=259)
1991	4,812	7,872	5,338	5,285	8,959	4,920	27,454	37,186
1992	4,386	7,462	5,495	5,711	8,302	4,531	26,970	35,887
1994	3,989	6,788	5,717	5,875	7,617	3,367	25,997	33,353
1996	2,585	5,744	5,722	5,967	7,170	3,407	24,603	30,595
1998	2,230 [1]	5,022	5,850	5,837	7,671	2,865	24,380	29,475 [1]
2000	2,353	4,817	4,568	4,996	7,000	1,650	21,381	25,384
2002	3,182	4,805	5,023	5,358	7,035	1,199	22,221	26,602
Percent change								
2000-2002	35.2	< 1	10	7.2	< 1	-27.3	3.92	4.8
1998-2002	42.7	-4.3	-14	-8.2	-8.3	-58.2	-8.86	-9.75
1991-2002	-33.9	-39	-5.9	1.4	-21.5	-75.6	-19.06	-28.46
Estimated annual rates of change: 1991 to 2002								
Annual change	-5.7	-5		-0.5	-1.9	-12.2	-2.2	-3.4
Upper 95% CI	0.1	-3.6		2	-0.7	-8.1	-1.4	-2.4
Lower 95% CI	-11.5	-6.4		2	-3.2	-16.2	-3	-4.4
P	0.054	< 0.001		0.489	0.012	< 0.001	< 0.001	< 0.001

[1] 1999 counts substituted for sites in the eastern Gulf of Alaska not surveyed in 1998.

[2] No 95% C.I. reported for P = 0.489.

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 with the remaining animals spread throughout the North Pacific Ocean. (Lloyd et al., 1981; NMFS, 1993). Two separate stocks of northern fur seals are recognized within U.S. waters: an Eastern Pacific stock and a San Miguel Island stock.

Population

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).

Population trends in northern fur seals have been monitored annually or biennially with few interruptions since the early 1900s. Numbers of northern fur seal pups are estimated by shear-sampling, a mark-recapture method (York and Kozloff, 1987). The most recent pup production estimate for the Pribilof Islands conducted in August of 2002, reflects a decreasing trend in population. The 2002 population estimate is the smallest pup production figure recorded since 1921. The current estimate is 145,701 (SE = 1,629) pups born on St. Paul Island; 8,262 (SE = 191) born on Sea Lion Rock, a small island approximately 500 m from St. Paul Island; and 17,593 (SE = 526.6) pups born on St. George Island (Tables 3 and 4). During 1998-2002, pup production declined on St. Paul Island at 5.14% per year (SE = 0.26%, P =0.03) and at 5.35% per year (SE = 0.67%, P = 0.08) on St. George Island. For the Pribilof Islands, as a whole (excluding Sea Lion Rock), pup production declined at 5.20% per year (SE = 0.19%, P = 0.02). A similar reduction in pup production on the Pribilof Islands occurred 1976-1982 at a rate of 4%-8% per year (York and Kozloff, 1987), the cause of which has yet to be determined. Estimated pup production is now below the 1921 level on St. Paul Island and below the 1916 level on St. George Island. During those years, the northern fur seal population was increasing at about 8% per year as it recovered from a pelagic harvest that took place in the late 19th and early 20th centuries. On Sea Lion Rock, pup production is only slightly greater than the 8,061 pups counted in 1922.

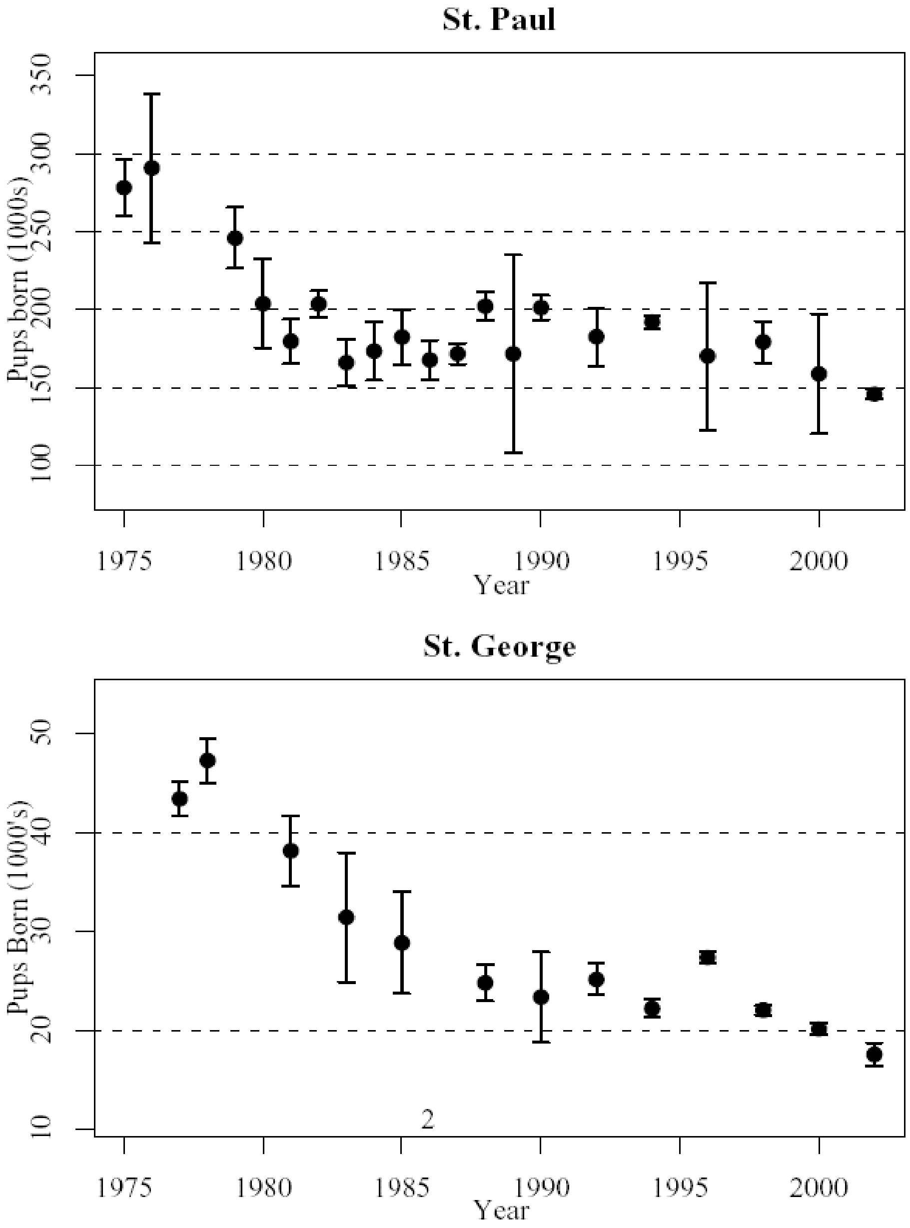

Figure 2. Northern fur seal pups born on the Pribilof Islands, 1975 - 2002. Error bars are approximate 95% confidence intervals.

Table 3. Numbers of northern fur seal, Callorhinus ursinus, pups born on St. Paul Island, AK in 2002. Estimates are shown of numbers alive at the time of shearing (live), counts of dead pups (dead), estimates of pups born, counts of breeding males (HB), estimates of pup mortality rate (%), and the ratio of pups to breeding males (P:HB).

Rookery	**Live**	**Dead**	**Born**	**SE**	**Mortality**	**HB**	**P:HB**
Lukanin	3,212	145	3,375	91.5	4.3	110	30.5
Kitovi	5,314	150	5,464	204.5	2.7	162	33.7
Reef	15,868	544	16,412	1,427	3.3	476	34.5
Gorbatch	11,308	476	11,784	158	4	291	40.5
Ardiguen	1,440	57	1,497	74	3.8	53	28.2
Morjovi	10,473	241	10,714	97	2.2	269	39.8
Vostochni	23,778	696	24,474	277.5	2.8	782	31.3
Polovina	2,773	100	2,873	121	3.5	52	55.2
Polovina Cliffs	13,439	277	13,716	367	2	321	42.7
Tolstoi	16,958	709	17,667	458.5	4	354	49.9
Zapadni Reef	5,384	203	5,587	172	3.6	139	40.2
Little Zapadni	12,276	440	12,716	208.5	3.5	217	58.6
Zapadni	18,628	737	19,365	127.5	3.8	441	43.9
Little Polovina	73	2	75	4.2	2.7	2	37.5
Total excluding SLR	140,924	4,777	145,701	1,629.00	3.3	3,669	39.7
Sea Lion Rock	8,098	164	8,262	191	1.9	NA	NA
Total including SLR	149,022	4,941	153,963	1,640.20	3.2	NA	NA

Table 4. Numbers of northern fur seal, Callorhinus ursinus, pups born on St. George Island, AK in 2002. Estimates are shown of numbers alive at the time of shearing (live), counts of dead pups (dead), estimates of pups born, counts of breeding males (HB), estimates of pup mortality rate (%), and the ratio of pups to breeding males (P:HB).

Rookery	**Live**	**Dead**	**Born**	**SE**	**Mortality**	**HB**	**P:HB**
South	3,518	173	3,691	51.5	4.7	212	17.4
North	6,181	167	6,348	18	2.6	306	20.7
East Reef	794	11	805	18.5	1.4	66	12.2
East Cliffs	3,124	82	3,206	42.5	2.6	182	17.6
Staraya Artil	1,161	19	1,180	79	1.6	43	27.4
Zapadni	2,282	81	2,363	244.5	3.4	90	26.3
Total	17,060	533	17,593	526.6	3	899	19.6

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. The NMFS has new genetic information on harbor seals in Alaska which indicates that the current boundaries between Southeast Alaska, Gulf of Alaska, and Bering Sea stocks of harbor seals in Alaska need to be reassessed. Evaluation of this new information and conclusions regarding population trends by stock will be available in 2004. Information provided below reflects the management plan for harbor seals through 2003 (Angliss and Lodge, 2002).

Population – Southeast Alaska

The most comprehensive aerial survey of harbor seals in southeast Alaska was conducted in 1993. The sum of all mean counts was 21,523 with a combined CV = 0.026 (Loughlin, 1994). After an applied correction factor (1.74 ; CV = 0.068) to account for animals in the water missed during aerial surveys (Withrow and Loughlin, 1995), the population estimate is 37,450 (21,523 × 1.74; CV = 0.073) for the Southeast Alaska stock of harbor seals (Table 5). The minimum population estimate (N_{MIN}) for this stock is calculated using Equation 1 from the PBR Guidelines (Wade and Angliss, 1997): $N_{MIN} = N/\exp(0.842\times[\ln(1+[CV(N)]^2)]^{1/2})$. Using the population estimate (N) of 37,450 and its associated CV(N) of 0.073, N_{MIN} for this stock of harbor seals is 35,226.

Population – Gulf of Alaska

Aerial surveys of harbor seals from the Gulf of Alaska stock were conducted during 1994 and 1996. The Aleutian Islands were surveyed from 29 August to 8 September of 1994 (Withrow and Loughlin, 1995). A maximum count of 3,437 is used for an abundance estimate for that region. Between 25 August and 3 September of 1996 the south side of the Alaska Peninsula, Cook Inlet, Kenai Peninsula, Kodiak Archipelago, and Copper River Delta were surveyed. The mean count for the 1996 surveys was 16,013 (CV = 0.025) harbor seals, with the following mean counts for the major survey areas: Copper River Delta 3,174 (CV = 0.078); Prince William Sound 2,245; Kenai Peninsula 713 (CV = 0.072); Cook Inlet 2,244 (CV = 0.105); Kodiak Archipelago 4,437 (CV = 0.035); and the south side of the Alaska Peninsula 3,200 (CV = 0.034) (Withrow and Loughlin, 1997). During summer of 1996, two different aerial surveys covered portions of Prince William Sound resulting in an adjusted mean count of 2,245 (CV = 0.032) harbor seals in Prince William Sound, excluding Columbia Bay. Therefore, for the Gulf of

Alaska stock of harbor seals, the total combined count from the 1994 and 1996 aerial surveys was 19,450 (CV = 0.023) animals.

Using the population estimate (N) of 29,175 and its associated CV(N) of 0.052, N_{MIN} for this stock of harbor seals is 27,917 (Table 5). Including the minimum population estimate for Columbia Bay (1,000 animals) results in an N_{MIN} of 28,917 harbor seals for the Gulf of Alaska stock

Population – Bering Sea

Aerial surveys of harbor seals in the Bering Sea were conducted during 28 August - 10 September, 1995 throughout northern Bristol Bay and along the north side of the Alaska Peninsula (Withrow and Loughlin, 1996) and on Otter Island (one of the Pribilof Islands) from July 2 through August 8. The total mean count for the 1995 surveys was 8,740 (CV = 0.040) harbor seals, with mean counts of 955 (CV = 0.071) for northern Bristol Bay and 7,785 (CV = 0.044) for the north side of the Alaska Peninsula (Withrow and Loughlin 1996a). The maximum count for Otter Island was 202 seals. A correction factor of 1.50 (CV = 0.047) multiplied by aerial survey counts results in an estimated abundance of 13,110 (8,740 × 1.50; CV = 0.062) harbor seals. Adding the Otter Island count to the corrected estimated abundance from the aerial surveys results in an estimated abundance of 13,312 (13,110 + 202) harbor seals for the Bering Sea stock. The minimum population estimate (N_{MIN}) for this stock is calculated using Equation 1 from the PBR Guidelines (Wade and Angliss, 1997): $N_{MIN} = N/\exp(0.842\times[\ln(1+[CV(N)]^2)]^{½})$. Using the population estimate (N) of 13,110 from the aerial surveys and the associated CV(N) of 0.062, results in an estimate of 12,446 harbor seals. Adding the maximum count of 202 seals from the Otter Island survey results in an N_{MIN} of 12,648 for the Bering Sea harbor seal stock.

Population Trends

Results from the Sitka, Ketchikan, and Glacier Bay trend analyses provide a strong indication that the number of harbor seals in Southeast Alaska has been increasing since at least 1983 (Small et al., 1997). Despite some positive signs of growth in certain areas, the overall Gulf of Alaska stock size remains small compared to its size in the 1970s and 1980s. The number of harbor seals in the Bering Sea stock is thought to have declined between the 1980s and 1990s (DeMaster 1996). Specifically, the maximum count on Otter Island in 1995 (202 seals) represents an 83% decline (Withrow and Loughlin, 1996). Further, counts of harbor seals on the north side of the Alaska Peninsula in 1995 were less than 42% of the 1975 counts, representing a decline of 3.5% per year. The number of harbor seals in northern Bristol Bay are also lower, but have remained stable since 1990 (Withrow and Loughlin, 1996).

CETACEA

Distribution and abundance patterns

Coordinated survey efforts conducted in the central eastern Bering Sea and southeastern Bering Sea during the summers of 1999 and 2000 respectively, are the first estimates of cetacean abundance and distribution that can be directly compared between two regions of the eastern Bering Sea (Moore et al., 2002). Prior to these studies, cetacean abundance and distribution information in the Bering Sea has been largely dependent on data from commercial whaling (Springer et al., 1996) and high seas driftnet fishery incidental take records (Hobbs and Jones, 1993). Removals of cetaceans from the North Pacific Ocean and Bering Sea were devastatingly large to the species of direct take (Miyashita et al., 1995), especially between 1835 and 1850 for North Pacific right whales (*Eubalaena japonica*) (Webb, 1988), between 1965 and 1979 for fin (*Balaenoptera physalu*s) and humpback whales (*Megaptera novaeanglia*e) (Wada, 1981), and during the 1980s for Dall's porpoise (*Phocoenoides dall*i) and pelagic dolphins (Hobbs and Jones, 1993). The indirect effects of such large scale removals on the marine ecosystem are largely unknown (Moore et al., 2002).

Based on 3,955 miles of visual line-transect surveys (Moore et al., 2002) fin whales occurred in greater numbers in the central eastern Bering Sea, differences in minke whale *(B. acutorostrat*a) and Dall’s porpoise abundance was negligible, and harbor porpoise *(Phocoena phocoen*a) were more common in the southeastern Bering Sea. Overall, fin whales were the most common large whales, and Dall’s porpoise the most common small cetacean in both regions surveyed. Uncorrected abundance estimates in the central eastern Bering Sea were: 3368 (CV= 0.29) fin whales, 810 (CV= 0.36) minke whales, 14,312 (CV= 0.26) Dall’s porpoise, and 693 (CV= 0.53) harbor porpoise. Abundance estimates in the southeastern Bering Sea were: 683 (CV= 0.32) fin whales, 102 (CV= 0.50) humpback whales), 1003 (CV= 0.26) minke whales, 9807 (CV= 0.20) Dall’s porpoise, and 1958 (CV= 0.21) harbor porpoise (Moore et al., 2002).

Distributions of some species were associated with bathymetric features of the continental shelf (Moore et al., 2002). Humpback whales were seen on the Middle Shelf, near the 50-m contour where the Inner Front often develops. In the central eastern Bering Sea fin whales occurred primarily on the Outer Shelf along the 200 m isobath, compared to the southeastern Bering Sea where fin whales occurred on the Middle Shelf (50–100 m) and on the Outer Shelf (100–200 m) near the Pribilof Canyon. Distribution and abundance estimates provided in these surveys indicate that baleen whales are re-occupying productive hydrographic zones in patterns similar to those depicted in summaries (Springer et al., 1999) of commercial whaling harvests (Moore et al., 2002). Commercial whaling records of catch reflect hydrographic patterns associated with abundance of zooplankton and forage fish (Nasu, 1974). Like planktivorous seabirds, baleen whales reflect oceanographic structure in the eastern Bering Sea and are generally good indicators of oceanographic productivity (Moore et al., 2002), since in order to feed efficiently, both birds and cetaceans (Croll et al., 1998; Piatt & Methven, 1992) need to find dense and predictable aggregations of prey which are strongly associated with water masses in the eastern Bering Sea (Hunt, 1997; Hunt et al., 1998).

Moore et al. (2002) conclude that in the Bering Sea, in recent years, that fin whales and Dall’s porpoise are responding to the comparatively high productivity of the shelf break and that minke whales, Dall's porpoise, and harbor porpoise are finding predictable aggregations of prey in the shallow Coastal Domain of the continental shelf.

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. The ecological significance of the incidental take of individual animals is not measureable. Interpretation of the significance is therefore limited to an accounting of the number of animals killed (Table 5), and subsequent population level responses. Based on counts of animals reported taken incidentally in fisheries in 2002, none of the marine mammal incidental mortality estimates for Alaskan groundfish fisheries exceed the PBRs (Hill and DeMaster, 1999) and are not expected to have direct, large ecosystem consequences.

Resource Competition - There is overlap in the species and size of primary prey consumed by marine mammals and targeted in commercial fisheries (Figure 3). 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 for resources may include walleye pollock (*Theragra chalcogramma*), Atka mackerel (*Pleurogrammus monopterygius*), salmon, and Pacific cod (*Gadus macrocephalus*) (Calkins and Pitcher, 1982; Sinclair and Zeppelin, 2002; Zeppelin et al., submitted). 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. Diet studies conducted since the early pelagic collections of 1958-1974 (Sinclair *et al*., 1994; Sinclair *et al*., 1996; Antonelis *et al*., 1997), indicate that groundfish consumption has increased as forage fishes have decreased (Sinclair *et al*., 1994; 1996) in fur seal diet. Some prey items, such as capelin, have disappeared from fur seal diets in the eastern Bering Sea and squid consumption has been markedly reduced. At the same time, pollock consumption has doubled from occurrences of 34%, while scat data indicate that the age and size of pollock eaten by adult female fur seals has decreased from predominantly adult-sized fish to age-0 and age-1 juveniles (Sinclair et al., 1994). Trites (1992) estimated that 133,000 mt of walleye pollock (ages 1 to 2) are consumed annually by northern fur seals in the eastern Bering Sea. Commercial fisheries exploit pollock that are mostly age 3 and older. Recent stable isotope work indicates the possibility that female northern fur seals may be consuming 2-4 year old pollock during summer in the eastern Bering Sea, although fasting during lactation may be responsible for the increase in nitrogen enrichment seen (Kurle and Worthy 2001).

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. Both adult and juvenile Steller sea lions forage in areas designated as critical habitat in the Bering Sea and Aleutian Islands where almost 70% of the pollock trawl fishery (total pollock catch from critical habitat of almost 850,000 mt) occurred as recently as 1995 (Fritz and Ferrero, 1998).

Most of this critical habitat catch of pollock occurred during the roe fishery in January-March (45% of the annual total), when 80% or more of the harvest often came from these sensitive areas. However, since 1999, catches of pollock from eastern Bering Sea critical habitat have been capped by season, and the Aleutian Islands critical habitat has been closed to the pollock fishery, as part of the Revised Final Reasonable and Prudent Alternatives (RFRPA) to mitigate jeopardy and adverse modification (NMFS, 2001). In addition, the NPFMC closed all of the AI region to the pollock fishery up through 2003. This has had the result of reducing the annual percentage removals from BSAI critical habitat to less than 40% and the catch to approximately 350,000 mt. These actions have not entirely eliminated competition for prey between pollock fisheries and Steller sea lions in critical habitats, but may have reduced them.

Indirect Competition - More difficult to identify and potentially more serious are interactions resulting indirectly, from competition for secondary prey resources and the influence of fisheries on marine mammal and prey habitat. Such interactions may limit foraging success through localized depletion, destabilization of prey assemblages, 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. The relative impact of fisheries perturbations compared to broad, regional events such as climatic shifts is uncertain, but given the potential importance of localized prey availability for foraging marine mammals, they warrant close consideration. 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. Captive studies have shown that Steller sea lions obtain a larger portion of ingested energy from numerous small meals than from fewer large ones, suggesting that prey distribution is an important factor in sea lion nutrition (Rosen and Trites, 1997). Sinclair and Zeppelin (2002) demonstrated that, among the Western Stock of Steller sea lions, diet diversity was highest where the population trends were most stable.

Such a case for concern over possible localized depletion has been identified for Steller sea lions and the Atka mackerel fishery in the western and central Aleutian Islands. Atka mackerel are a major item in the diet of Steller sea lions in the central and western Aleutian Islands. The Atka mackerel fishery is concentrated in several compressed locations, most of which are adjacent to Steller sea lion haulouts and rookeries, inside critical habitat. Evidence of Atka mackerel localized depletion has been presented by Lowe and Fritz (1997) based on reductions in catch per unit effort (CPUE) of Atka mackerel over the course of the fishing season. The potential for impacts to Steller sea lion recovery efforts was recognized by NMFS and the NPFMC, warranting action to move fishing effort away from sea lion critical habitat beginning in 1999. Spatial as well as temporal Atka mackerel fishery dispersion measures enacted in 1999 consisted of a 4-year time schedule for reducing to 40% the proportion of Atka mackerel catch taken from critical habitat, as well as splitting the annual TAC into two seasons (beginning in January and September). These actions both reduced the catches from critical habitat and the likelihood of creating localized depletions of sea lion prey.

Disturbance from either vessel traffic or fishing activities may also be a disadvantage to marine mammals. Vessel traffic alone may temporarily cause fish to compress into tighter, deeper schools (Freon et al., 1992) or split schools into smaller concentrations (Laevastu and Favorite, 1988). Hydroacoustic observation of the effects of trawling on Pacific whiting school structure in Puget Sound, Washington suggest that while the school deforms and has a "hole" in it due to the removal of fish and their avoidance of the gear, its structure returns relatively quickly (on the order of 10 minutes) to a pre-trawling condition (Nunnallee, 1991). Preliminary results on the effects of the noise produced by a single vessel (no trawl in the water) on pollock school structure suggests that the fish may move down and to either side of the vessel, but return to the undisturbed structure within minutes of the vessel passage (C. Wilson, NMFS, AFSC, personal communication). Neither study, however, documents the effects of repeated trawling by many vessels over several days or weeks on fish school structure, nor the possible impact on prey availability to Steller sea lions.

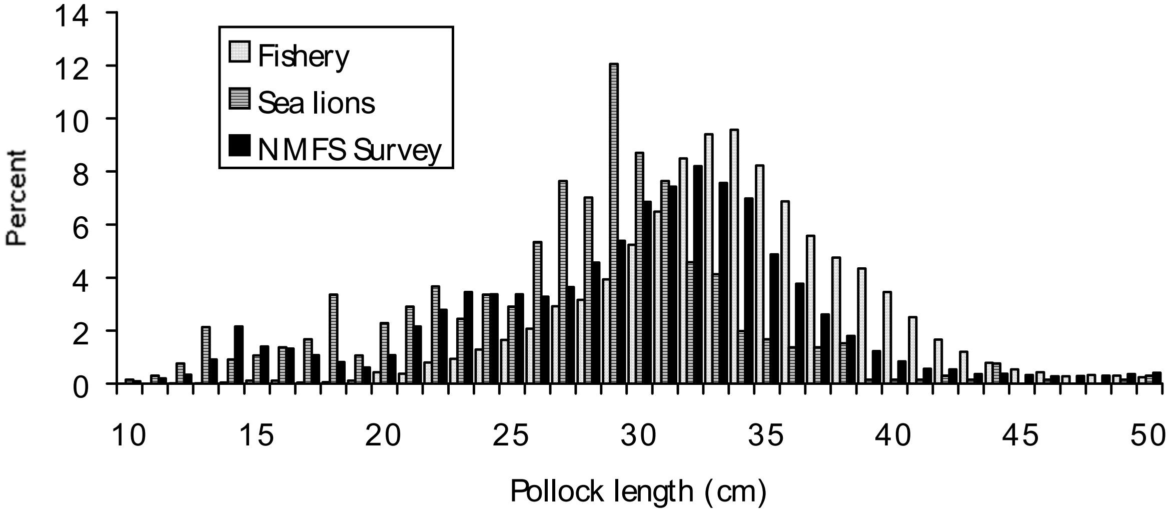

Figure 3.-- Overlap in selection of pollock by NMFS surveys, commercial harvest, and Steller sea lions from area 521 in the Bering Sea in spring and summer 1981.

Environmental and climatic change - From December 1976 to May 1977, an intense Aleutian Low was observed over the BSAI, and GOA. During this period, most of the North Pacific Ocean was dominated by this low pressure system, which signaled a change in the climatic regime of the BSAI, and GOA (NRC, 1996). The system shifted from a "cold" regime to a "warm" regime that persisted for several years. Since 1983, the GOA and Bering Sea have undergone different temperature changes. Sea surface temperatures in the GOA were generally above normal and those in the Bering Sea were below normal. The temperature differences between the two bodies of water have jumped from about 1.1° C to about 1.9° C. Recent evidence now indicates that another regime shift occurred in the North Pacific in 1989 (NRC, 1996).

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. Fish productivity of the Bering Sea was high from 1947 to 1976, reached a peak in 1966, and declined from 1966 to 1997. Some authors suggest that the regime shift changed the composition of the fish community and 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) propose 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) hypothesize 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, which contained 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 5 Stock summary table. Stock assessment reports for marine mammals in Alaska, including estimates of fishery mortality and native subsistence harvest levels, last updated in 2002. Fishery mortality expressed as an annual average for the time period 1998-2002.

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	see txt	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	435	0.23			0.23	360	0.02	0.3	2.2	0	0	S
Bowhead whale	W. Arctic	8,200	0.069			0.069	7,738	0.02	0.5	77	0.2	52	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	42	0	NS
Fin whale	NE Pacific						n/a	0.02	0.1	n/a	0	0	S
Gray whale	E. N. Pacific	26,635	0.101			0.1006	24,477	0.0235	1	575	8.9	97	NS
Harbor Porpoise	SE Alaska	10,508	0.207	2.96	0.18	0.274	8,376	0.02	0.5	83	3*	0	NS
Harbor porpoise	Gulf of Alaska	21,451	0.252	2.96	0.18	0.304	16,630	0.02	0.5	166	25	0	NS
Harbor porpoise	Bering Sea	10,946	0.243	3.1	0.171	0.3	8,549	0.02	0.5	86	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	see txt	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	0.6	0	S
Humpback whale	Cent.N. Pacific	4,005	0.095			0.095	3,698	0.02	0.1	7.4	4.1	0	S
Killer whale	E. N. Pacific N. resident	723	n/a			see txt	723	0.02	0.5	7.2	1.4	0	NS
Killer whale	E. N. Pacific transient	346	1				346	0.04	0	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	941,756		4.48	n/a	0.2	797,112	0.043	0.5	17,138	15	1,495	S
Pacific white-sided dolphin	Cent.N. Pacific	26,880					26,880	0.02	0.5	269	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	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	0.8	1,396	3.4**	0	S
Steller sea lion	W.U. S.	34,595					34,595	0.06	0.1	208	29.5	167.5	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 reported take by fishery observers; however, observer coverage was minimal or nonexistent.
** = this does not include intentional take in British Columbia

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Seabirds

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The 2003 section on seabirds provides updates 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). As we move towards providing updates from previous years and annual trend data, we hope to revise those sections periodically and collaborate with subject matter experts to make data from annual field operations readily available for use in ecosystem considerations.

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 reducing seabird incidental catch (bycatch) in commercial fisheries, and to support its sister agencies in work that helps to promote the conservation and understanding of this important marine resource.

General Life History

Seabirds spend the majority of their life at sea rather than on land. The group includes the albatrosses, shearwaters, and petrels (Procellariiformes), cormorants (Pelecaniformes), and two families of the Charadriiformes: gulls (Laridae), and auks, such as, murres, murrelets, auklets, and puffins (Alcidae). Several species of sea ducks also spend much of their life in marine waters. Other bird groups contain pelagic members such as swimming shorebirds (Scolopacidae), but they seldom interact with groundfish fisheries and, therefore, will not be discussed further. Thirty-eight species breed in Alaska and at least five additional species breed elsewhere but return regularly to Alaskan waters to feed, typically during the summer months.

Seabirds are a broad grouping whose members exhibit different breeding, foraging, and other life history strategies. Diets range from zooplankton to forage fish, invertebrates, and offal from commercial fishing vessels. Breeding may occur in isolated nests or in large colonies that can include millions of birds. Age at first breeding ranges from 1 year after birth to 5 or more years. Basic information on seabird life histories, population biology, and foraging ecology is provided in the draft Programmatic SEIS on Alaska Groundfish Fisheries (NMFS 2003).

Distribution

Seabirds are distributed throughout the Bering Sea and North Pacific marine ecosystems. During most of the year they are widely distributed throughout the marine environment. During the breeding season, breeding pairs occupy nest areas and colonies, but continue to forage at sea. Migrants, juveniles, and adult non-breeding birds occupy the pelagic marine environment while breeding birds nest in burrows, rocky cliffs, in rock crevices, and in open nests on the ground.

Pelagic

Little directed work was conducted throughout the 1990's on the at-sea distribution of seabirds in pelagic waters of the Bering Sea and Gulf of Alaska. Most of the pelagic work was conducted in the 1970's and 1980's as part of the Outer Continental Shelf Ecosystem Assessment Program (OCSEAP). Updating these surveys is necessary to examine current seabird distribution at sea relative to fisheries. During the 1990's, survey effort by the USFWS and USGS was focused on inshore and inside waters, including Southeast Alaska, Yakutat, Prince William Sound, Cook Inlet, and the Kodiak Archipelago. These surveys provided information on the temporal and spatial patterns of birds away from the colonies. Ultimately, they will enable scientists to examine changes in seabird distribution and abundance in response to natural variation in the environment and commercial fishing operations.

Groundwork has been laid to facilitate implementation of pelagic seabird surveys again so that research, conservation, and fishery management issues can be addressed. An important development is the creation of the North Pacific Pelagic Seabird Database (NPPSD) by the USGS-BRD and USFWS so that various survey data can be archived, managed, and made accessible to many end-users. While current efforts are focusing on populating this database with earlier surveys, the structure will facilitate integration of new survey data. In the 2002 Ecosystem Chapter, the NPPSD was used to illustrate areas of overlap between seabird occurrence and fishing effort. This exercise had to assume that seabird distribution in 1998-2000 was generally similar to what it was during the pre-1990 surveys, because there was no seabird data current with that of the fishery effort data (NPFMC 2002).

Washington Sea Grant also promoted the initiation of stationary surveys in 2002 that took advantage of existing longline surveys conducted by the International Pacific Halibut Commission (IPHC), the NMFS-AFSC, and the Alaska Department of Fish and Game (ADFG). Counts of seabird abundance were performed after each set was brought aboard and within a standardized area astern. Currently, data collected in 2002 and 2003 are being analyzed by the IPHC and Washington Sea Grant through a Letter of Understanding. The 2002 NMFS-AFSC survey data have been made available to the IPHC and Washington Sea Grant. Results of the 2002 surveys are expected to be available in fall, 2003.

Colonies

The sizes of seabird colonies and their species composition differ among geographic regions of Alaska (Figure 1), due to differences in marine habitats and shoreline features (Stephensen and Irons, *in press*). 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 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 BS. Relatively few colonies are located along the mainland of the BS coast, and colonies along the Chukchi and Beaufort seas are small and dispersed.

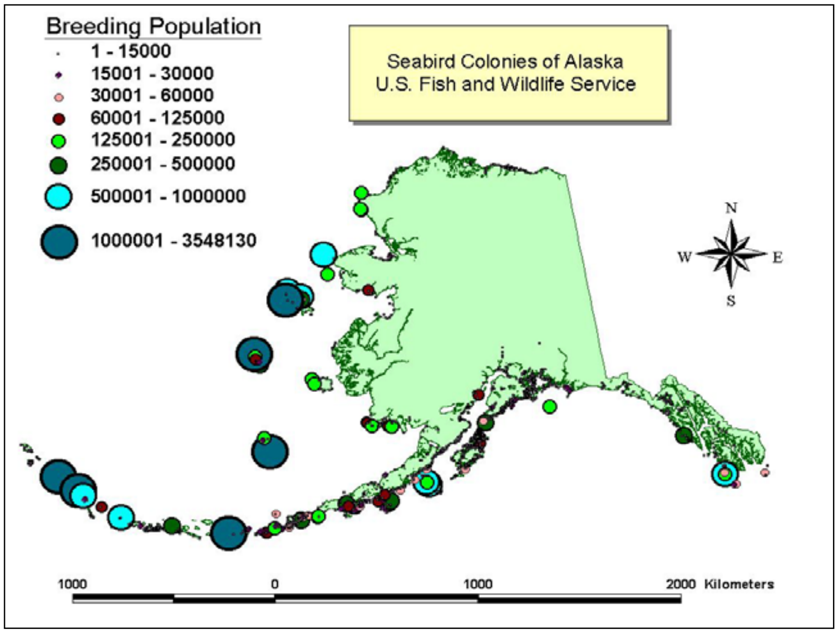

Figure 1. Seabird Colonies of Alaska. Beringian Seabird Colony Catalog, 2002. USFWS.

Abundance and Productivity

Breeding populations are estimated to contain 36 million individuals in the Bering Sea (BS) and 12 million individuals in the Gulf of Alaska (GOA) (Table 1); 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 (Table 2). 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, *in press*).

Although the number of birds is nearly three times greater in the EBS, because of the smaller body sizes of the most abundant species there, total biomass in the EBS is only 1.85 times that of the GOA. Planktivorous seabirds (primarily auklets and storm-petrels) are five times as abundant in the EBS as in the GOA. Fish-eating (piscivorous) birds are also more abundant in the EBS, but only 1.6 times more so than in the GOA (Stephensen and Irons, *in press*). The higher biomass in the EBS reflects the presence of high zooplankton concentrations (Stabeno *et al.* 2003), greater fish abundance (NMFS 2002a, 2002b), and possibly the distribution of suitable nesting habitats (Stephensen and Irons, *in press*).

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

Species	Population[1,2]		Diet[3,4]
	BSAI	GOA	
Northern Fulmar (*Fulmarus glacialis*)	1.500,000	600,000	Q,M,P, S,F,Z,I,C
Fork-tailed Storm-Petrel (*Oceanodroma furcata*)	4,500,000	1,200,000	Q,I,Z,C,P,F
Leach's Storm-Petrel (*Oceanodroma leucorrhoa*)	4,500,000	1,500,000	Z,Q,F,I
Double-crested Cormorant (*Phalacrocorax auritis*)[5]	9,000	8,000	F,I
Pelagic Cormorant (*Phalacrocorax pelagicus*)	80,000	70,000	S,C,P,H,F,I
Red-faced Cormorant (*Phalacrocorax urile*)	90,000	40,000	C,S,H,F,I
Brandt's Cormorant (*Phalacrocorax penicillatus*)	0	Rare	H,F,G,I
Pomarine Jaeger (*Stercorarius pomarinus*)	Uncommon-Rare	Uncommon	C,S,F
Parasitic Jaeger (*Stercorarius parasiticus*)	Uncommon	Uncommon	C,S,F
Long-tailed Jaeger (*Stercorarius longicaudus*)	Uncommon	Rare	C,S,F
Bonaparte's Gull (*Larus philadelphia*)	Rare	Uncommon	Z,I,F
Mew Gull (*Larus canus*) [5]	700	40,000	C,S,I,D,Z
Herring Gull (*Larus argentatus*) [5]	50	300	C,S,H,F,I,D
Glaucous-winged Gull (*Larus glaucescens*)	150,000	300,000	C,S,H,F,I,D
Glaucous Gull (*Larus hyperboreus*)[5]	30,000	2,000	C,S,H,I,D
Black-legged Kittiwake (*Rissa tridactyla*)	800,000	1,000,000	C,S,H,P,F,M,Z
Red-legged Kittiwake (*Rissa brevirostris*)	150,000	0	M,C,S,Z,P,F
Sabine's Gull (*Xema sabini*)	Uncommon	Uncommon	F,Q,Z
Arctic Tern (*Sterna paradisaea*) [5]	7,000	20,000	C,S,Z,F,H
Aleutian Tern (*Sterna aleutica*)	9,000	25,000	C,S,Z,F
Common Murre (*Uria aalge*)	3,000,000	2,000,000	C,S,H,G,F,Z
Thick-billed Murre (*Uria lomvia*)	5,000,000	200,000	C,S,P,Q,Z,M,F,I
Pigeon Guillemot (*Cepphus columba*)	100,000	100,000	S,C,F,H,P,I,G,Q
Black Guillemot (*Cepphus grylle*)	Rare	0	S,F,I
Marbled Murrelet (*Brachyramphus marmoratus*)	Uncommon	Common	C,S,H,P,F,G,Z,I
Kittlitz'sMurrelet (*Brachyramphus brevirostris*)	Uncommon	Uncommon	S,C,H,Z,I,P,F
Ancient Murrelet (*Synthliboramphus antiquus*)	200,000	600,000	Z,F,C,S,P,I
Cassin's Auklet (*Ptychoramphus aleuticus*)	250,000	750,000	Z,Q,I,S,F
Least Auklet (*Aethia pusilla*)	9,000,000	50	Z
Parakeet Auklet (*Cyclorrhynchus psittacula*)	800,000	150,000	F,I,S,P,Z,C,H
Whiskered Auklet (*Aethia pygmaea*)	30,000	0	Z
Crested Auklet (*Aethia cristatella*)	3,000,000	50,000	Z,I
Rhinoceros Auklet (*Cerorhinca monocerata*)	50	200,000	C,S,H,A,F
Tufted Puffin (*Fratercula cirrhata*)	2,500,000	1,500,000	C,S,P,H,F,Q,Z,I
Horned Puffin (*Fratercula corniculata*)	500,000	1,500,000	C,S,P,H, F,Q,Z,I
Total	36,000,000	12,000,000	

1 = Source of population data for colonial seabirds that breed in coastal colonies: modified from USFWS 1998. Estimates are minima, especially for storm-petrels, auklets, and puffins.

2 = Numerical estimates are not available for species that do not breed in coastal colonies. Approximate numbers: abundant $\geq 10^6$; common = 10^5-10^6; uncommon = 10^3-10^5; rare $\leq 10^3$.

3 = Abbreviations of diet components: M, Myctophid; P, walleye pollock; G, other gadids; C, capelin; S, sandlance; H, herring; A, Pacific saury; F, other fish; Q, squid; Z, zooplankton; I, other invertebrates; D, detritus; ?: no information for Alaska. Diet components are listed in approximate order of importance. However, diets depend on availability and usually are dominated by one or a few items (see NPFMC 2000).

4 = Sources of diet data: see species accounts in seabird section of NPFMC 2000.

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

Table 2. Comparative population estimates and diets of nonbreeding seabirds that frequent the Bering Sea and Aleutian Islands and Gulf of Alaska regions.

Species	Population [1,2]			Diet [3,4]
	BSAI	GOA	World[5]	
Short-tailed Albatross (*Phoebastria albatrus*)	Rare	Rare	1,600	Q,F,I
Black-footed Albatross (*Phoebastria nigripes*)	Uncommon	Common	250,000	Q,M,F,I,D
Laysan Albatross (*Phoebastria immutabilis*)	Common	Common	2.5 million	Q,M,F,I
Sooty Shearwater (*Puffinus griseus*)	Common	Abundant	>30 million	M,C,S,A,Q,S,F,Z,I
Short-tailed Shearwater (*Puffinus tenuirostris*)	Abundant	Common	23 million	Z,I, C,Q, F,S
Ivory Gull (*Pagophila eburnea*)	Uncommon	0	~35,000	M,P,R,I,F,Q

1. Source of population data for colonial seabirds that breed in coastal colonies: modified from USFWS 1998. Estimates are minima.
2. Numerical estimates are not available for species that do not breed in coastal colonies. Approximate numbers: abundant $\geq 10^6$; common = 10^5-10^6; uncommon = 10^3-10^5; rare $\leq 10^3$.
3. Abbreviations of diet components: M, Myctophid; P, walleye pollock; G, other gadids; C, capelin; S, sandlance; H, herring; A, Pacific saury; F, other fish; Q, squid; Z, zooplankton; I, other invertebrates; D, detritus; ?, no information for Alaska. Diet components are listed in approximate order of importance. However, diets depend on availability and are usually dominated by one or a few items (see text seabird section of NPFMC 2000).
4. Sources of diet data: see species accounts in text.
5. World population estimates are provided solely to provide a relative scale. In populations where multiple breeding colonies exist, any analysis of effects on populations must be considered at the colony level, not at the global level. These estimates provided by: Hasegawa, pers. comm.; Whittow, 1993; C. Baduini, pers. comm.; Oka et al. 1987; USFWS.

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, *in press*). 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 (Kuletz and Rivera 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 Tables 3 - 5 (reprinted with permission from Dragoo *et al.* 2003), with a focus on broad regional trends, using each species x site as a sample (Figures 2 – 4).

Overall, breeding chronology (Table 3; Figure 2) was early or typical 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 (Table 4; Figure 3) 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. 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 (Table 5; Figure 4) 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 (Table 5; Dragoo *et al.* 2003). Regionally, declining seabird populations were most prevalent in the SEBS (which includes the Pribilof Islands) and GOA (Figure 4). 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.

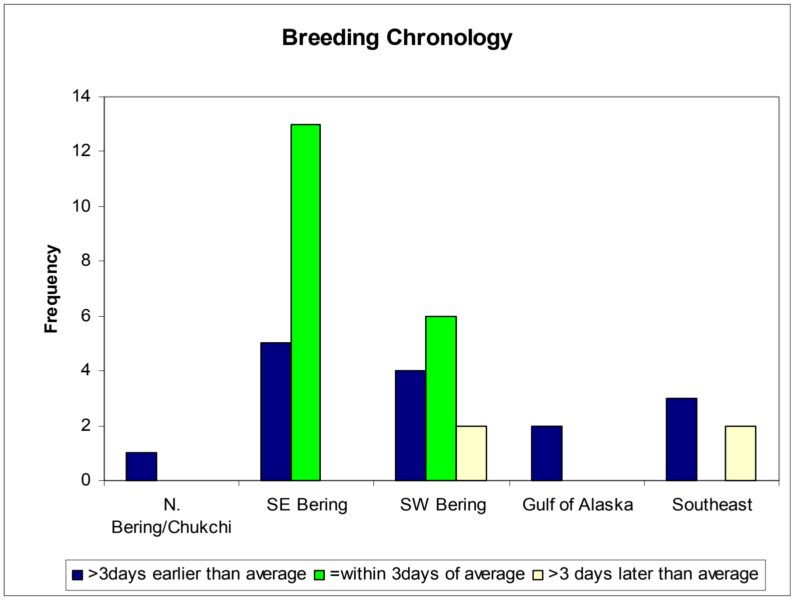

Figure 2. Seabird breeding chronology for species monitored at selected colonies in Alaska in summer 2001. Frequency is the number of samples (species x site) for each region, showing earlier than average, average, or later than average dates for breeding. Chronology usually used hatch dates. Data are from Table 3, which is reprinted from Dragoo *et al.* 2003.

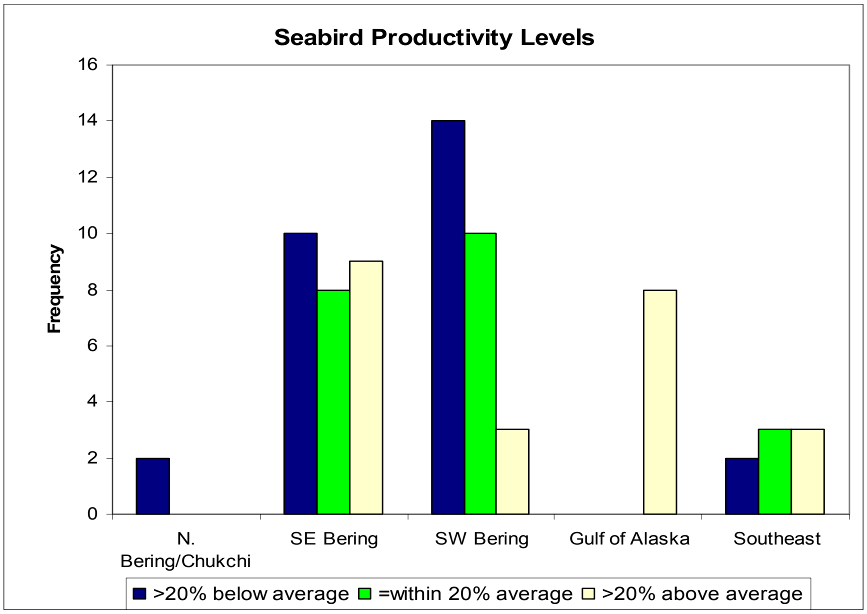

Figure 3. Seabird breeding success for species monitored at selected colonies in Alaska in summer 2001. Frequency is the number of samples (species x site) for each region, showing below average, average, or above average productivity rates. Productivity was usually expressed as chicks fledged per egg (but see individual reports referenced in Dragoo *et al.* 2003 for variants). Data are from Table 4, which is reprinted from Dragoo *et al.* 2003.

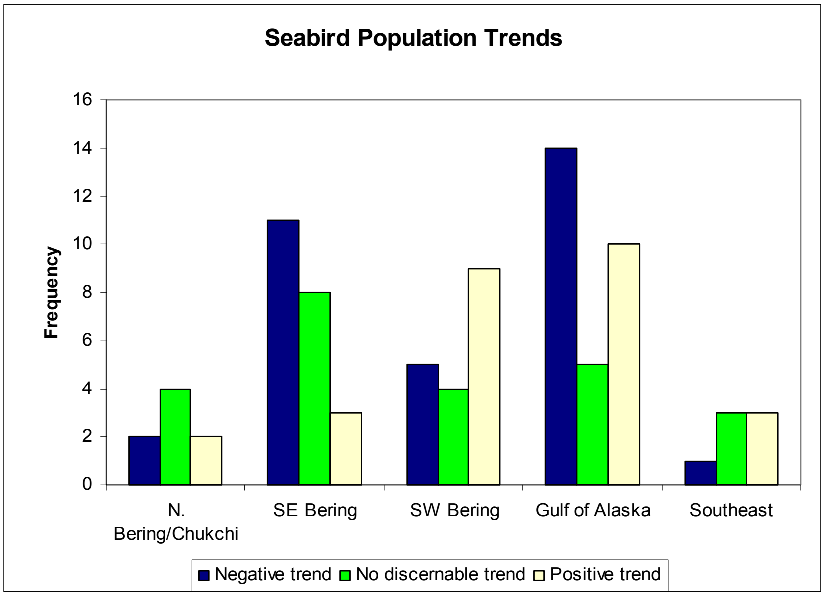

Figure 4. Seabird population trends for species monitored at selected colonies in Alaska in summer 2001. Frequency is the number of samples (species x site) for each region, showing negative trends, no statistically significant trend, or positive trends in population, derived from exponential regression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

Table 3. Seabird relative breeding chronology compared to averages for past years within regions[a]. Only sites for which there were data from 2001 are included. This table is printed with permission of the Alaska Maritime National Wildlife Refuge, from their report: Breeding Status and Population Trends of Seabird in Alaska in 2001 (Dragoo et al. 2003).

Region	Site	FTSP	LHSP	PECO	GWGU	BLKI	RLKI	COMU	TBMU	AMNU	PAAU	LEAU	WHAU	CRAU	HOPU	TUPU
N. Bering/ Chukchi	Bluff							–								
SE Bering	St. Paul I.					–	–	=	=							
	St. George I.					–	–	=	=							
	C. Peirce			=		=		=								
	Aiktak I.	=	=		–			=	=	=						=
SW Bering	Buldir I.					–	–	–	=		–	=	=	=	+	+
	Kasatochi I.											=		=		
Gulf of Alaska	Puale Bay							–	–							
Southeast	St. Lazaria I.	+	+		–			–	–							

[a] Codes:

"– " indicates hatching chronology was > 3 days earlier than average for this site or region,
"=" indicates within 3 days of average
"+" indicates hatching chronology was > 3 days later than average for this site or region.

Table 4. Seabird relative productivity levels compared to averages for past years within regions[a]. Only sites for which there were data from 2001 are included. Printed with permission from: Breeding Status and Population Trends of Seabird in Alaska in 2001 (Dragoo et al. 2003).

Region	Site	FTSP	LHSP	RFCO	PECO	GWGU	BLKI	RLKI	COMU	TBMU	ANMU	PAAU	LEAU	WHAU	CRAU	RHAU	HOPU	TUPU
N. Bering/ Chukchi	C. Lisburne						–											
	Bluff						–											
SE Bering	St. Paul I.			+			–	–	+	=								
	St. George I.			–			–	–	=	=								
	C. Peirce				=		–		–									
	Round I.				+		–		–									
	Bogoslof I.						=	–										
	Aiktak I.	+	+	+	+	=			=	+	=							+
SW Bering	Buldir I.	=	=		=	–	–	–	=	–		–	=	–	=		+	=
	Kiska I.						–						–		–			
	Ulak I.	=		+	+													
	Kasatochi I.			=	–				–	–			=		–			
	Koniuji I.						–											
Gulf of Alaska	Puale Bay			+					+	+								
	Chiniak Bay			+	+		+											
	E. Amatuli I.						+											
	Pr. Will. Snd.						+											
	Middleton I.															=		
Southeast	St. Lazaria I.	=	–		=	+			+	+						=		–

[a] Codes:
"– " indicates productivity was > 20% below average for this site or region,
"=" indicates within 20% of average
"+" indicates productivity was > 20% above average for this site or region.

Table 5. Seabird population trends compared within regions[a]. Printed with permission from (Dragoo et al. 2003).

Region	Site	NOFU	STPE	RFCO	PECO	UNCO	GWGU	BLKI	RLKI	COMU	TBMU	UNMU	PIGU	LEAU	CRAU	RHAU	TUPU
N. Bering/ Chukchi	C. Lisburne							=				+					
	C. Thompson							=				–					
	Bluff							=		+							
	Hall I.									=	–						
SE Bering	St. Paul I.	=						–	–	–	–						
	St. George I.	=						–	–	=	=						
	C. Newenham							=		–							
	C. Peirce				=			–		–							
	Bogoslof I.																+
	Aiktak I.		+			–	=					=	–				+
SW Bering	Nizki I.																+
	Buldir I.		=		–		–	+	+		+		–				+
	Adak I.																+
	Ulak I.											=					
	Kasatochi I.					+	=							–	+		
	Koniuji I							=	–			+					
Gulf of Alaska	Semidi Is.			–	–												
	Chowiet I.	=						–				+					
	Puale Bay						=	–				–					
	Chiniak Bay			–	–			+									
	Nord I.									=							
	E. Amatuli I.		+				+	+		+							=
	Gull I.				–			+		+							
	Chisik/Duck Is.							–		–							
	Chiswell Is.									=							
	P. William Snd							+									–
	Middleton I.				–		+	–				–					
Southeast	St. Lazaria I.		+		+		=					–	+			=	=

[a]Codes:
"– " indicates negative population trend for this site or region,
"=" indicates no discernable trend
"+" indicates positive population trend for this site or region.

Ecosystem Factors Affecting Seabirds

Food Availability

A detailed discussion on seabird diets and biomass consumption in Alaska was presented in the 2002 Ecosystem chapter (Kuletz and Rivera 2002). Stephensen and Irons (*in press*) further integrated current data from the Beringian Seabird Colony Catalog (USFWS 2003) and Hunt *et al*. (2000) to examine daily energy needs of seabirds by feeding guild and region (Table 6).

Table 6. Seabird population, biomass, and daily energy needed in the eastern Bering Sea (EBS) and Gulf of Alaska (GOA) for piscivores and planktivores (Hunt et al. 2000, USFWS 2003). Reprinted with permission from Stephensen and Irons*, in press*.

	Seabird Population		**Seabird Biomass (kg)**		**Daily Energy Needs (kj)***	
Guild	**EBS**	**GOA**	**EBS**	**GOA**	**EBS**	**GOA**
Piscivorous	7,123,044	4,625,126	5,772,574	3,460,912	10,526,987,272	6,441,155,818
Planktivorous	13,747,242	2,531,800	1,570,691	216,686	4,701,704,030	697,737,850
All Species	20,870,286	7,156,926	7,343,265	3,677,598	15,228,691,302	7,138,893,668

* Hunt et al. 2000.

The remainder of this section is a review of seabird diet from the 2002 Ecosystem Chapter. As data are received from field work accomplished in 2003, new information will be provided.

Seabird prey species. – Seabird diets consist mainly of fish or squid less than 15 cm long, large zooplankton, or a combination of both. The fish and invertebrates taken by seabirds varies by season, location and bird species, and can vary between adults and juveniles of the same species in the same location. Most information on seabird diet has been obtained during the breeding season, often from the prey that adults bring to their chicks.

Seabirds use the juvenile age-classes (age-class 0-1) of a variety of commercial fish, including Pacific herring (*Clupea pallasi*), walleye pollock (*Theragra chalcogramma*), Pacific tomcod *(Microgadus proximus*), salmon (*Oncorhynchus* spp.), rockfish (*Sebastes* spp.), lingcod (*Ophiodon elongatus*), smelts (*Osmeridae* spp.), and flatfish (*Pleuronectiformes* spp.). Squid are also a favored prey of many seabird species. Bottom-feeding birds such as scoters, cormorants, and guillemots may also consume juvenile stages of commercial shrimp and crab species. Non-commercial forage fish include juveniles and adults of Pacific sand lance (*Ammodytes hexapterus*), capelin *(Mallotus villosus*) Pacific sandfish (*Trichodon trichodon*), greenlings (Hexagrammidae spp.), and several species of lanternfish, or myctophids (*Myctophidae* spp). Birds that feed near the coast and near the sea floor may also take sculpins, blennies, octopus, molluscs and small crustacea.

Most of the fish used by seabirds are caught in shallow waters (< 100 m; usually < 50 m) or in the upper portions of the water column. Deep-water fish like the myctophids are usually taken at night, when they make their vertical migration to surface waters. Fish that in general have high energetic value to seabirds include the myctophids, herring, sand lance, and capelin, whereas the fish with lower energetic value include pollock and most other bottom-dwelling fish (Van Pelt *et al.* 1997, Anthony *et al.* 2000).

Fishery Interactions

Seabirds interact with fisheries in several ways. Seabirds are incidentally caught and killed by some commercial fisheries. They may compete for the same food resources, or a food resource may be affected indirectly. Also, food resources are provided directly to birds in the form of discards and offal. This section focuses on updating data on the incidental take of seabirds in Alaska groundfish fisheries, as reported in previous years.

Incidental take by fisheries.

Many factors affect the incidental catch of seabirds by commercial fisheries, including sea state, time of day, gear type, daily fishing patterns, attraction to vessels, interannual variation, and the bird's age, sex, or breeding status (Jones and DeGange 1988, Melvin et al. 1999, Ryan and Moloney 1988, Tuck et al. 2001, Melvin et al. 2001). Gear types in Alaskan waters with known seabird bycatch include longline, bottom and pelagic trawl, pot, and gillnet fisheries. There may be some bycatch in purse seine and salmon troll fisheries, but we expect these to be very limited. No data are currently available for the purse seine and troll fisheries. In addition to fishing gear, bird mortalities also result from collisions with vessel's superstructure, rigging, or other gear components such as the sonar transducer cables and trawl warp cables.

This report updates the direct mortality estimates from groundfish longline, trawl, and pot fisheries in Alaskan waters. We do not report on mortalities from the crab (pot), gillnet, halibut longline, or various other fisheries in Alaskan waters. In many cases, these other fisheries are unobserved, so no seabird bycatch data are available. There have been observer programs on several Alaskan salmon gillnet fisheries (Prince William Sound, 1990 – 1991; Cook Inlet, 2000 – 2001), with additional programs planned. Seabird bycatch information was collected during these programs, but are not reported here (data are available from the Protected Resources Division, Alaska Region Office).

In groundfish fisheries off Alaska, longlines have historically accounted for most of the seabird incidental catch. Trawls also take some seabirds, and pots occasionally take diving seabirds. These bycatch numbers are reported below. To simplify reporting, we provide estimates for eleven species or species groups. These are short-tailed albatross, black-footed albatross, Laysan albatross, unidentified albatross, northern fulmars, gulls, shearwaters, unidentified tubenoses (procellarids), alcids (murres, puffins, etc.), other bird species, and unidentified seabirds (those not identified to one of the other ten groups).

Methodologies: Methodologies for estimation of seabird incidental catch have been described previously (Stehn et al., 2001; NPFMC 2002). Several comprehensive reports are being prepared by staff at the Alaska Fisheries Science Center and other researchers that will also provide details on field and analytical methodologies, biases, and catch by time, area, or fishery component. Therefore, only a brief description of methods will be provided here.

Estimates rely on data collected by NMFS-Certified North Pacific groundfish observers (observers). Commercial fishing vessels are required to have observers on board for 100%, 30% or 0% or their fishing days by calendar quarter, depending on vessel size. Some special programs require 100% of the catch to be monitored, which typically requires two observers on board. Observers record total catch, species composition, and biological sampling.

Estimates of seabird incidental catch were based on the number of seabirds, by species, in samples collected by observers from sampled longline, pot, and trawl hauls. Observers also recorded the groundfish catch during the sample period, and the effort (hook or pots) where appropriate. These constitute one source of data necessary for completing an estimate of total bird catch. The other data source is the total commercial fish catch as estimated by the NMFS Blend program, Alaska Region. Estimates of bird mortality were made using either total tons of groundfish catch per haul or set for the trawl fishery, available from the Blend program, or the number of hooks or pots per set for both the longline and pot fisheries (as estimated using average number of hooks or pots expanded up to total catch in the NMFS Blend program). The number of observed birds in a species composition sample was extrapolated to the number of seabirds in the whole haul or set, and similarly upwards to the whole fishery, including the unobserved effort. The methods typically used to estimate seabird bycatch rely primarily on standard statistical procedures such as the separate ratio estimators of stratified random sampling (Cochran 1977). Incidental catch estimates from each stratum were summed to yield total estimates for statistical fishing areas and regions. No estimates were made for those few strata in the NMFS Blend program which consisted only of data from unobserved vessels; in this regard the estimates are conservative.

Both the catch rate of birds (number of birds per weight of fish, or birds per 1,000 hooks) and the catch rate of fish (total weight of all fish species per hook/pot/net) were assumed to be equal for observed and unobserved hauls of the same gear, area, and time period. These assumptions may not hold, not necessarily because the presence of the observer may change the fishing practices of the skipper or crew, but rather because, for some other operational reason, the smaller (unobserved) vessels may have different catch rates than the large or mid-sized vessels. The constant catch rates for birds and/or fish among vessel size categories are untested and critical assumptions. If different catch rates do exist for different vessel size categories, then the average area catch rates and the estimates of the total seabird incidental catch number may be overestimated or underestimated.

Incidental Catch in Longlines: Estimates of the annual seabird incidental catch for the Alaska groundfish fisheries, based on 1993 to 2002 data, indicate that approximately 14,307 seabirds are taken annually in the combined BSAI and GOA groundfish longline fisheries (13,345 in the BSAI; 962 in the GOA) at the average annual rates of 0.08 and 0.03 birds per 1,000 hooks in the BSAI and in the GOA, respectively (Table 7).

Note that a total of 3,835 seabirds were taken in BSAI longline fisheries in 2002 (Table 8). This represents a steady reduction over the last few years, and is a 6-fold decrease from the high of over 24,000 birds taken in 1998. There is a 7-fold reduction in the rate from 0.14 to 0.02 seabirds per 1,000 hooks. A similar pattern occurs in the GOA, where a 6-fold decrease in bycatch has occurred from the high of nearly 1,634 birds in 1996 (Table 9). Bycatch in the GOA has decreased steadily in each of the last 4 years. The reduction in seabird bycatch in the BSAI and GOA could be due to a variety of factors, including the normal inter-annual variation that we have observed previously. Note that in 2002 several components of the longline industry began deploying the seabird avoidance measures recommended by Melvin et al. (2001) and adopted by the North Pacific Fisheries Management Council in December, 2001. These efforts may have contributed substantially to the observed reduction, although no analysis has been completed yet to ascertain how different factors may have contributed to reduced bycatch, and whether we can expect that trend to continue.

NMFS is currently engaged in implementing these measures into regulation, with the hopes that seabird bycatch would be further reduced when the measures are used uniformly throughout the fleet. The measures have been developed to meet safety and logistic requirements that commercial fishermen face while also effectively keeping birds away from the baited hooks while the longline is being set. Additional work is being carried out by the fishing industry, Washington Sea Grant, the FWS, and NMFS with an expectation of further reducing seabird bycatch. This work investigates the use of integrating weight into the groundline itself. If successful, this technique could further reduce seabird incidental take.

Of the estimated annual bycatch of 13,345 seabirds that are incidentally caught in the BSAI, the species composition is: 59 percent fulmars, 20 percent gull species, 12 percent unidentified seabirds, 4 percent albatross species, 3 percent shearwater species, and 2 percent ‘all other’ species (Table 8). Of the estimated 962 seabirds that are incidentally caught in the GOA, the species composition is: 46 percent fulmars, 34 percent albatrosses, 12 percent gull species, 5 percent unidentified seabirds, 2 percent shearwater species, and less than 1 percent ‘all other’ species (Table 9).

It is difficult at this time to make valid comparisons of bird bycatch rates between regions. We cannot discern if the differences between the BSAI and GOA estimated bycatch rates are due to the vastly different levels of fishing effort in each region, the different types of vessels used in each region (‘small’ catcher vessel in GOA, ‘large’ catcher-processor in BSAI), different distribution and abundance of birds, etc. An analysis of covariance would allow for a valid statistical comparison of the regional bycatch rates.

Effects of the incidental catch in longline 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 longline fisheries represents only a portion of the fishing mortality that occurs, particularly with the albatrosses. The endangered short-tailed albatross population is currently increasing, the total population estimated at about 1,700. Mortality of black-footed and Laysan albatrosses occurs in both Alaskan and Hawaiian longline fisheries and may be assumed to occur in other North Pacific longline fisheries conducted by Japan, Taiwan, Korea, Russia, and China (Brothers et al. 1999, Lewison and Crowder 2003).

For the longline bycatch numbers, spectacled eider, Steller's eider, marbled murrelet, and Kittlitz's murrelet were not reported by observers in any observed sample from 1993 to 2002, and red-legged kittiwakes were not reported from 1993 through 2001. One red-legged kittiwake was reported caught by the longline fishery in the Bering Sea in 2002; the estimated take was 5 (1-14) red-legged kittiwakes in 2002 (these takes are included in the "Other" category in the table). None were taken by the GOA longline fishery. Although of these birds only the 2 eider species are listed under ESA in the action area, USFWS identifies the other 3 species as 'species of concern' because of low and/or declining population levels. 'Species of concern' is an informal classification by the USFWS, Office of Migratory Bird Management. Inclusion on the 'species of concern' list has no regulatory implications.

In the NMFS analysis of 1993 to 2002 observer data, only three of the albatrosses taken were identified as short-tailed albatrosses (and all from the BSAI region). Of the albatross taken, not all were identified. This analysis of 1993 to 2002 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 fisheries on the short-tailed albatross is based on the actual reported takes and not on extrapolated estimated takes.

Based on estimates of seabirds observed taken in groundfish fisheries from 1989 to 1993, 85 percent of the total seabird bycatch was caught in the BSAI, and 15 percent in the GOA.

Longline gear accounted for 90 percent of the total seabird bycatch, trawls for 9 percent, and pots 1 percent. (Wohl et al. 1995). NMFS analysis of 1997 to 2002 observer data indicates similar patterns as those seen in the 1989 to 1993 data. Depending on which trawl estimate is used (see below), longline gear accounted for 94 (or 65) percent of the total average annual seabird incidental catch, trawl gear for 6 (or 35) percent and pot gear for less than 1 percent. The higher percentage of trawl incidental catch coincides with the alternate trawl estimation methods as described below (also see table 11). Based on the average annual estimates of seabirds observed taken in groundfish longline fisheries from 1993 to 2002, 93 percent of the longline seabird bycatch was caught in the BSAI, and 7 percent in the GOA (Table 7). Also of note, the bycatch rates in the BSAI are approximately 3 times higher than in the GOA (Table 7).

Table 7. Annual Estimates, by area, of total fishery effort, total numbers and bycatch rates of seabirds taken in longline fisheries.

Year	Effort (No. of Hooks in 1,000s)	Number of Birds	95% Confidence Bounds	Bycatch Rate (Birds per 1,000 Hooks)	Percent of Hooks Observed
Bering Sea and Aleutian Islands					
1993	123,232	7,975	6,981-8,968	0.065	24.5
1994	134,954	10,637	9,608-11,666	0.079	24.5
1995	141,779	19,214	17,853-20,576	0.136	24.2
1996	141,810	8,526	7,641-9,412	0.060	23.8
1997	176,594	18,063	16,491-19,634	0.102	22.6
1998	175,530	24,602	22,779-26,425	0.140	23.5
1999	157,319	12,418	10,950-13,887	0.079	25.0
2000	192,994	18,191	16,599-19,783	0.094	22.8
2001	226,185	9,992	9,027-10,958	0.044	21.0
2002	216,197	3,835	3,328-4,342	0.018	22.5
BSAI Average Annual Estimates					
1998-2002	193,645	13,808	13,201-14,415	0.071	22.8
1993-2002	168,659	13,345	12,941-13,750	0.079	23.2
Gulf of Alaska					
1993	56,300	1,309	1,056-1,563	0.023	10.2
1994	49,452	532	397-668	0.011	4.9
1995	42,357	1,519	1,302-1,736	0.036	12.7
1996	33,195	1,634	1,206-2,062	0.049	10.8
1997	28,047	514	338-689	0.018	10.0
1998	29,399	1,498	795-2,200	0.051	8.1
1999	31,895	1,093	812-1,375	0.034	8.6
2000	35,345	751	402-1,101	0.021	6.5
2001	34,216	512	311-713	0.015	7.8
2002	37,166	259	114-404	0.007	9.3
GOA Average Annual Estimates					
1998-2002	33,604	823	648-997	0.024	8.1
1993-2002	37,737	962	857-1,067	0.025	8.9

Table 8. Estimated total incidental catch of seabirds by species or species groups in Bering Sea and Aleutian Islands longline fisheries, 1993–2002. Values in parentheses are 95% confidence bounds.

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

Year	Actual No. Taken[a]	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tubenoses	Alcid	Other	Unid. ALB	Unid. Seabird	Total
2002	877	0	0	48 (19-77)	701 (582-819)	2,523 (2,040-3,006)	154 (95-213)	17 (5-34)	10 (2-23)	16 (4-32)	5 (1-14)	361 (259-462)	3,835 (3,328-4,342)
Average Annual Estimate													
1998-2002	na	2 (0-4)	10 (4-15)	586 (503-669)	8,107 (7,564-8,650)	3,229 (2,989-3,469)	549 (491-608)	126 (71-181)	15 (8-22)	32 (20-45)	6 (1-10)	1,146 (1,006-1,287)	13,808 (13,201-14,415)
1993-2002	na	1 (0-3)	19 (12-26)	490 (439-541)	7,854 (7,501-8,207)	2,693 (2,536-2,851)	460 (414-507)	164 (126-203)	14 (7-22)	27 (19-35)	57 (39-75)	1,565 (1,433-1,697)	13,345 12,941-13,750

a Actual number taken is the total number of seabirds recorded dead in the observed hauls.
Source: (NMFS observer data; analyzed by Alaska Fisheries Science Center/National Marine Mammal Laboratory, 2002).

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

Table 9. Estimated total incidental catch of seabirds by species or species groups in Gulf of Alaska longline fisheries, 1993–2002. Values in parentheses are 95% confidence bounds. Source: Alaska Fisheries Science Center/National Marine Mammal Laboratory, 2002. See Table 8 for species codes.

Year	Actual No. Taken	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tubenoses	Alcid	Other	Unid. ALB	Unid. Seabird	Total
Gulf of Alaska													
1993	318	0	29 (9-50)	125 (62-187)	833 (615-1,052)	45 (12-77)	59 (18-99)	0	0	3 (1-7)	3 (1-9)	213 (107-318)	1,309 (1,056-1,563)
1994	126	0	7 (2-16)	169 (89-250)	258 (165-351)	30 (2-81)	26 (5-54)	0	0	0	8 (2-18)	33 (8-66)	532 (397-668)
1995	374	0	236 (169-304)	67 (35-99)	520 (348-692)	99 (53-145)	39 (9-69)	6 (1-16)	0	3 (2-6)	376 (275-476)	173 (105-240)	1,519 (1,302-1,736)
1996	250	0	658 (455-860)	154 (90-128)	668 (352-985)	121 6-317)	14 (2-35)	0	0	0	0	19 (3-42)	1,634 (1,206-2,062)
1997	74	0	99 (32-167)	40 (5-109)	307 (164-451)	46 (14-79)	9 (2-21)	0	0	0	0	12 (2-30)	514 (338-689)
1998	184	0	289 (25-596)	217 (56-378)	922 (310-1,533)	53 (14-92)	13 (3-30)	0	0	0	4 (1-12)	0	1,498 (795-2,200)
1999	159	0	183 (70-297)	202 (123-280)	277 (156-399)	358 (136-581)	50 (8-93)	0	0	7 (1-21)	0	16 (4-37)	1,093 (812-1,375)
2000	72	0	148 (62-235)	93 (25-160)	297 (70-524)	179 (15-415)	0	0	0	0	0	34 (2-102)	751 (402-1,101)
2001	45	0	72 (20-124)	67 (6-128)	230 (115-344)	98 (4-244)	20 (1-58)	0	6 (1-18)	0	15 (1-44)	3 (1-9)	512 (311-713)
2002	51	0	33 (10-57)	0	129 (24-238)	83 (17-177)	0	0	0	0	0	14 (3-30)	259 (114-404)
Average Annual Estimate													
1998-2002	na	0	145 (76-214)	116 (75-156)	371 (234-508)	154 (80-229)	16 (4-29)	0	1 (0-4)	1 (0-5)	4 (0-10)	14 (2-28)	823 (648-997)
1993-2002	na	0	176 134-217	113 (88-138)	444 (362-526)	111 (68-154)	23 (14-32)	1 (0-2)	1 (0-2)	1 (0-3)	41 (30-52)	52 (36-67)	962 (857-1,067)

Pot: Seabird mortality from groundfish pot fishing has traditionally been very limited (Table 10). That trend continues, with only 6 birds observed taken in 2002, extrapolating up to an estimated 21 total mortalities. The overall average bycatch in this fishery, 1993 through 2002 is 45 seabirds. Spectacled eider, Steller's eider, marbled murrelet, red-legged kittiwake, and Kittlitz's murrelet were not reported by observers in any observed sample from pot fisheries during 1993 to 2002.

Trawl: On trawl vessels only, observers use either whole haul, partial haul, or basket sampling to record prohibited species bycatch and determine the species composition of the haul. Observers are often required to use 2 sample types in a single haul, in order to best sample for either of these goals. Observers have been instructed to use the largest sample available when monitoring for seabird bycatch. Unfortunately, that has not always occurred. This would not be a problem for estimation purpose, as observers record their sample size for each species, 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 to use when extrapolating from hauls with birds to those without. Thus, it has been necessary to calculate two alternative sets of estimates of seabird bycatch for trawlers based on the smallest (alternative1) and largest (alternative2) sizes of sampling effort recorded for fish species (see “low” and “high” estimates in Table 11). 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. Although, it is not known with certainty which of the 2 sets of estimates is more accurate, the probable level of seabird bycatch on trawl vessels lies somewhere between the 2 sets of estimates. 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.

One red-legged kittiwake was reported caught by the trawl fishery in the Bering Sea in 2001; the estimated take was 1 (low) and 37 (high). One red-legged kittiwake was also reported caught by the trawl fishery in the Bering Sea in 2002; the estimated take was 9 (low) and 124 (high). Each of these takes are included in the "Other" category in the Table 11. Spectacled eider, Steller's eider, marbled murrelet, and Kittlitz's murrelet were not reported by observers in any observed sample from trawl fisheries during 1993 to 2002.

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. 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. We do not currently have estimates on total effort, seabird mortality rates, or overall mortalities from this source. Information will become available as this project is carried out.

Table10. Estimated total incidental catch of seabirds by species or species froups[a] in the combined Bering Sea and Aleutian Islands and Gulf of Alaska pot fisheries, 1993–2002. Values in parentheses are 95% confidence bounds. Source: Alaska Fisheries Science Center/National Marine Mammal Laboratory, 2002. See Table 8 for species codes.

Year	Actual Number Taken [b]	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tubenoses	Alcid	Other	Unid. ALB	Unid. Seabird	Total c
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	6	0	0	0	9 (2-23)	3 (1-10)	7 (1-20)	0	19 (2-55)	0	0	0	39 (6-79)
1996	9	0	0	0	80 (7-174)	0	0	2 (1-6)	0	0	0	7 (1-19)	89 (9-183)
1997	4	0	0	0	14 (3-29)	0	0	0	9 (1-26)	0	0	0	23 (4-46)
1998	2	0	0	0	19 (1-54)	15 (1-44)	0	0	0	0	0	0	33 (2-79)
1999	47	0	0	0	166 (71-261)	0	9 (1-26)	14 (5-28)	0	0	0	0	189 (91-286)
2000	1	0	0	0	0	0	0	0	0	0	0	42 (1-122)	42 (1-22)
2001	3	0	0	0	13 (2-33)	3 (1-8)	0	0	0	0	0	0	16 (3-36)
2002	6	0	0	0	18 (5-34)	0	0	0	0	0	0	3 (0-26)	21 (6-38)
Average Annual Estimate													
1998-2002	na	0	0	0	43 (22-64)	4 (0-10)	2 (0-6)	3 (1-6)	0	0	0	9 (0-26)	60 (32-88)
1993-2002	na	0	0	0	32 (17-46)	2 (0-6)	2 (0-4)	2 (0-4)	3 (0-7)	0	0	5 (0-14)	45 (28-63)

a See the species and species groups notations in the text.

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

Table11. Range of estimates of total incidental catch of seabirds by species or species groups[a] in the combined Bering Sea and Aleutian Islands and Gulf of Alaska trawl fisheries, 1998–2002. Source: Alaska Fisheries Science Center/National Marine Mammal Laboratory, 2002. See Table 8 for species codes.

Year	Actual Number Taken [b]	Estimate Range[c]	STAL	BFAL	LAAL	NOFU	Gull	SHWR	Unid. Tubenoses	Alcid	Other d	Unid. ALB	Unid. Seabird	Total
1998	45	low	0	0	135	96	1,590	856	1	110	3	0	8	2,798
		high	0	0	343	4,012	707	1,353	163	543	2,494	0	1,110	10,725
1999	154	low	0	0	8	858	0	82	0	664	2	0	17	1,630
		high	0	0	27	8,528	0	1,149	0	730	85	0	1,025	11,604
2000	101	low	0	0	0	298	37	10	2	1	0	0	60	407
		high	0	0	0	10,678	114	3,086	155	182	0	0	603	14,969
2001	141	low	0	0	8	323	4	329	9	1	3	0	65	741
		high	0	0	150	10,022	288	887	1,075	68	297	0	681	13,468
2002	69	low	0	0	1	3,111	4	4	0	1	9	0	59	3,193
		high	0	0	56	6,809	71	595	0	68	124	0	475	9,008
Average Annual Estimate														
1998-2002	na	low	0	0	30	937	327	256	2	156	3	0	42	1,754
		high	0	0	115	8,010	236	1,414	279	523	600	0	779	11,955

a See the species and species groups footnoted in Table 8.

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

c See text

Competition for food resources (not updated from 2002)

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). However, some species, such as larids, pigeon guillemots, and murrelets, may arrive at breeding sites in April, and others, including fulmars, puffins, and murres, are still rearing young in September. Among the 'latest' breeding species are the fulmars, which have a long incubation and chick-rearing periods and generally fledge chicks in September or early October. Both fork-tailed and Leach's storm-petrels do not fledge young until October (DeGange and Sanger 1986, Hatch and Hatch 1990, Dragoo *et al.* 2000). Seabird attachment to the colony is thus 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. Fishery seasons have shifted and could do so in the future. For example, since 2000, the Pacific cod longline fishery in the BSAI has begun in August, and in the GOA, a large portion of the catcher-vessel trawl pollock fishery occurs in June and September (NMFS 2001).

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). Competition for prey may also be involved, as suggested by the negative relationship between age-3+ pollock biomass in the eastern Bering Sea and the reproductive success of black-legged kittiwakes in the Pribilof Islands (Livingston *et al.* 1999, Hunt and Stabeno 2002). The interpretation of this relationship is that adult pollock consume the small fish (mainly, age-1 pollock and adult capelin) required by kittiwakes to successfully raise young (Hunt and Stabeno 2002). Thus, higher catch levels of some top-level species such as pollock might indirectly benefit piscivorous birds. This scenario is complicated, however, by the effects of warm vs cold-water regimes, which can directly affect some forage species such as capelin, and indirectly drive the system by altering top-down or bottom-up regulatory processes (Hunt *et al.* 2002). Additionally, the benefit of reducing the biomass of key predators such as pollock might be lost if populations of other large predatory fish increase due to reduced competition with pollock (Hunt and Stabeno 2002).

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). The 2002 Ecosystem chapter provides a review of commercial fishery activity in relation to seabird colonies 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.

Short-tailed albatross

Five endangered short-tailed albatrosses were reported caught in the longline fishery since reliable observer reports began in 1990: two in 1995, one in 1996, and two in 1998. All five individuals were taken in the BSAI. Both of the birds caught in 1995 were in the vicinity of Unimak Pass and were taken outside the observers' samples; the bird caught in 1996 was near the Pribilof Islands. This bird and the two short-tails taken in 1998 were in observers’ samples.

Research projects are underway to better understand the pelagic behavior of short-tailed albatross. The U.S. Fish and Wildlife Service, Japanese Ministry of the Environment, Oregon State University (OSU) and Yamashina Institute of Ornithology have undertaken a study of the movements of the critically endangered short-tailed albatross. Albatross are being instrumented with satellite transmitters (PTTs) both on Torishima Island, their principal nesting island in Japan, and in Aleutian Island passes where they concentrate during the non-breeding season. To date, 30 birds have been instrumented; 26 at Torishima and 4 in Seguam Pass in the Aleutians. Funding for the study has been provided by all of the partner agencies and organizations and the North Pacific Research Board.

Rob Suryan (OSU), who is analyzing the satellite data for his doctoral dissertation, provided an update on the movement of instrumented birds. Birds tagged at Torishima in 2003 were tracked for 7 – 15 weeks, usually reaching the Aleutian Islands before their PTTs failed (Figure 5). In 2003, the birds were located farther north in the Bering Sea than other tagged birds were in 2002, but still showed highly localized movements along the coast of Japan and near shore waters in the Aleutians. Three of the four birds tagged in Seguam Pass are still transmitting signals as of October 2003, and generally show movement near the central Aleutians (Figure 6). One bird moved farther north and west along the continental shelf. The combined location data from 2002 and 2003 illustrate the general use of the coastal and shelf waters of eastern Japan to the

Kamchatka Peninsula and along the western and central Aleutian Islands, with some excursions along the continental shelf of the Bering Sea (Figure 7).

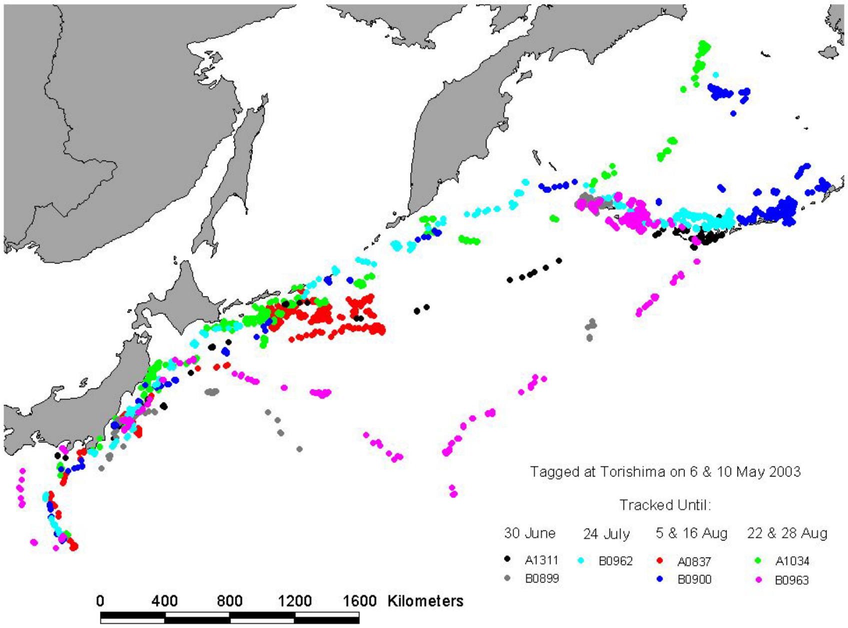

Figure 5. Locations of satellite transmissions for short-tailed albatross tagged on Torishima Island in May 2003.

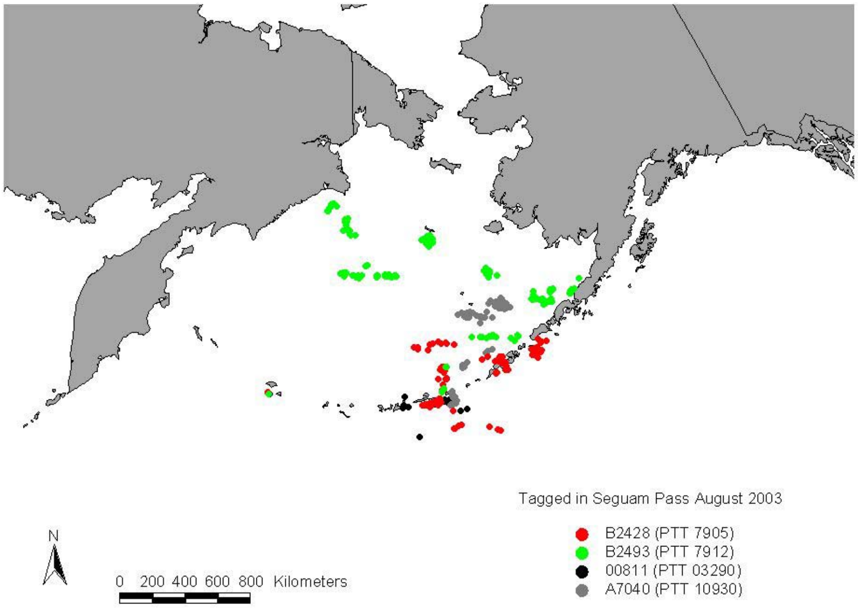

Figure. 6. Locations of satellite transmissions for short-tailed albatross tagged at Seguam Pass in August 2003.

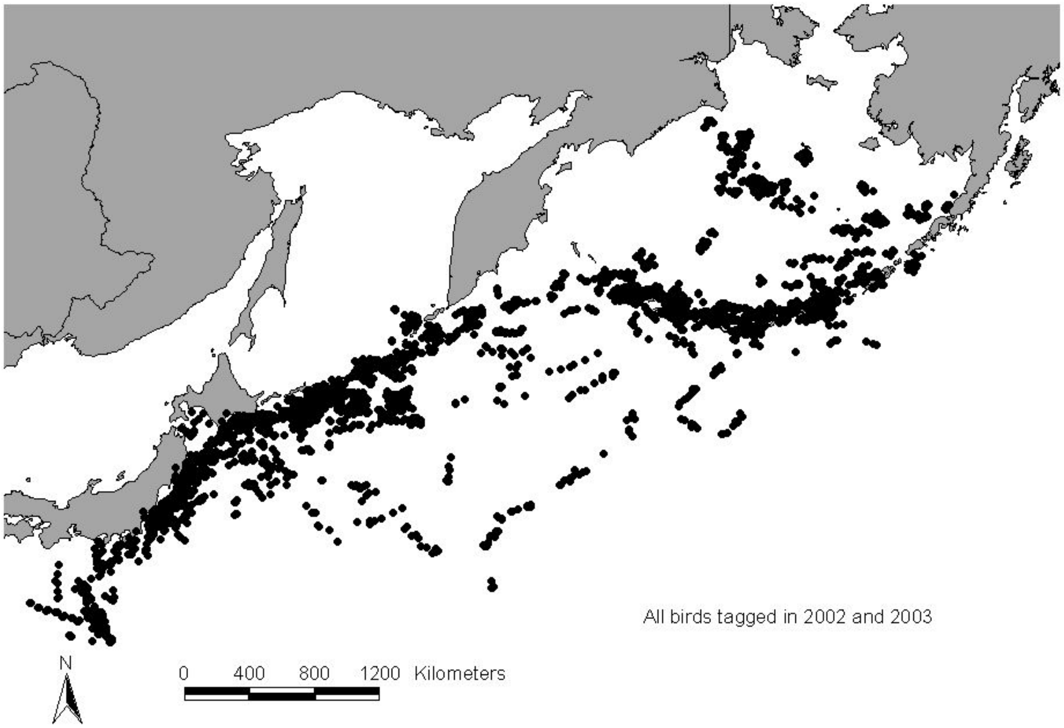

Figure 7. Locations of short-tailed albatross for all birds tagged with satellite transmitters in 2002 and 2003, combined.

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 ecosystem (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 12 summarizes these research needs, and provides a brief account on the status of these efforts.

Steps toward addressing many of the identified research needs (Table 12) have been made, although in most cases these are works in progress. Efforts are underway (or have been completed) 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.

For albatrosses, work is also underway to identify the temporal / spatial patterns of birds at sea in relation to foraging habitat, prey, and fisheries. This type of research and analysis is lacking, however, for most other species affected by Alaska longline fisheries. Most dietary information on seabirds is collected during the breeding season (compiled in Dragoo et al. 2003). A broad overview of regional dietary patterns, based on Dragoo et al. 2002, was presented in NPFMC 2002 (Kuletz and Rivera 2002), but there has not been a comprehensive synthesis of regional or seasonal patterns in seabird diet, particularly in relation to fisheries.

Research related to the distribution of birds at sea and how their overlap with fisheries might influence bycatch rates, have several on-going efforts. There are species-specific studies (i.e., R. Suryan et al., OSU), as well as a more comprehensive examination of the seabird bycatch data from Alaska's groundfisheries, to determine which factors influence bycatch rates (i.e. K. Dietrich, UW). The development of the North Pacific Pelagic Seabird Database will make historic data available for further examination of the relationships between seabird distribution, oceanographic features, and fisheries. However, there is a recognized gap in data on current seabird distribution in more pelagic waters. Another notable gap is the lack of research on the potential impact of offal discards on seabirds. The SSC identified several research needs related to fishery discards, including potential population level-effects and impacts on seabird distribution, but little has been done to address these issues in Alaska.

Considerable effort has been made toward research and development of methods to reduce seabird bycatch in Alaska longline fisheries, with favorable results (see 'Incidental Catch in Longlines', this report). For background on seabird mitigation strategies and funded initiatives, see the Seabird section of NPFMC 2002. Many of these cooperative efforts between industry, universities, and federal agencies, are continuing with 2003-2004 funding (http://www.afsc.noaa.gov/refm/reem/Seabirds/Default.htm).

Table 12. Research needs identified by the NPFMC Science and Statistical Committee and other seabird biologists, to address issues of seabird – fisheries interactions for groundfish fisheries in Alaska.

CATEGORY	IDENTIFIED RESEARCH / ANALYSIS NEED	CURRENT STATUS / EFFORT
Population level effects	Quantitative models to evaluate potential population-level impact of seabird bycatch, for species frequently taken (i.e., fulmars), abundant species (i.e., shearwaters, Laysan albatross), & less abundant species of concern (i.e., black-footed albatross).	BFAL model available (Lewison & Crowder 2003); preliminary efforts for STAL (unpubl.). BFAL & LAAL are monitored and banded in Hawaii for trends & demographic studies, by USFWS & USGS, but comprehensive analysis not completed.
Population level effects	Assess bycatch mortality at the colony level. Are particular colonies more susceptible to impacts because of the temporal & spatial distribution of fisheries?	Efforts begun (2001-2003) for genetic profiling of fulmar populations to determine provenance of birds killed in longline fisheries, by S. Hatch, USGS-BRD, Anchorage. Genetic profiling of albatrosses also begun (2002-2003) by H. Walsh, UW.
Population level effects	Develop quantitative models to evaluate potential population-level impacts from the availability of fishery discards & offal, particularly on juvenile birds.	None
Population level effects	Ascertain how much benefit seabirds derive from discards & offal, then determine adverse impacts associated with the incidental take of seabirds as a result of vessels attracting birds via the processing wastes & offal that are discharged.	None
Distribution & fisheries	Determine potential effects of spatial / temporal distribution of offal discharge relative to seabirds, including the variable energy needs of birds over seasons.	None
Distribution & fisheries	Compile at-sea data on distribution of seabirds in Alaska & N. Pacific. Critical to assess the potential interactions between commercial fisheries and seabirds	N. Pacific Pelagic Seabird Database begun in 2002; development underway by USGS-BRD & USFWS, with agency & NPRB funding. But - lacking data on current at-sea distribution of seabirds for more pelagic waters of Alaska.
Distribution & fisheries	Satellite telemetry studies on short-tailed albatross, to identify spatial & temporal distribution patterns as they intersect with commercial fishing activity	Begun in 2001 on Torishima Is. and on-going. Cooperative venture with Japan, USFWS, Oregon State U.; funded via Japan, USFWS. At-sea capture in Alaska begun 2003, with OSU, USFWS, WSGP, & funding by NPRB.
Distribution & fisheries	Develop & support a minimal program to piggyback marine bird observations on suitable monitoring platforms (e.g. ADF&G, IPHC, NMFS longline surveys; research cruises).	WSGP worked with IPHC in 2002 (ongoing), to conduct spot-counts of seabirds following halibut longline vessels.

Food & foraging	Examine temporal & spatial scale of seabird aggregations with respect to ephemeral & stable oceanographic features & prey aggregations.	Analysis of data on STAL underway (R. Suryan et al., OSU). Work on albatrosses available for central & S. Pacific (various publications). For species most affected by groundfisheries, nothing specific to Alaska waters.
Food & foraging	Identify & quantify food items used by seabirds in areas of overlap between fisheries & seabirds.	None specific to this issue in Alaska.
Food & foraging	Use telemetry & standard ship transect methods to define (horizontally & vertically) seabird feeding areas both in the Being Sea during summer & in areas outside the Bering Sea that may be visited seasonally, & define the relationship of feeding areas to principal fishing areas.	Begun for STAL, but no comprehensive study.
Food & foraging	Expand collection & synthesis of data on seabird diet to include fall through spring months, & for all seasons, examine regional patterns of prey use & trends over time.	No comprehensive study. Preliminary overview in Ecosystem Considerations chapter of NPFMC 2002 (Kuletz & Rivera 2002). Compilation of data from seabird colonies monitored during breeding season are available in Dragoo et al. 2003.
Gear & mitigation methods	Explore whether pulsed fishing saturates the ability of the seabirds to take advantage of the waste produced (thus cutting down on effects from offal discharge).	None
Gear & mitigation methods	Evaluate seabird interaction with trawl third wire, & develop practical and effective methods to reduce seabird interactions	Begun in 2003 by NMFS, UW, USFWS, with funding by agencies & NPRB. Separate incentive program to develop mitigation methods, by Marine Conservation Alliance & USFWS.
Gear & mitigation methods	Detailed analysis of multi-year data sets of seabird bycatch to include factors such as: spatial & temporal factors for both fishing effort & seabird distribution, vessel type, effectiveness of seabird deterrent devices, etc.	UW graduate project (K. Dietrich) near completion covering some of these issues. Preliminary, broad-scale examination of overlap between Alaska groundfish fisheries & birds available in NPFMC 2002 & presented at symposium (Kuletz et al. 2003). Analyses of deterrent devices requires more years with new regulations.
Gear & mitigation methods	Cooperative gear research on commercial fishing vessels to evaluate effective methods for setting longlines underwater to prevent access by seabirds. Methods could include: underwater setting chutes, lining tubes, line-weighting.	Various projects, 1999 – ongoing. Cooperative ventures by WSGP, industry, NMFS, USFWS, with funding by USFWS & NMFS. Descriptions of these projects available in this report and in NPFMC 2002, and NMFS web site.

Acknowledgments

We thank all the biologists from the Alaska Maritime National Wildlife Refuge, USFWS, USGS, and universities that contributed data to the Dragoo et al. report on seabird trends. Liz Labunski produced the graphs on seabird populations and productivity. Shawn Stephensen and David Irons graciously permitted use of information from their article in press. Kim Dietrich provided information on the stationary seabird survey work currently being completed. Heather Renner provided valuable comments on an earlier draft.

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Ecosystem or Community Indicators

A compilation of written source material documenting the traditional ecological knowledge of Alaska natives, with a focus on marine resources.

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Christina Package, AFSC,
Jon Isaacs, URS Corp.
Kelley Nixon, URS Corp.

Traditional knowledge of Alaska natives has been collected and entered into a database of relevant quotes from published literature. We also have an accompanying data base of marine species and terms translated into the five Native languages of coastal Alaska that can be inserted into already drafted documents fairly easily. The goal of our document is to make these materials useful to biologists and managers who are writing NMFS documents. The data is entered into an ACCESS database with the following fields:
TKText, Author, Year, ConType (eg. quote), Speaker, Speaker affiliation, Region, Title, Journal, Page, Keyword.
A draft hard copy of the database can be borrowed and consists of four volumes organized by main topic and key words:

Volume I
Physical Environment
Threatened and Endangered Species
Target Species
Prohibited Species

Volume II
Other species of fishes
Fish habitat
Seabirds
Marine Mammals

Volume III
Marine Mammals continued
Socioeconomics

Volume IV
Ecosystem

Contact Jennifer Sepez for access to the database.

Biodiversity as Index of Regime Shift in the Eastern Bering Sea

By Gerald R. Hoff.

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 1). 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 1). 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.

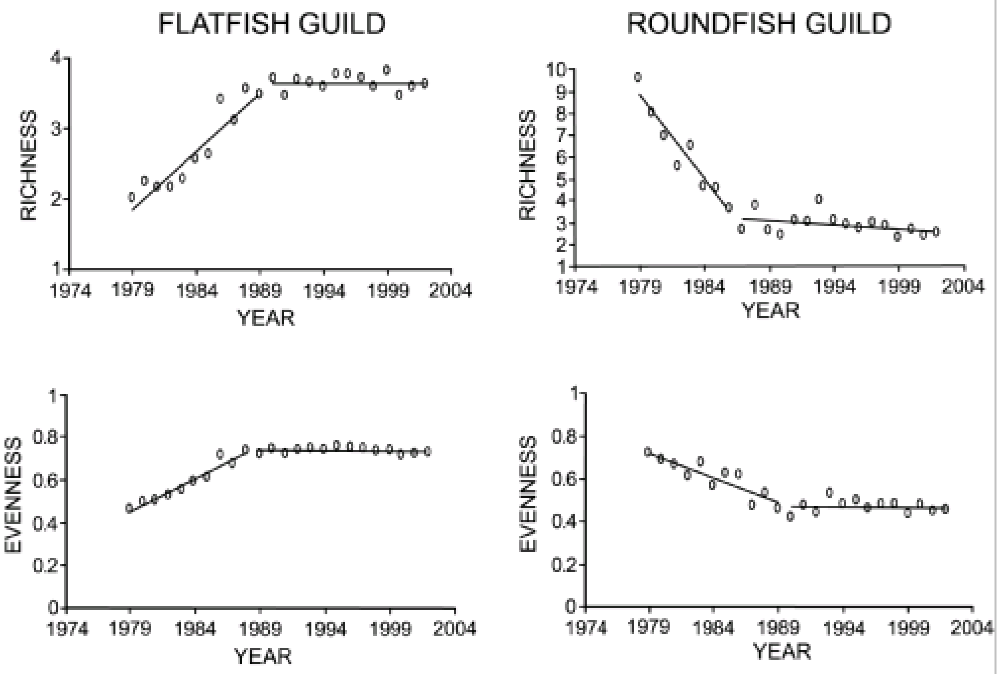

Figure 1. Plots of biodiversity (richness and evenness) indices for two fish guilds (Flatfish and Roundfish) from the eastern Bering Sea. Biodiversity showed a distinct shift in trends in the late 1980s which corresponds to reported regime shift events.

Combined Standardized Indices of recruitment and survival rate

Contributed by Franz Mueter
Joint Institute for the Study of the Atmosphere and the Oceans,University of Washington

This section provides indices of overall recruitment and survival rate (adjusted for spawner abundance) across the major commercial groundfish species and across major pelagic stocks in both the Bering Sea and Gulf of Alaska (GOA). Time series of recruitment and spawning biomass for demersal fish stocks were obtained from 2002 SAFE reports. Recruitment and spawner abundances for salmon stocks, grouped by region, are based on Peterman et al (1998), Pyper et al (2001, 2002), and Mueter et al (2002). Herring recruitment series are from Williams & Quinn (2000). Survival rate (SR) indices for each stock were computed as residuals from a Ricker spawner-recruit model. A Ricker model with first-order autocorrelated errors was fit to each spawner-recruit series using a generalized least-squares regression of log(recruits-per-spawner) on spawner abundance. 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 (ocean-entry year for salmon), resulting in matrices of recruitment (or SR indices) by year with missing values at the beginning and end of many series. A combined standardized index of recruitment (CSI_R) and survival (CSI_{SR}) was then computed following Boyd & Murray (2001). Briefly, all pairwise correlations between time series in a given data matrix (e.g. recruitment series for all demersal stocks in the Bering Sea) are computed based on those years with data for all stocks. The resulting correlation matrix is used to estimate annual means of standardized recruitment across all stocks. This approach allows estimation of annual average indices even for years that have missing data for some (or most) stocks. However, indices based on data for only a few stocks are highly uncertain. Uncertainty in the annual estimated means decreases if the component series are highly correlated (Boyd and Murray 2001). No estimates of variability were computed for this report but work is in progress to quantify uncertainty in annual CSI values.

The CSI_R suggests that recruitment of demersal species in the Gulf of Alaska and Bering Sea follows a similar pattern with mostly above-average recruitments from 1976/77 to 1989 and below-average recruitments in the early 1970s and most of the 1990s (Figure 1). These changes correspond to the regime shifts of 1976/77 and 1989/90. The CSI_R for pelagic stocks reflects a strong increase in recruitment around the 1976/77 ocean entry year but no apparent change after 1989.

The CSI_{SR} is more variable but shows similar patterns. A marked increase in survival is apparent in Gulf of Alaska groundfish and pelagic fishes, as well as in Bristol Bay sockeye, in 1976 or 1977 (Figure 2). However, in Bering Sea groundfish stocks, no similar increase in survival is apparent in the late 1970s, suggesting that the observed increase in recruitment was due to increases in spawner abundance rather than improved survival of recruits. Survival of demersal stocks was relatively low in the 1990s both in the Gulf of Alaska and Bering Sea, with the exception of 1999 in the GOA and 2000 in the Bering Sea. However, the CSI is based on few stocks in the late 1990s.

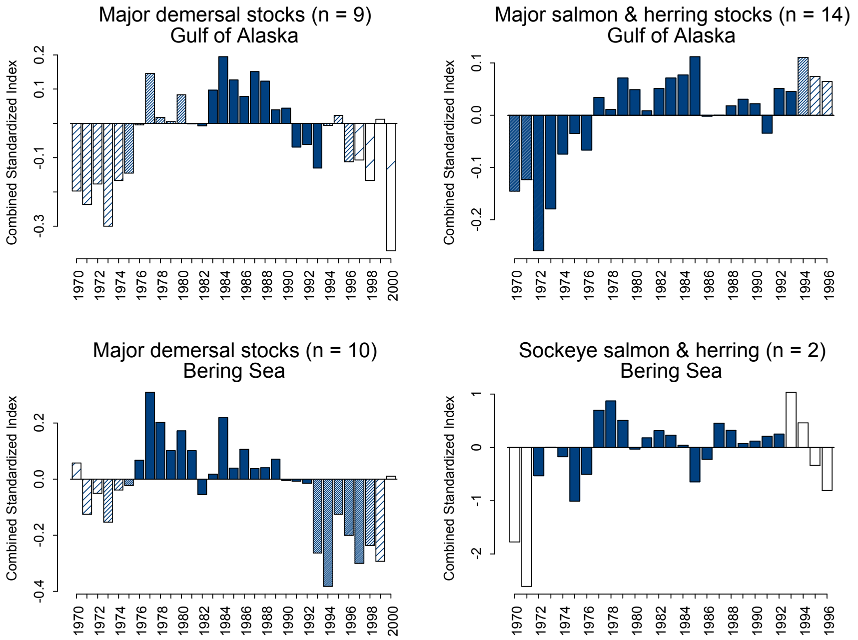

Figure 1: Combined Standardized Index of recruitment across demersal and pelagic stocks in the Bering Sea and Gulf of Alaska. Solid bars represent years with data for all stocks or stock groups. Lighter shading corresponds to years with more missing stocks. Series were truncated in 1970 and only years with data for at least 2 stocks were included, except in the lower right panel, where open bars correspond to a single stock group (Bristol Bay sockeye).

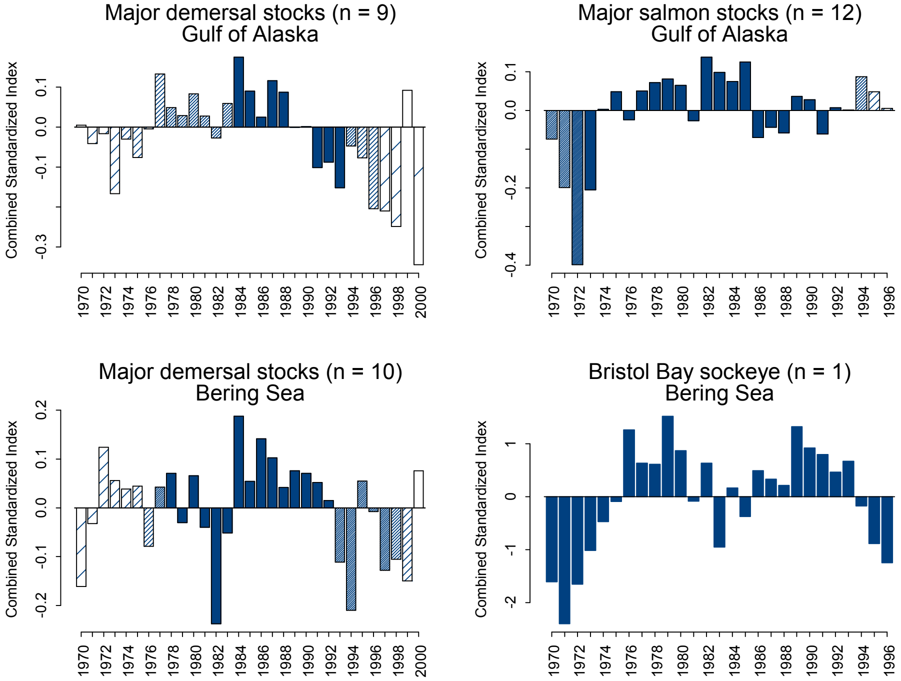

Figure 2: Combined Standardized Index of survival rates (residuals from Ricker spawner-recruit model) across demersal and pelagic stocks or stock groups in the Bering Sea and Gulf of Alaska. Solid bars represent years with data for all stocks. Lighter shading corresponds to years with more missing stocks. Series were truncated in 1970 and only years with data for at least 2 stocks were included, except in the lower right panel, which represents the combined survival rate index of Bristol Bay sockeye salmon.

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Average species richness, evenness, and diversity of groundfish community

Contributed by Franz Mueter
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We estimated several indices of species diversity based on standard bottom trawl surveys in the Gulf of Alaska and Bering Sea. Indices included the number of fish taxa per haul, Pielou's (1975) evenness index based on numerical abundances of fishes, and the Shannon-Wiener index of diversity (Magurran 1988) based on CPUE (by weight) of each fish species (or taxon) by haul. Indices were based on a total of 65 fish taxa in the Gulf of Alaska and 55 fish taxa in the Bering Sea. Taxa were included at the lowest possible taxonomic level, i.e. at a level that was consistently identified throughout all surveys. Indices were computed following Mueter & Norcross (2002). Briefly, annual average indices of richness, evenness, 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, Julian day, area swept, and year.

Species richness and diversity of the groundfish community in the Gulf of Alaska increased from 1990 to 1999 with all three indices peaking in 1999 and sharply decreasing thereafter (Figure 1). Species richness, evenness and diversity on the Eastern Bering Sea shelf have undergone significant variations from 1982 to 2002 (Figure 2). Species diversity was below average through much of the 1980s, increased in the early 1990s and has been higher and more variable throughout the 1990s. As in the Gulf of Alaska, all three indices decreased significantly in the most recent survey.

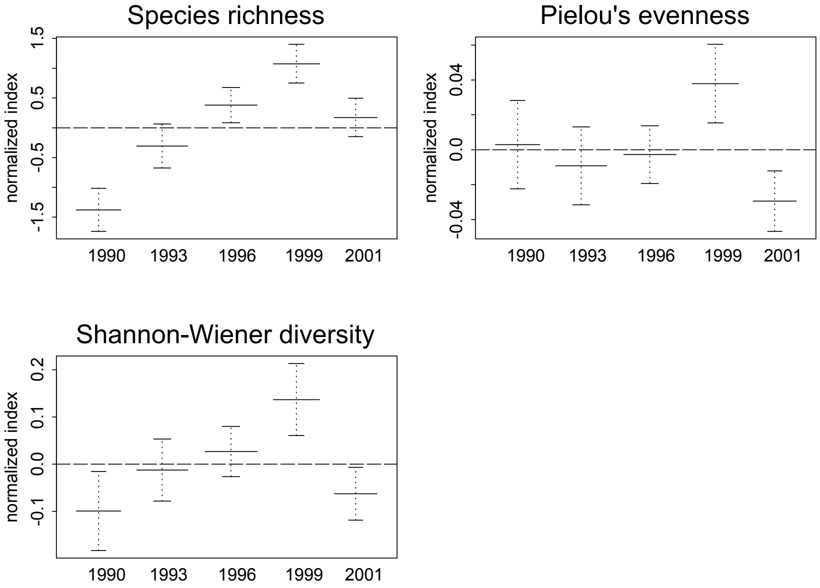
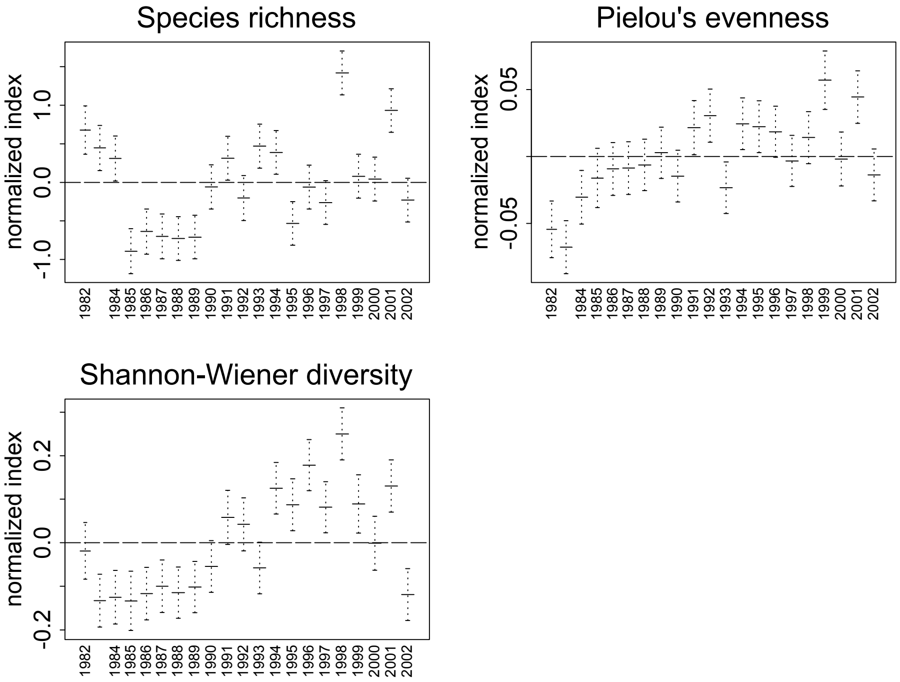


Figure 1: Estimated annual averages of species richness, evenness, and diversity in the western Gulf of Alaska, 1990-2001, based on 65 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Each index is on a normalized scale because actual values vary by depth, Julian day, area swept, and geographic location.



Species richness

Pielou's evenness

Shannon-Wiener diversity

Figure 2: Estimated annual averages of species richness, evenness, and diversity in the eastern Bering Sea, 1982-2002, based on 55 fish taxa collected by standard bottom trawl surveys with 95% confidence intervals. Each index is on a normalized scale because actual values vary by depth, Julian day, area swept, and geographic location.

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Total catch-per-unit-effort of all fish and invertebrate taxa in bottom trawl surveys

Contributed by Franz Mueter
Joint Institute for the Study of the Atmosphere and the Oceans, University of Washington

We estimated average catch-per-unit-effort of all fish and invertebrate taxa captured by standardized bottom trawl surveys in the Bering Sea (BS) and Gulf of Alaska (GOA). Spatial and temporal patterns in total CPUE of all taxa combined were modeled using Generalized Additive Models (GAM) as a function of depth, alongshore distance, Julian day, time of day (hour), and area swept following Mueter & Norcross (2002). Although catches were standardized to account for the area swept by each haul we included area swept in the model because of differences in catchability of certain taxa with changes in net width (Dave Somerton, pers. comm.) and because there was strong evidence that total CPUE tends to decrease with area swept (or net width), all other factors being constant. The model for the Bering Sea further included bottom temperatures, which appeared to strongly reduce CPUEs at low temperatures (< 1˚C). Total CPUE over time was computed separately for the eastern (east of 147° W) 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 for the 1984 and 1987 surveys because a large portion of these surveys used non-standard gear types. Results are only shown for the western GOA and Bering Sea. Trends in CPUE over time in the eastern GOA were highly uncertain due to large differences in sampling dates among years, which appeared to have a strong effect on total CPUE. Generally, CPUE tends to increase over time during the summer sampling season, and large differences in the time of sampling between 1990/93 and 1996/99 were strongly confounded with annual differences in total CPUE in the eastern GOA.

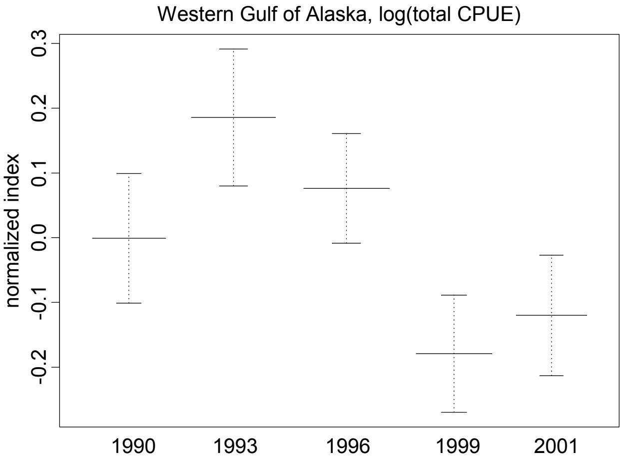

Figure 1: Estimated log-transformed CPUE of all fish and invertebrate taxa captured in bottom trawl surveys from 1990 to 2001 for the western Gulf of Alaska (west of 147˚ W) with approximate 95% confidence intervals. Y-axis is on normalized scale because actual values vary by depth, hour of sampling, area swept, and geographic location.

Total CPUE in the western Gulf of Alaska peaked in 1993 and decreased significantly between 1993 and 1999 (Figure 1). Total CPUE in the Bering Sea has undergone substantial variations and peaked in 1993, similar to the Gulf of Alaska. CPUE decreased to below average in 2000 and was near its 20-year average in 2002 (Figure 2).

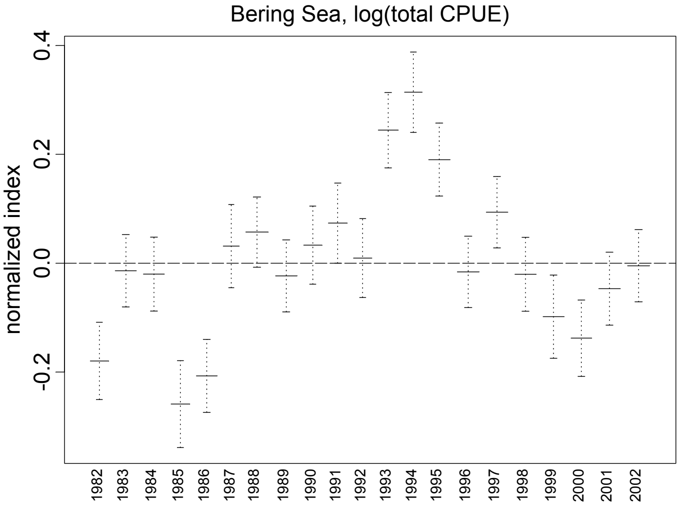

Figure 2: Estimated log-transformed CPUE of all fish and invertebrate taxa captured in bottom trawl surveys from 1982 to 2002 in the Bering Sea with approximate 95% confidence intervals. Y-axis is on normalized scale because actual values vary by depth, bottom temperature, hour of sampling, area swept, and geographic location.

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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 1. 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

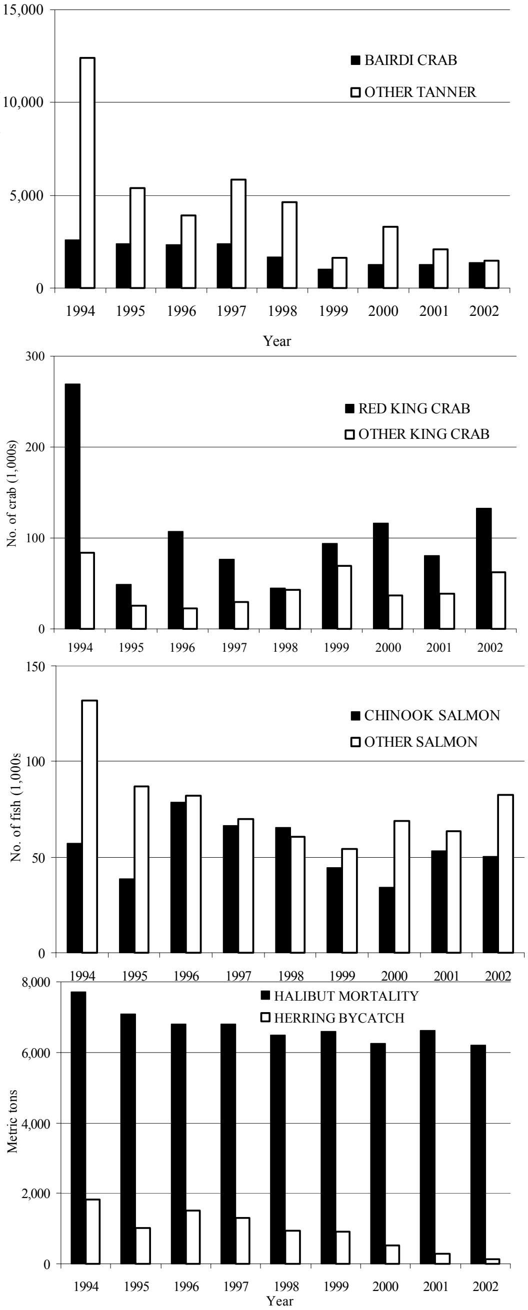

Figure 1. Bycatch of tanner and king crab, salmon, halibut, and herring in groundfish fisheries off Alaska, 1994-2002.

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.

Time trends in groundfish discards

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

The amount of managed groundfish species discarded in Federally-managed groundfish fisheries dropped in 1998 compared to the amounts discarded in 1994-97 (Figure 1). The aggregate discard rate in each area dropped below 10% of the total groundfish catch. The substantial decreases in these discard rates are explained by the reductions in the discard rates for pollock and Pacific cod. Regulations that prohibit discards of these two species were implemented in 1998. 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. It should be noted that although the blend estimates are the best available estimates of discards, these estimates are not necessarily accurate because they are based on visual observations of observers rather than data from direct sampling.

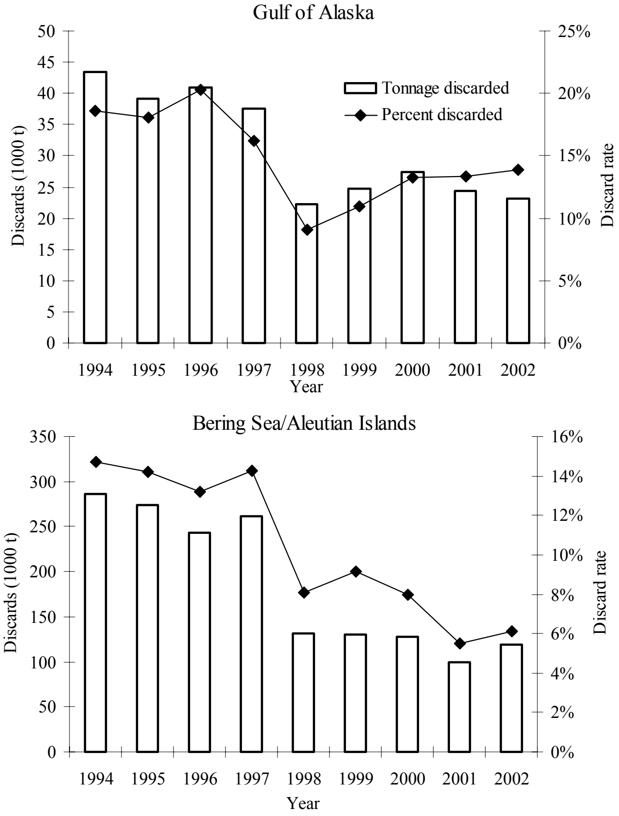

Figure 1. Total biomass and percent of total catch biomass of managed groundfish discarded in the GOA and BSAI areas 1994-2002. (Included only catch counted against federal TACS).

Time Trends in Non-Target Species Catch

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 1). 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).

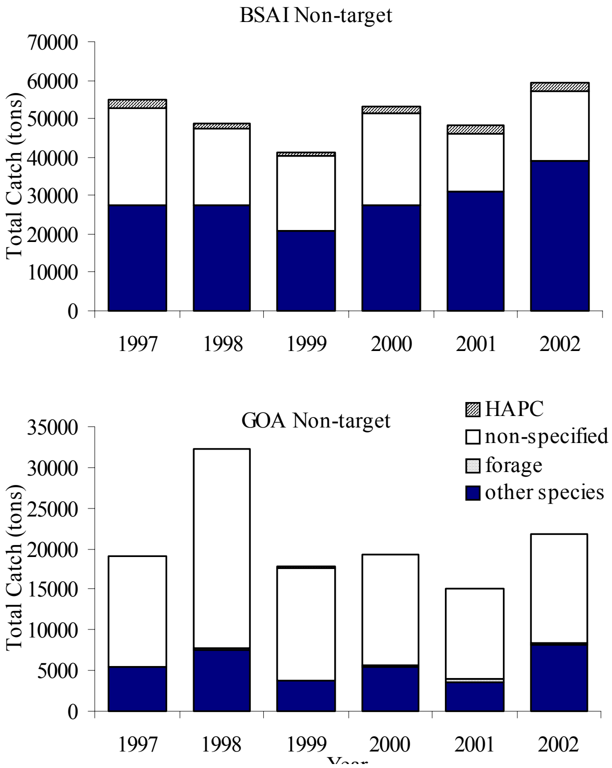

Figure 1. Total catch of non-target species (tons) in the BSAI and GOA areas by groundfish fisheries.

In the BSAI, non-target catch was primarily comprised of non-specified and other species categories (Figure 1). 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 1, 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) (Figure 1 and Table 1). 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 1. 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, and some specific fishery restrictions in 2000 and 2001. For 2001, over 90,000 nmi of the EEZ off Alaska was closed to trawling year-round. Additionally 40,000 nmi were closed on a seasonal basis. State waters (0-3nm) are also closed to bottom trawling in most areas.

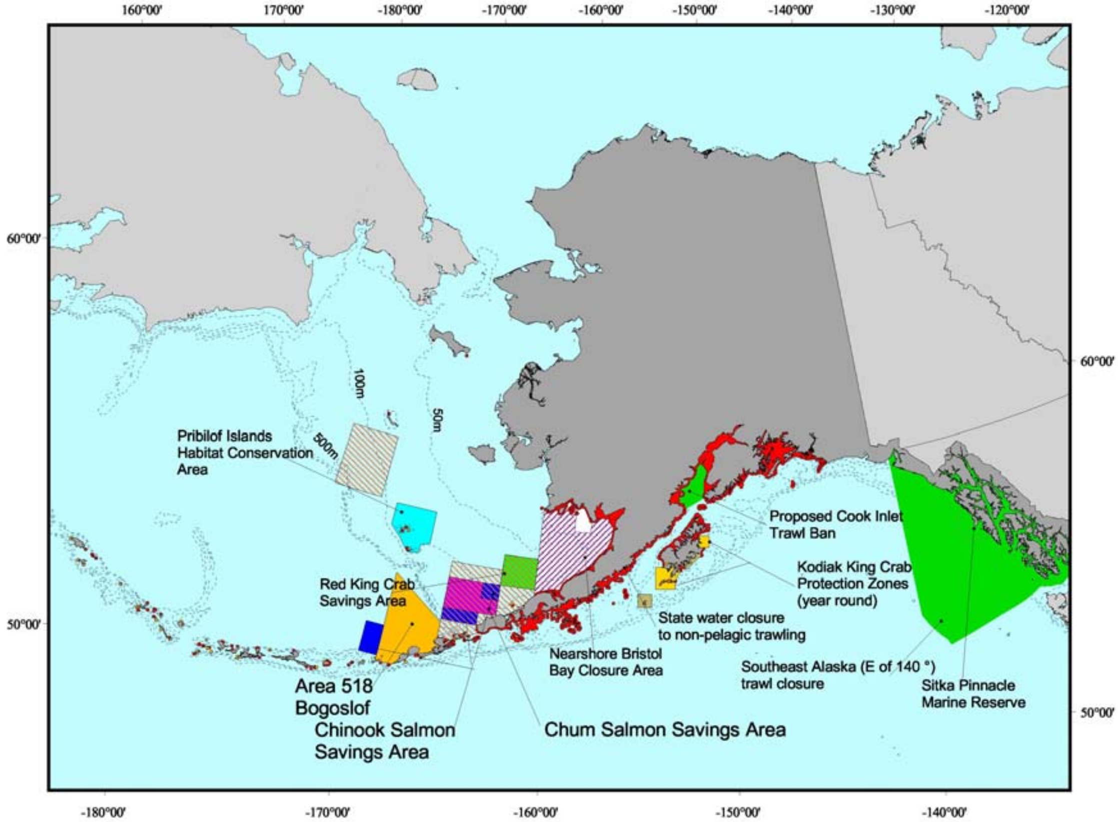

Figure 1. Groundfish closures in Alaska's Exclusive Economic Zone

Table 1. Time series of groundfish trawl closure areas in the BSAI and GOA, 1995-2003.
CSSA= chum salmon savings area; CHSSA= Chinook salmon savings area; RKCSA = red king crab savings area; HSA = herring savings area; SSL= Steller sea lion; COBLZ= c. opilio bycatch limitation zone.

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:

Location	Season	Area size	Notes
Bristol Bay	year-round	19,000 nm^2	expanded area 512 closure
COBLZ	trigger	90,000 nm^2	closed to specified fisheries when trigger reached

1998 same closures in effect as in 1995, 1996, and 1997

1999 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 29,000 nm^2
Mackerel Restrictions

2002 same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001
with additions of Steller Sea Lion protections
Pollock haulout trawl exclusion zones for EBS, AI **** areas include GOA***
No trawl all year 11,900 nm^2*
No trawl (Jan-June) 14,800 nm^2*
No Trawl Atka 29,000 nm^2
Mackerel Restrictions

2003 same closure in effect as in 1995, 1996, 1997 ,1998 and 1999, 2000, 2001,2002
including 2002 additions of Steller Sea Lion protections

Gulf of Alaska

Year	**Location**	**Season**	**Area size**	**Notes**
1995	Kodiak	year-round	1,000 nm^2	red king crab closures, 1987
	Kodiak	2/15-6/15	500 nm^2	red king crab closures, 1987
	SSL Rookeries	year-round	3,000 nm^2	10 mile no-trawl zones around 14 rookeries
	SSL Rookeries	seasonal ext,	1900 nm^2	20 mile extensions around 3 rookeries

1996 same closures in effect as in 1995

1997 same closures as in 1995 and 1996

1998 same closures as in 1995, 1996 and 1997, with one addition:
Southeast trawl year-round 52,600 nm2 adopted as part of the license limitation program (11,929 nm2 area on the shelf)
1999 same closures as in 1995, 1996, 1997 and 1998, with two additions:
Sitka Pinnacles Marine reserve year-round 3.1 nm2 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 nm2*
No trawl (Jan-June) 14,800 nm2*
2001 same closures as in 1995, 1996, 1997, 1998 and 1999, 2000
Pollock haulout trawl exclusion zones for GOA**** areas include EBS, AI***
No trawl all year 11,900 nm2*
No trawl (Jan-June) 14,800 nm2*

2002	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001
	Pollock haulout trawl exclusion zones for GOA*** *areas include EBS, AI***
	No trawl all year 11,900 nm2*
	No trawl (Jan-June) 14,800 nm2*
2003	same closures as in 1995, 1996, 1997, 1998 and 1999, 2000, 2001, 200

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

Contributed by Cathy Coon, NPFMC

This fishery is prosecuted with stationary lines, onto which baited hooks are attached. Gear components include the anchors, groundline, gangions, and hooks. The fishery is prosecuted with both catcher vessels and freezer longliners. The amount of effort (as measured by the number of sets) in longline fisheries is used as an indicator for target species distribution as well as for understanding habitat effects. Figures 1-3 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.

Bering Sea

For the period 1998-2002, there were a total of 75,543 observed longline sets in the Bering Sea fisheries. Spatial patterns of fishing effort were summarized on a 5km2 grid (Figure 1). Areas of high fishing effort are north of False Pass (Unimak Island) as well as the shelf edge represented by the boundary of report areas 513 and 517, as well as 521-533. This fishery occurs mainly for Pacific cod, Greenland turbot, and sablefish.

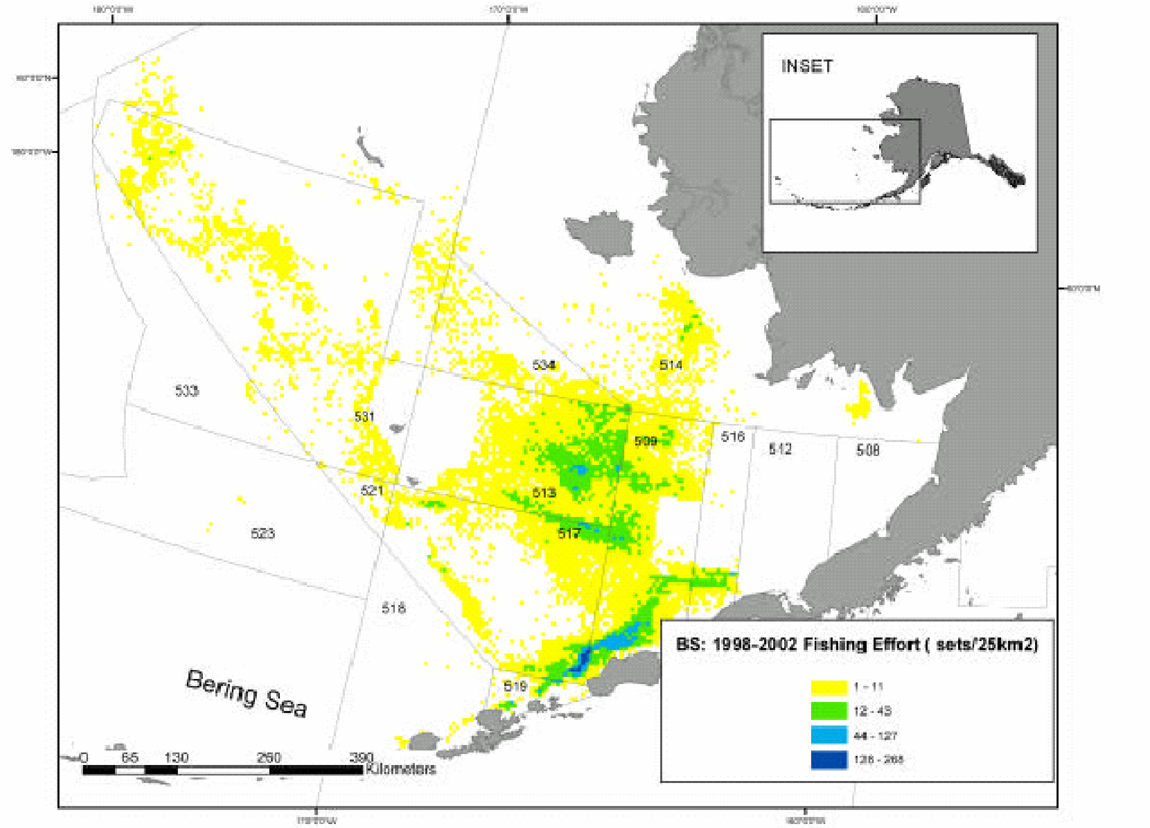

Figure 1. Spatial location and density of hook & line (longline) effort in the Bering Sea 1998-2002.

Aleutian Islands

For the period 1998-2002 there were 14,705 observed hook and line sets in the Aleutian Islands. The spatial pattern of this effort is dispersed over a wide area. Patterns of high fishing effort are dispersed along the shelf edge (Figure 2).

This fishery occurs mainly on Pacific cod, Greenland turbot, and sablefish. The catcher vessel longline fishery occurs over mud bottoms. In the summer, the fish are found in shallow (150-250 ft) waters, but are deeper (300-800 ft) in the winter. Catcher-processors fish over more rocky bottoms in the Aleutian Islands. The sablefish/Greenland turbot fishery occurs over silt, mud, and gravel, bottom at depths of 150 to 600 fm.

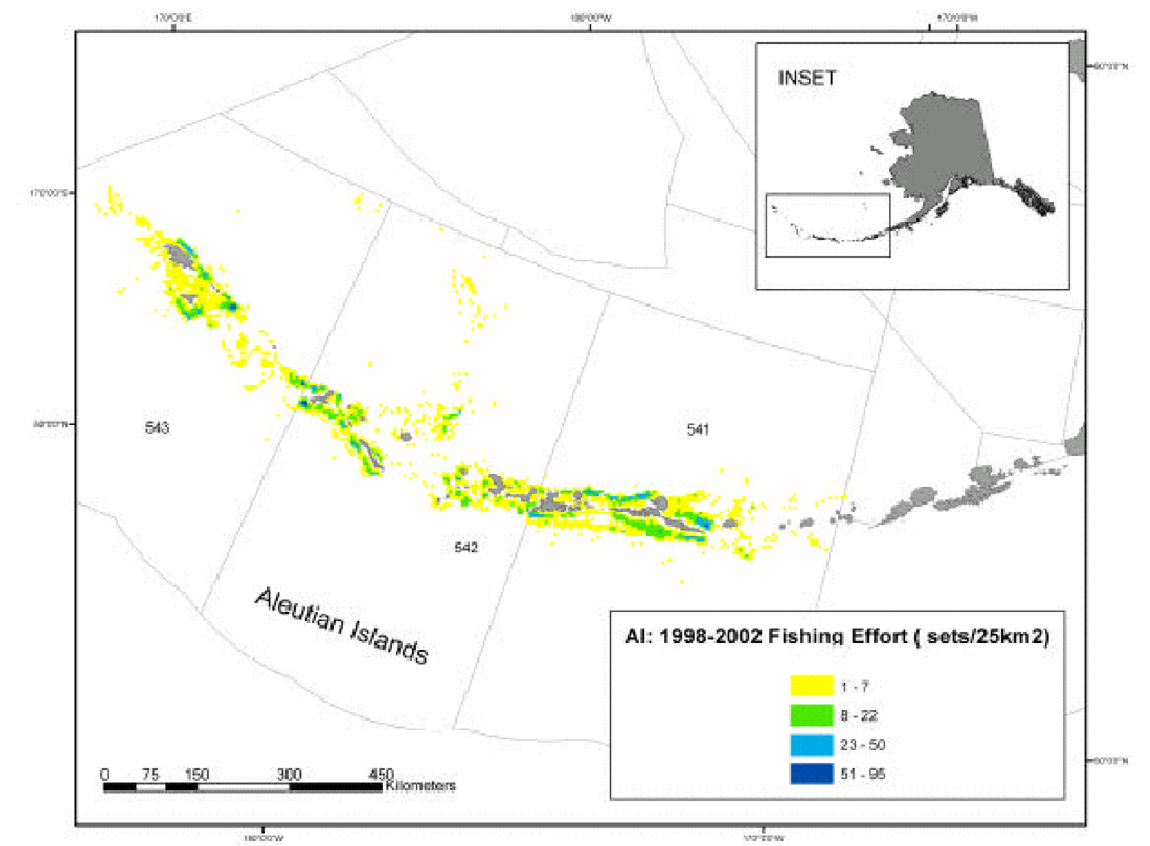

Figure 2. Spatial location and density of hook & line effort in the Aleutian Islands, 1998-2002.

Gulf of Alaska

For the period 1998-2001 there were 8,854 observed hook and line sets in the Gulf of Alaska. Patterns of high fishing effort are dispersed along the shelf (Figure 3). The predominant hook and line fisheries in the Gulf are composed of sablefish and Pacific cod. Southeast Alaska includes a demersal rockfish fishery whose dominant species include yelloweye rockfish (90%), with lesser catches 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 25 fathoms to 140 fathoms.

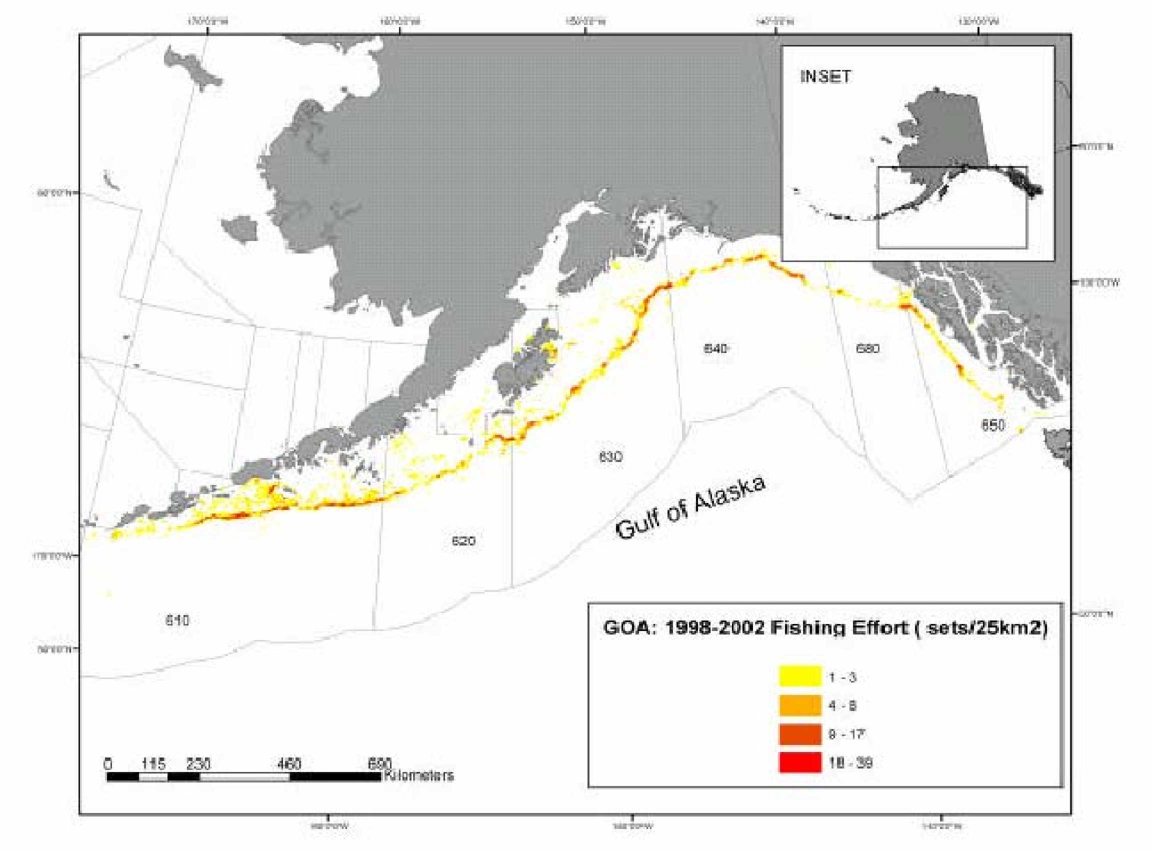

Figure 3. Spatial location and density of hook & line effort in the Gulf of Alaska, 1998-2002.

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 1. 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 has remained relatively stable from 1991 through 1997, peaked in 1997, then declined. Fluctuation in fishing effort track well with overall landing of primary bottom trawl target species; namely flatfish and to a lesser extent pollock and cod. Since 1999, only pelagic trawls can be used in the Bering Sea pollock fisheries. The locations where bottom trawls have been used are of interest for understanding habitat effects. Figures 2-4 show the spatial patterns and intensity of bottom trawl effort, based on observed data. Spatial changes in fisheries effort may in part be affected by fishing closure areas (i.e. Steller sea lion protection measures) as well as changes in markets and increased bycatch rates of non-target species. The magnitude of the Bering Sea trawl fisheries are twice as large in terms of effort than both the Aleutian Islands and Gulf of Alaska combined.

Bering Sea

For the period 1990-2002, there were a total of 248,073 observed bottom trawl sets in the Bering Sea fisheries. During 1999, trawl effort consisted of 14,631 sets which was the low for the 10 year period. Spatial patterns of fishing effort were summarized on a 5km2 grid (Figure 2). 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.

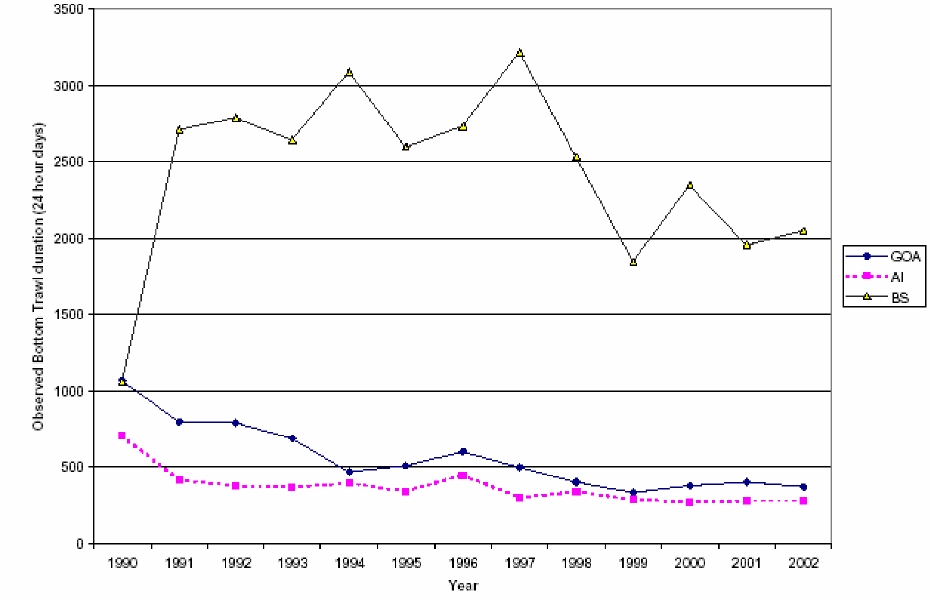

Figure 1. Estimated bottom trawl time in the Gulf of Alaska, Bering Sea, and Aleutian Islands during 1990-2002.

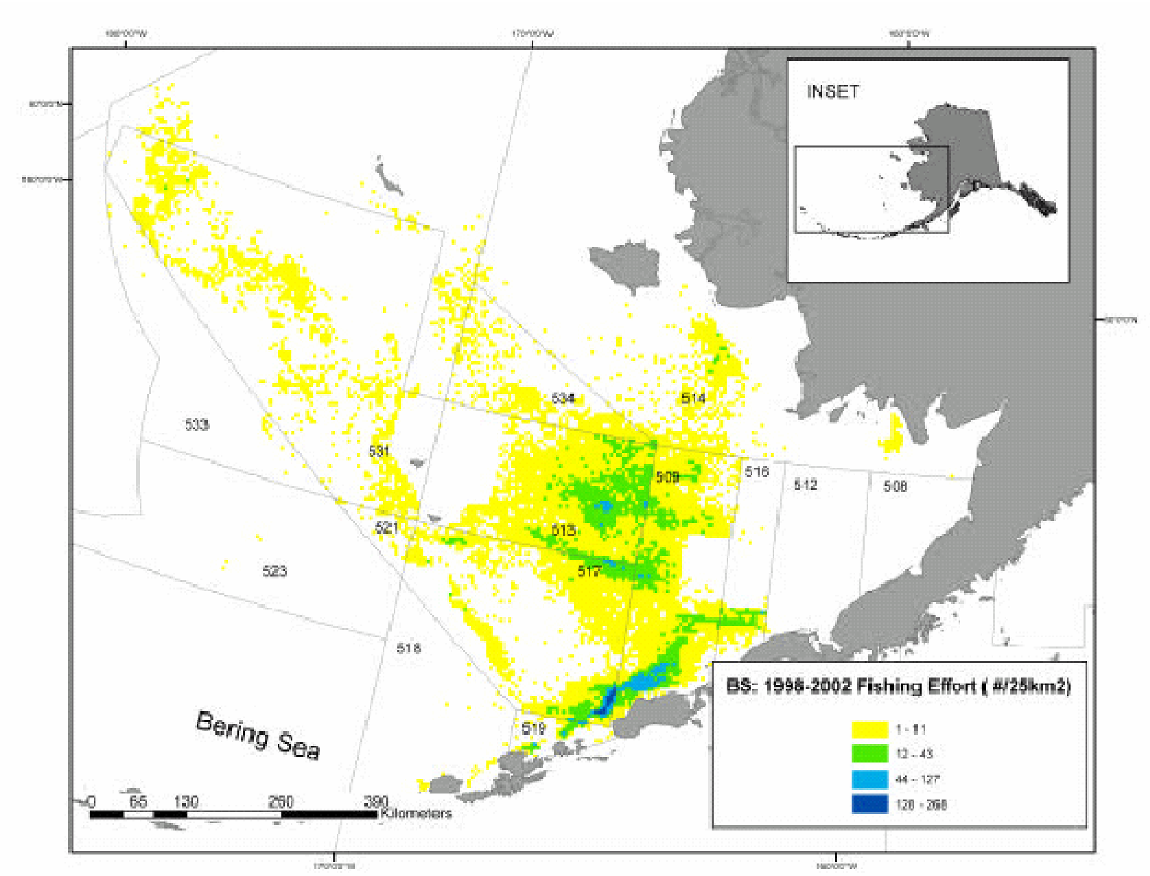

Figure 2. Spatial location and density of bottom trawl effort in the Bering Sea 1998-2002.

Aleutian Islands

For the period 1990-2002 there were 45,559 observed bottom trawl sets in the Aleutian Islands. The spatial pattern of this effort is dispersed over a wide area. During 2000, the amount of trawl effort was 2,583 sets, which was the low for the 10 year period. Patterns of high fishing effort is dispersed along the shelf edge (Figure 3). The primary catch in these areas was pollock, Pacific cod, and Atka Mackerel. Catch of Pacific Ocean Perch by bottom trawls was also high in earlier years.

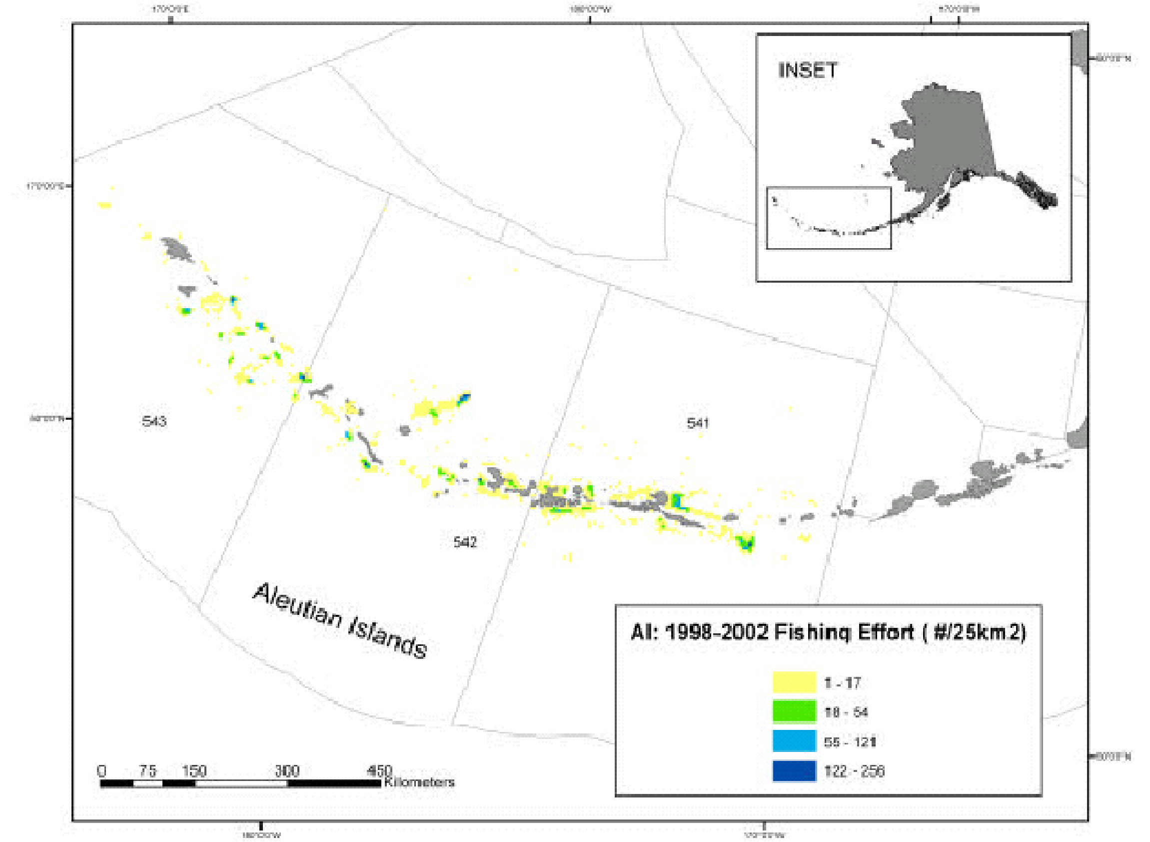

Figure 3. Spatial location and density of bottom trawl effort in the Aleutian Islands, 1998-2002.

Gulf of Alaska

For the period 1990-2002 there were 70,723 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. Patterns of high fishing effort is dispersed along the shelf edge with high pockets of effort near Chirikov, Cape Barnabus, Cape Chiniak and Marmot Flats (Figure 4). 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.

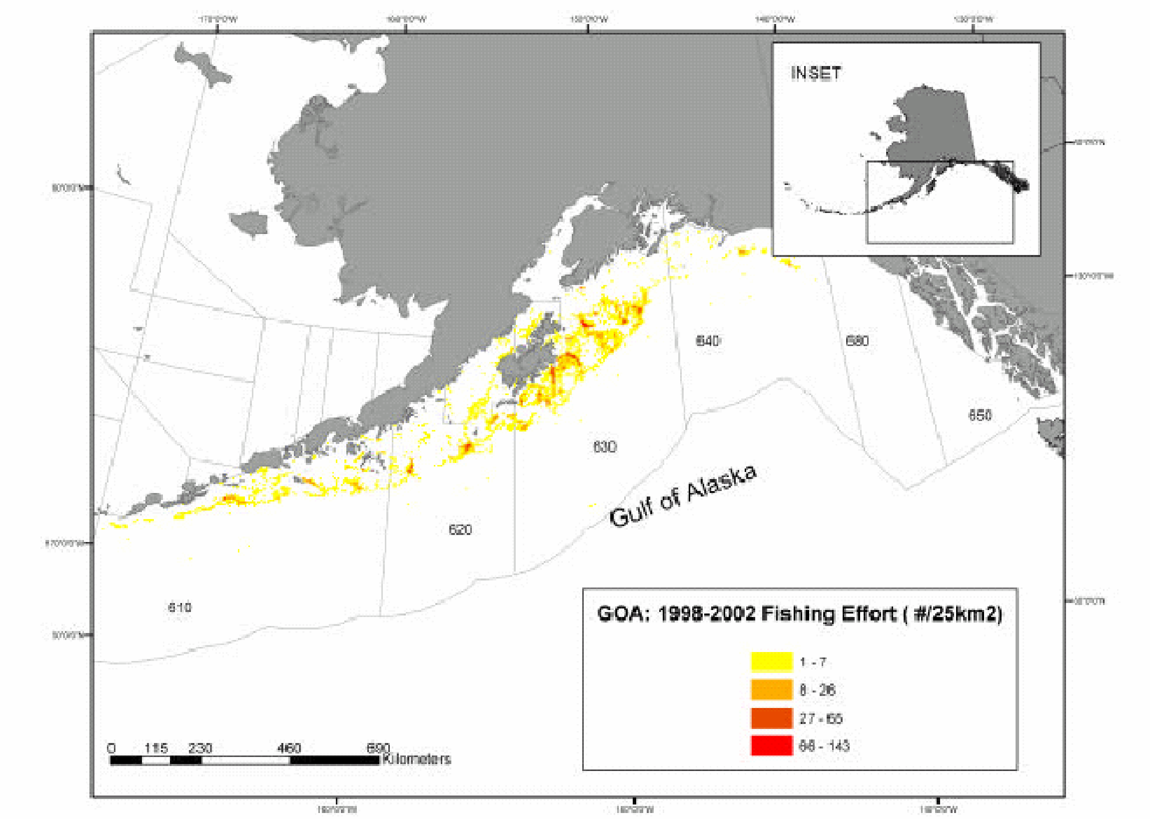

Figure 4. Spatial location and density of bottom trawl effort in the Gulf of Alaska, 1998-2002.

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 Pauly's (2001) Fishery Is Balanced (FIB) Index in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska areas were determined. Total catch levels and composition for the three regions show the dominance of walleye pollock in the catch from around the 1970's to at least the early 1990's. 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.

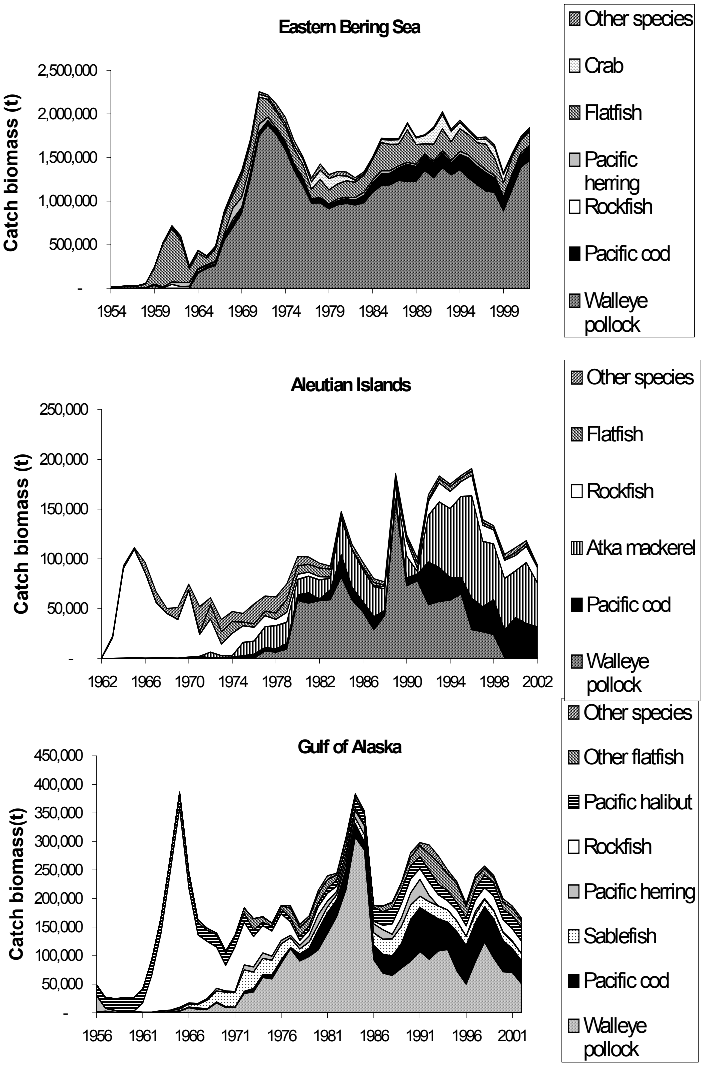

Figure 1. Total catch biomass (except salmon) in the EBS, GOA, and AI through 2002.

The trophic level of each species in the catch was obtained from published accounts of diet for non-groundfish species and from the food habits data base of the Alaska Fisheries Science Center for groundfish species. Trophic level (e.g., 1 for phytoplankton, 2 for consumers of primary production, 3 for consumers of secondary production, etc.) of the total catch was determined by weighting the trophic level of each species in the catch by the proportion (by weight) of that species in the total catch and summing the weighted trophic levels in each year. Stability in the trophic level of the total fish and invertebrate catches in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska (Figure 2) 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. This result is consistent with the previous analysis of Livingston et al. (1999) that described the lack of a fishing-down effect in the eastern Bering Sea.

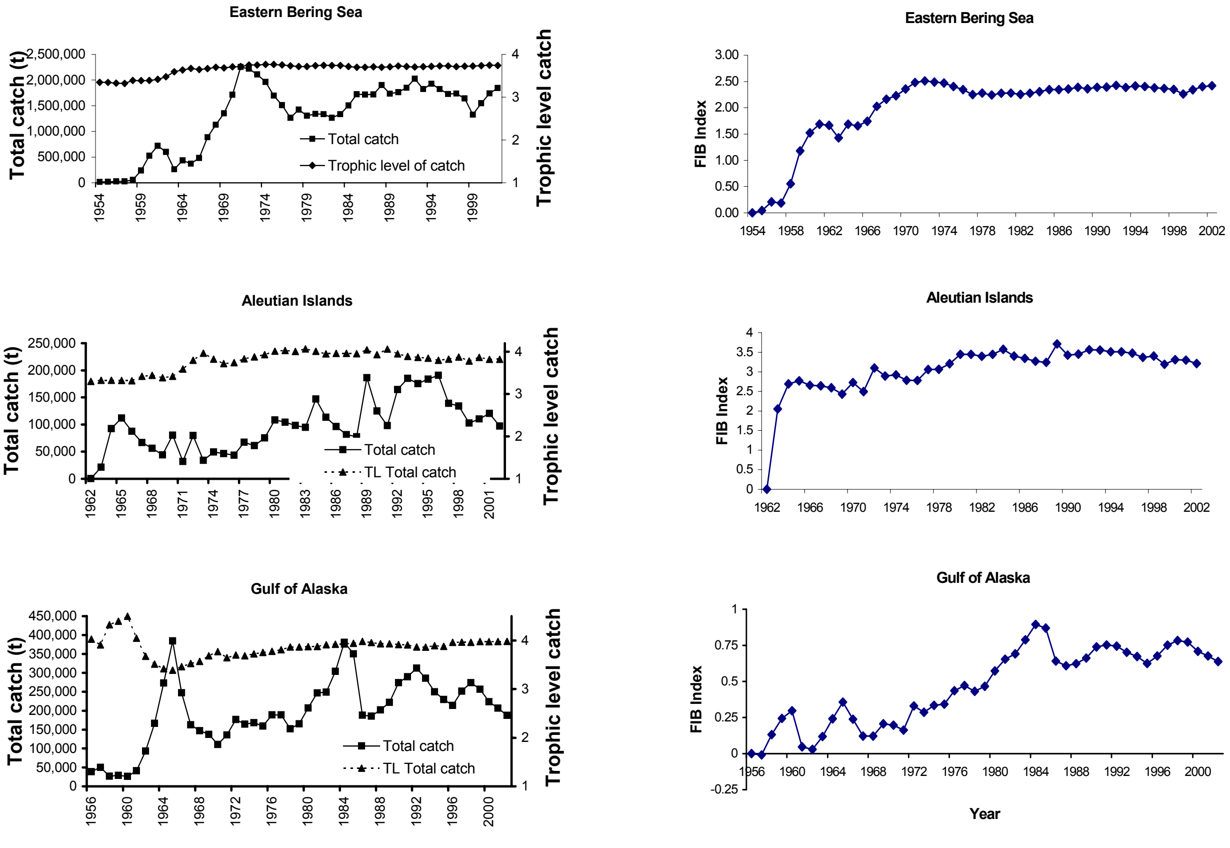

Figure 2. Total catch (groundfish, herring shellfish, and halibut) and trophic level of total catch in the EBS/AI and GOA through 2002.

Pauly et al. (2000) noted the possibility that trophic level catch trends may be a reflection of deliberate choice and not of a fishing down the food web effect. Thus, they propose a new index that declines only when catches do not increase as expected when moving down the food web. The FIB index for any year *i* in a series is defined by

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

Where Y is the catch biomass, TL the mean trophic level in the catch, TE the transfer efficiency of energy from one trophic level to the next (assumed = 0.1), and 0 is the baseline year. In this case the baseline year used was the initial year of the time series. The FIB index for each Alaskan region was calculated (Figure 3) 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.

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Status of groundfish, crab, salmon and scallop stocks

Updated by Pat Livingston, Alaska Fisheries Science Center

Table 1 summarizes the status of Alaskan groundfish, crab, salmon and scallop stocks or stock complexes managed under federal fishery plans in 2002 from the April 2003 NMFS report to Congress available on the web at: http://www.nmfs.noaa.gov/sfa/reports.html

Although only two minor stocks are considered in the overfished category (Bering Sea Tanner crab and St. Matthew Island Blue king crab), rebuilding plans for three crab stocks are presently in place because Bering Sea snow crab is above the minimum stock size threshold but is still rebuilding. 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. The status of a large proportion of minor stocks is unknown. In 2001, unknown status stocks comprised <1% of the total landings. In 2002, there were 21 stocks that are defined as major stocks for which overfished status is unknown (11 GOA Groundfish, 8 BSAI Groundfish, 2 BSAI crab).

Table 1. Status of groundfish and crab stocks or stock complexes managed under federal fishery management plans off Alaska, 2002.

	Number of Stocks or Stock Complexes by Overfished Category			
FMP	**Overfished**	**Not Overfished**	**Unknown**	**Total**
GOA Groundfish				
Major	0	9	11	20
Minor	0	0	80	80
BSAI Groundfish				
Major	0	12	8	20
Minor	0	0	71	71
Crab				
Major	0	2	2	4
Minor	2*	2	12	16
High Seas Salmon	0	5	0	5
Scallop				
Major	0	1	0	1

* after the April 2003 NMFS report to Congress was produced, 4 stocks of crab were considered overfished.

Total production and overall exploitation rate

Contributed by Franz Mueter, Joint Institute for the Study of the Atmosphere and the Oceans,University of Washington

A simple index of net groundfish production on the Eastern Bering Sea and Gulf of Alaska shelves was constructed by estimating total production across all major groundfish stocks. Annual estimates of total groundfish biomass were obtained by summing across all commercial groundfish stocks for which age-structured assessments were available. These species represent at least 80-90% 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), the estimated net production in year t can be expressed as the change in total groundfish biomass from year t (B_t) to year t+1 (B_{t+1}) plus total catches in year t (C_t), which is equivalent to the sum of new growth and recruitment minus natural mortality (i.e. mortality from all non-fishery sources).

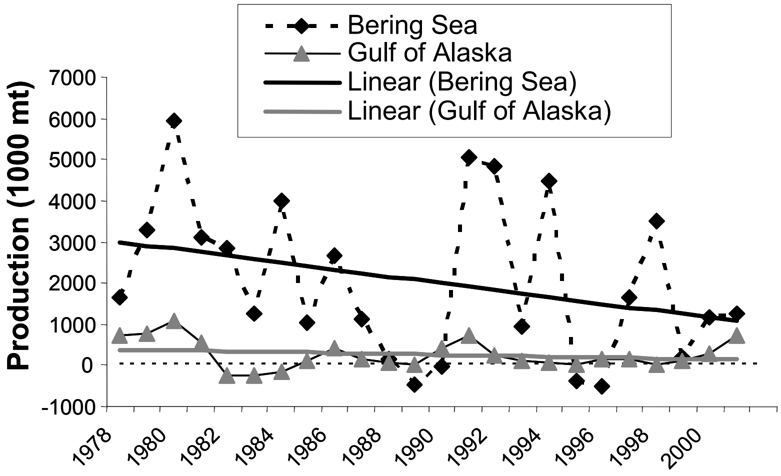

Figure 1. Total net production (change in biomass plus catch) across all major groundfish species in the Gulf of Alaska and Bering Sea with estimated linear trends.

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

We estimated an index of total exploitation rate within each system by dividing the total groundfish catch by the combined biomass estimates at the beginning of the year:

$$u_t = C_t / B_t$$

The resulting indices suggest high variability in groundfish production in the Bering Sea (Figure 1) and a (non-significant) decrease in production between 1978 and 2001 (generalized least-squares regression with first-order autocorrelation, slope = - 81,000 mt/ year, t = -1.29, p = 0.21). Production in the Gulf was much lower on average, less variable, and decreased slightly from 1978 to 2001 (slope = - 3,960 mt/ year, t = -0.12, p = 0.90).

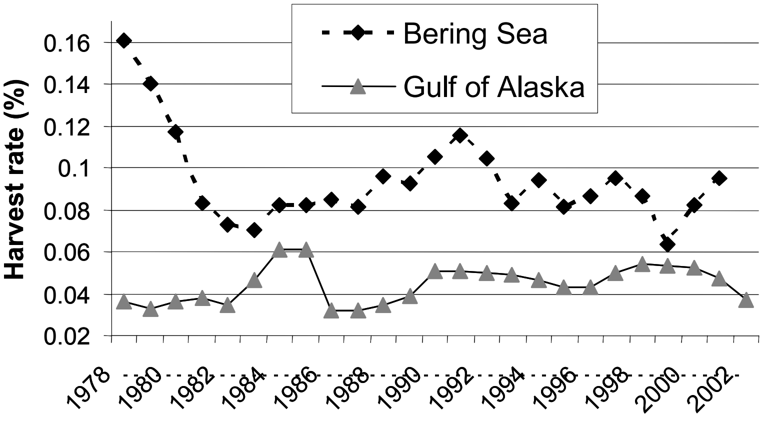

Figure 2.Total exploitation rate (total catch / total biomass) across all major groundfish species in the Gulf of Alaska and Bering Sea.

Total exploitation rates were generally much higher in the Bering Sea than in the Gulf of Alaska and were highest in the early part of the time series due to high exploitation rates of walleye pollock (Figure 2). Total exploitation has remained relatively constant in both systems from the mid-1980s to the present.

Ecosystem indicators for the bottom trawl fish community of the eastern Bering Sea

Shannon Bartkiw, Pat Livingston, and Gary Walters, AFSC

Ecosystem-based fisheries management requires analyses beyond assessments of species that are targets of fisheries. The ICES working group on "Ecosystem Effects of Fishing Activities" has provided some ideas for developing additional ecosystem management indicators that measure more system-wide properties that might change due to fishing. Two indicators that have been found to be relatively explanatory of fishing induced changes at a more system-wide level are community size spectrum and k-dominance curves. These indicators have been derived for several systems (Greenstreet & 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.

Data

Eastern Bering Sea bottom trawl survey data was obtained from the Resource Assessment and Conservation Engineering (RACE) Division of the NOAA Fisheries Alaska Fisheries Science Center (AFSC) for the years 1975 and 1979-2002. This summer survey region was divided into six subareas, or strata, bounded by the 50-m, 100-m, and 200-m isobaths and by a line separating the northwest and southeast portions of the study area based on oceanographic domains which seem related to distributions of eastern Bering Sea fishes. The standard station pattern is based on a systematic 20 x 20 nautical mile grid, with collections taken from the center of each 20 x 20 nautical mile grid block. While samples are frequently collected at corner stations, these were omitted from this analysis.

Catch per unit effort (CPUE) data was derived for species and species groups known to be consistently present in the eastern Bering Sea. In some cases it was necessary to group species together to account for inconsistent identification at lower taxonomic levels or low representation. In other cases, species that are known to be found only in certain strata but were only identified to genus in survey data were first grouped together and then recoded to the appropriate species (Table 1). This resulted in 52 species groupings (Table 2), of which there are 13 commercial fish and 39 nontarget fish groups. Unidentified and uncommon species were excluded from the analysis.

For these analyses, bottom trawl fishing effort data were obtained from the NMFS Observer database (NORPAC) for the years 1973-2001, for domestic, foreign, and joint venture fleets. Fishing effort was reported as number of tows and official total catch (metric tons) by latitude and longitude and encompassed fishing effort throughout the year. This position data was used to identify each effort data point to the corresponding RACE survey station. Effort data taken outside the survey area were excluded from further analysis.

Table 1. Species known to be found in certain strata

Species	Strata
Gymnocanthus pistilliger	1 - 2
Gymnocanthus galeatus	3 - 6
Triglops pingeli	1 - 4
Triglops scepticus	5 - 6
Myoxocephalus jaok	1 - 2
Myoxocephalus verrucosus	3 - 4
Myoxocephalus polyacanthocephalus	5 - 6
Icelus spatula	1 - 4
Icelus spiniger	5 - 6

Methods

The community size spectrum (CSS) in each survey year was estimated as the frequency (numbers CPUE) by 5-cm size class without regard to species. In order to determine number per size class for grouped species, we first determined mean individual weight (w_{ij}), calculated by dividing the weight of the sample (W_{ij}) by the number of individuals in the sample (N_{ij}), where i = year and j = station, after Bianchi et al. (2000). A number of species groups were missing N_{ij} and therefore w_{ij} could not be directly calculated for those samples. In those cases, an average was taken of all available non-zero w_{ij} values for that species group in the same year and stratum. If sufficient data was not available, data was taken from neighboring strata in the same shelf region for that year (i.e. inner shelf). If sufficient data was still not available, averages were taken across all years from the same stratum. Approximately 1% of all w_{ij} values were estimated using these indirect methods. N_{ij} for those samples was back calculated as W_{ij}/w_{ij}. Average weight per individual was converted to length by assuming the relationship length = $(100*\text{weight})^{1/3}$. The number of individuals in each size class (N_k) was calculated by distributing all N_{ij} over the size classes according to their W_{ij} (Bianchi et al. 2000). The 4th root of the size class midpoint was plotted against the 4th root of N_k. Fourth root, or root-root, transformations are the preferred transformation (Field et al. 1982); similar to a log(X+1) transformation in reducing the importance of abundant species, a 4th root transformation has advantages when doing analyses using Bray-Curtis similarities, as in comparison of k-dominance curves. Slopes and intercepts of the descending limb of the distribution curves were calculated for organisms 20-90 cm, in order to be comparable with analyses done for other marine systems.

Linear regression of the time trend in the slopes and intercepts was performed to determine if there was or was not a significant change. Zero slope of the intercept regression line implies no change in the amount of small sized animals across years, thus allowing the interpretation of differences in slope of the size distribution curves to changes in abundance of larger size animals across time.

Spearman rank correlation coefficients of catch per unit effort (CPUE) by year and mean individual weight (w_i) by year were also computed to determine significant time trends in those variables for the years 1982-2002, years in which the survey methodology had been standardized. To determine if there were changes in dominant species groups, k-dominance curves were generated and compared for each year group. These curves were generated using Plymouth Routines In Multivariate Ecological Research (PRIMER) software. To test for differences between k-dominance curves, samples were first grouped into 5-year intervals, and Bray-Curtis dissimilarities between each set of curves were compared using Analysis of Similarities (ANOSIM), in PRIMER. P-values were determined within the program by permutation, and comparing the observed R-value with simulations under the null hypothesis (Clarke 1990).

In order to resolve which species groups influenced any observed changes in slope of the community size spectrum, the percent contribution of species through time was also examined. The SIMPER routine in PRIMER determines which species are typical of a group; in this case, the groups compared were years. The more abundant a species is within a year, the more it contributes to the intra-year similarities, typifying a year if it is found at consistent abundance throughout all survey stations in that year. SIMPER was performed using untransformed CPUE (kg/ha) data on species groups contributing to the top 90% of the total CPUE across all survey stations. The change in percent contribution of typifying species in each stratum was compared with trends in CSS and results of Spearman rank correlation of w_i and year and CPUE and year.

Some authors have indicated that fishing effort is directly proportional to the slope of the community size spectrum (Gislason and Rice 1998, Bianchi et al. 2000). Bottom trawl fishing effort data was summed across all stations within the survey area for each year, and correlated with the slope of the size spectrum, along with available environmental data.

Table 2. Species groups used for analysis of EBS ecosystem indicators.

RACE code	Scientific name	Common name	Commercially exploited?
150	sharks	sharks	
400	Rajidae	Rays	
10110	*Athersthes stomias*	Arrowtooth flounder	X
10115	*Reinhardtius hippoglossoides*	Greenland turbot	X
10120	*Hippoglossus stenolepis*	Pacific halibut	X
10130	*Hippoglossoides elassodon*	Flathead sole	X
10180	*Microstomus pacificus*	Dover sole	
10200	*Glyptocephalus zachirus*	Rex sole	X
10210	*Limanda aspera*	Yellowfin sole	X
10211	*Limanda proboscidea*	Longhead dab	
10220	*Platichthys stellatus*	Starry flounder	X
10260	*Lepidopsetta sp.*	Rock sole	X
10285	*Pleuronectes quadrituberculatus*	Alaska plaice	X
20000	Agonidae	Poachers	
20006	*Leptagonus frenatus*	Sawback poacher	
20040	*Podothecus acipenserinus*	Sturgeon poacher	
20050	*Aspidophoroides bartoni*	Aleutian alligatorfish	
20061	*Occella dodecaedron*	Bering poacher	
20202	*Ammodytes hexapterus*	Pacific sand lance	
20700	Bathymasteridae	Ronquils	
21110	*Clupea pallasi*	Pacific herring	X
21300	Cottidae	Sculpins	
21314	*Gymnocanthus pistilliger*	Threaded sculpin	
21316	*Gymnocanthus galeatus*	Armorhead sculpin	
21347	*Hemilepidotus jordani*	Yellow Irish lord	
21348	*Hemilepidotus papilio*	Butterfly sculpin	
21354	*Triglops scepticus*	Spectacled sculpin	
21355	*Triglops pingeli*	Ribbed sculpin	
21368	*Myoxocephalus verrucosus*	Warty sculpin	
21370	*Myoxocephalus polyacanthocephalus*	Great sculpin	
21371	*Myoxocephalus jaok*	Plain sculpin	
21390	*Dasycottus setiger*	Spinyhead sculpin	
21420	*Hemitripterus bolini*	Bigmouth sculpin	
21438	*Icelus spiniger*	Thorny sculpin	
21441	*Icelus spatula*	Spatulate sculpin	
21592	*Trichodon trichodon*	Pacific sandfish	
21720	*Gadus macrocephalus*	Pacific cod	X
21725	*Boreogadus saida*	Arctic cod	
21735	*Eleginus gracilis*	Saffrons	
21740	*Theragra chalcogramma*	Walleye pollock	X
21900	*Hexagrammidae*	Greenlings	
21932	*Hexagrammos stelleri*	Whitespotted greenling	
22170	Cyclopterinae	Lumpsuckers	
22200	Liparidinae	Snailfish	
23000	Osmeridae	Smelts	
23010	*Thaleichthys pacificus*	Eulachon	
23041	*Mallotus villosus*	Capelin	
23800	Stichaeidae	Pricklebacks	
23871	Pholidae	Gunnels	
24185	*Lycodes palearis*	Wattled eelpout	
24191	*Lycodes brevipes*	Shortfin eelpout	
30000	Scorpaenidae	Scorpionfish and Rockfish	X

Results

The shape of the eastern Bering Sea CSS for all fish species showed most of the numbers were in size classes 25 to 30 cm (Figure 1). Significant changes in CSS were found for all groups. The intercept of the CSS for all fish showed a modest but significant decrease (slope= -0.38, p<< 0.005) (Figure 2a). When groupings were analyzed separately for commercial and nontarget fish, both commercial and nontarget fish showed a negative trend in average intercept (slope= -0.55, p<<0.005; slope= -0.17, p= 0.02, respectively). There was also a statistically significant increase in the slope of the overall fish community size spectrum (CSS) (slope =0.14, p<< 0.005) (Figure 2b). When analyzed separately, commercial fish and nontarget fish each had a significantly positive change in slope (slope= 0.20, p<<0.005; slope= 0.06, p= 0.006, respectively).

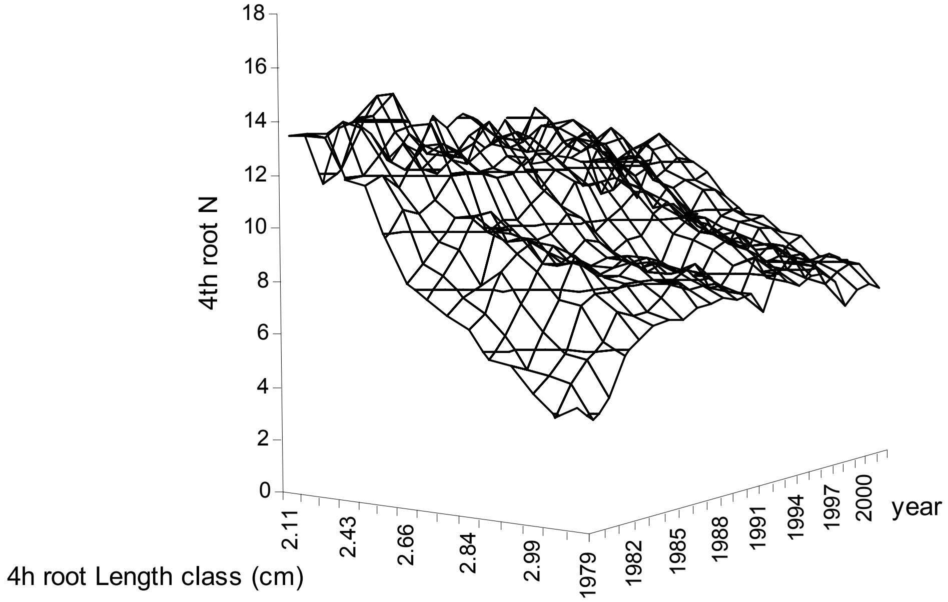

Figure 1. Eastern Bering Sea demersal fish community size spectrum

Spearman rank correlation of catch per unit effort (CPUE) and year did not correlate significantly for any group. The correlation for mean individual weight (w_i) of all fish species and time was not significant, although nontarget fish showed a positive correlation of w_i over time (Table 3). The species which showed positive relationships for w_i were yellow Irish lord, warty sculpin, and plain sculpin. These three species also had negative trends in CPUE over time. Seven of thirteen commercial fish species showed a significant positive correlation between w_i and time, including arrowtooth flounder, Greenland turbot, Pacific halibut, flathead sole, yellowfin sole, starry flounder, and rock sole. Five of these also had significant positive relationships for CPUE and year. Pacific cod was the only commercial fish species to show a significant negative correlation, in both w_i and CPUE.

No significant differences were found in k-dominance curves between year groups (Figure 3).

SIMPER analysis showed 9 species typified the eastern Bering Sea bottom trawl fish community between 1979 and 2002, dominated by walleye pollock, yellowfin sole, rock soles, and Pacific cod (Figure 4). Across all years, walleye pollock and flathead sole contributions remained more or less constant. Rock soles appeared consistently after 1983 and increased significantly thereafter. Skates began contributing regularly to the top 90% of fish CPUE in 1993, and their contribution has increased in the ensuing years. Alaska plaice, yellowfin sole and Pacific cod have decreased in percent contribution to CPUE over time. Arrowtooth flounder were contributors in 1996 and 1998, but do not appear regularly because their distribution is concentrated within a few strata.

Simple correlation analysis of fishing effort, expressed as number of bottom tows per year, bottom temperature, and slope and intercept of CSS for the various groups showed that fishing effort was correlated with slope (r = 0.52), and intercept (r = -0.44) of the CSS (Table 4). Bottom temperature was correlated with both slope and intercept of all fish and nontarget fish groups.

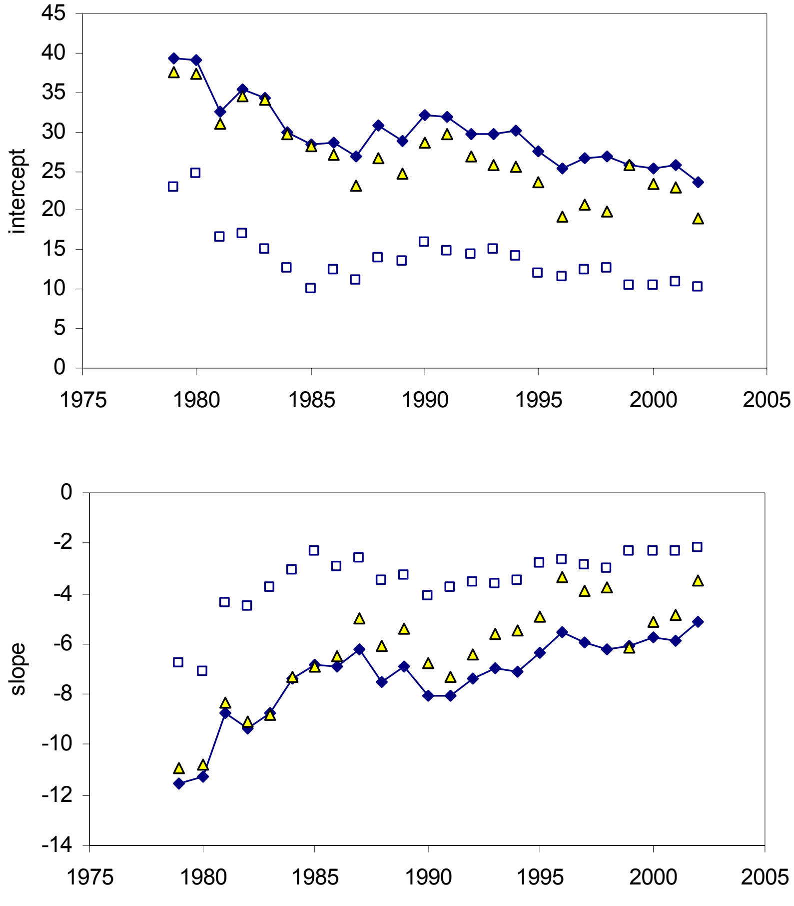

Figure 2. Changes in intercept and slope of the CSS for the eastern Bering Sea from 1979 to 2002. A) Intercept B) Slope. Key: ♦ = All fish species; Δ = Commercial fish species; □ = nontarget species.

Table 3. Spearman rank correlation coefficients of mean individual weight (kg) and CPUE (kg/ha) with year for the eastern Bering Sea, 1982-2002 (*=significant at $p<0.05$; n.s.= not significant).

	w_i	CPUE
ALL FISH	0.308 n.s.	-0.201 n.s.
commercial fish	0.273 n.s.	-0.152 n.s.
nontarget fish	0.504*	0.266 n.s.
Arrowtooth flounder	0.821*	0.590*
Greenland turbot	0.842*	0.403 n.s.
Pacific halibut	0.570*	0.694*
flathead sole	0.930*	0.581*
rex sole	0.388 n.s.	0.184 n.s.
yellowfin sole	0.531*	-0.701*
starry flounder	0.649*	0.904*
rock sole	0.600*	0.834*
Alaska plaice	0.253 n.s.	-0.712*
Pacific herring	-0.138 n.s.	0.190 n.s.
Pacific cod	-0.669*	-0.551*
walleye pollock	0.382 n.s.	-0.192 n.s.
rockfish	0.175 n.s.	0.227 n.s.
skates	-0.060 n.s.	0.416 n.s.
Dover sole	-1.327*	-1.596 n.s.
longhead dab	-0.634*	-0.386 n.s.
poachers	-0.245 n.s.	-0.456*
sawback poacher	-0.097 n.s	0.383 n.s.
sturgeon poacher	-0.171 n.s.	0.299 n.s.
Aleutian alligatorfish	-0.130 n.s.	0.035 n.s.
Bering poacher	-0.231 n.s.	0.142 n.s.
Pacific sand lance	-0.229 n.s.	-0.140 n.s.
Ronquils	-0.094 n.s.	-0.557*
sculpins	-0.357 n.s.	-0.231 n.s.
threaded sculpin	-0.151 n.s.	-0.065 n.s.
armorhead sculpin	-0.297 n.s.	-0.799*
yellow Irish lord	0.457*	-0.657*
butterfly sculpin	-0.173 n.s.	-0.847*
spectacled sculpin	0.019 n.s.	0.226 n.s.
ribbed sculpin	-0.034 n.s.	-0.006 n.s.
warty sculpin	0.851*	-0.726*
great sculpin	0.117 n.s.	0.756*
plain sculpin	0.581*	-0.151 n.s.
spinyhead sculpin	-0.178 n.s.	0.561*
bigmouth sculpin	0.261 n.s.	0.684*
thorny sculpin	-0.021 n.s.	-0.181 n.s.
spatulate sculpin	-0.129 n.s.	-0.045 n.s.
Pacific sandfish	0.193 n.s.	0.237 n.s.
Arctic cod	-0.197 n.s.	0.248 n.s.
saffrons	0.212 n.s.	-0.167 n.s.
whitespotted greenling	0.109 n.s.	0.096 n.s.
lumpsuckers	-0.312 n.s.	-0.421 n.s.
snailfish	-0.305 n.s.	-0.108 n.s.
smelts	-0.443 n.s.	-0.472*
eulachon	-0.053 n.s.	0.309 n.s.
capelin	-0.179 n.s.	-0.401 n.s.
pricklebacks	-0.140 n.s.	-0.519*
wattled eelpout	0.264 n.s.	0.099 n.s.
shortfin eelpout	-0.677*	0.181 n.s.

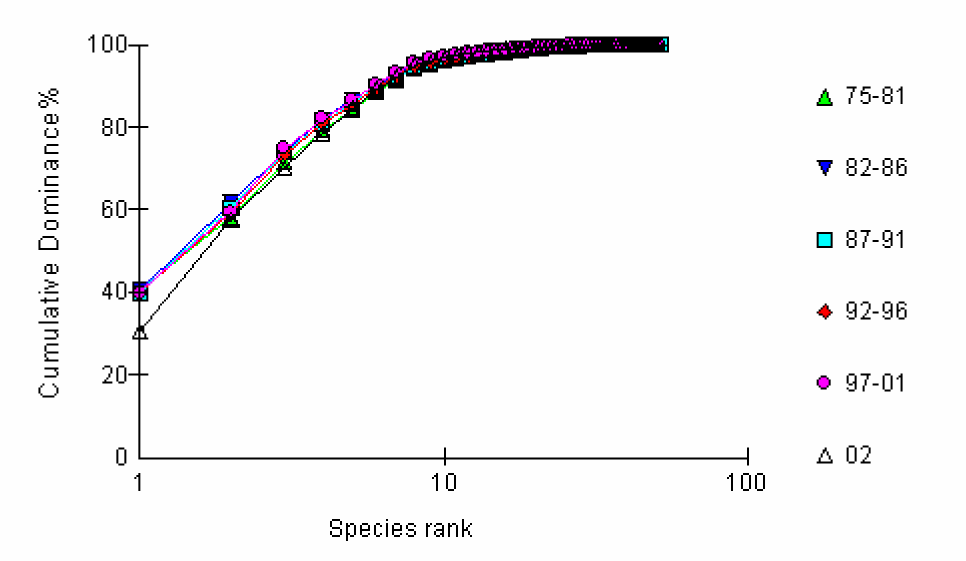

Figure 3. k-dominance curves for the eastern Bering Sea, for the years 1975 and 1979-2002. Grouped by 5-year intervals where possible. 1975-1981 were grouped together because survey gear was not standardized prior to 1982.

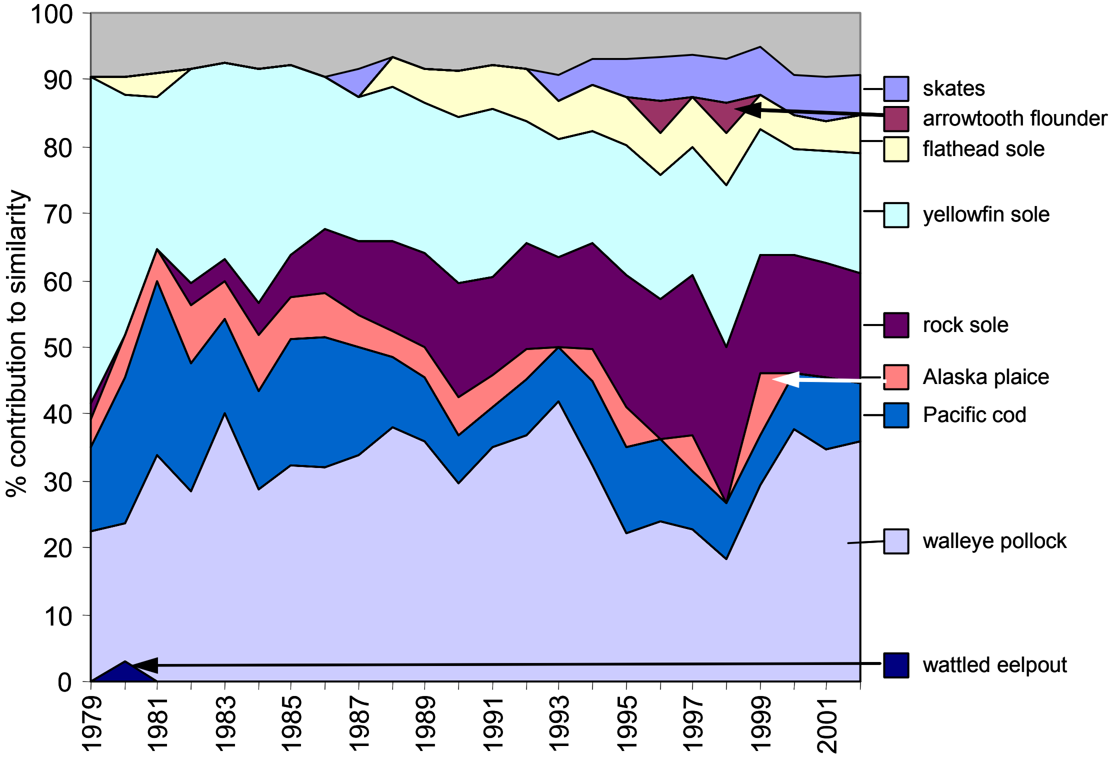

Figure 4. SIMPER results showing the top 90% of typifying fish species in the eastern Bering Sea. Typifying species contribute to similarities between all survey stations.

Table 4. Correlation analysis results for fishing effort (number of tows) and bottom temperature with slope and intercept of community size spectra. (*=significant at $p<0.05$; n.s.= not significant)

	NTOWS	BTEMP	ALLFISHslope	COM_FISHslope	NC_FISHslope	ALLFISHint	COM_FISHint	NC_FISHint
NTOWS	--							
BTEMP	-0.435*	--						
ALLFISHslope	0.520*	-0.378*	--					
COM_FISHslope	0.505*	-0.225 n.s.	0.949*	--				
NC_FISHslope	0.529*	-0.452*	0.955*	0.837*	--			
ALLFISHint	-0.443*	0.348*	-0.991*	-0.932*	-0.939*	--		
COM_FISHint	-0.442*	0.186 n.s.	-0.942*	-0.994*	-0.817*	0.939*	--	
NC_FISHint	-0.500*	0.437*	-0.943*	-0.819*	-0.997*	0.932*	0.803*	--

Discussion

Overall, there was a slight increase in the value of the slope (less steep slope over time) and a decrease in the intercept of the fish community size spectrum. The bottom trawl fish community appears to have fewer small individuals and more large individuals through time, leading to these observed trends. Modeling results from Gislason & Rice (1998) indicate that both slopes and intercepts are linear functions of fishing mortality, while changes in intercept have alternatively been related to changes in system productivity (Greenstreet & Hall 1996, Jennings et al. 1999, Bianchi et al. 2000). Slopes of the CSS for all groups were positively correlated with fishing effort in this system, and effort was negatively correlated with the overall intercept for all groups. This is opposite of what other studies have found (Bianchi et al. 2000, Zwanenburg 2000, Rice & Gislason 1996), in which they verified the expectation that increases in fishing effort would remove a proportionally greater amount of larger animals, thereby increasing the proportion of small animals in the community or release them from competition and/or predation, leading to a decrease in value of the slope (steeper slope).

Both slope and intercept of the CSS for all fish and nontarget fish were correlated with bottom temperature. Year class strength has been associated with oceanic conditions, with strong year classes observed through the ‘warm’ regime, 1976-1988, and a regime shift in 1989 leading to widespread declines in production and lower recruitment for the years 1989-1996 (Benson & Trites 2002, Conners et al. 2002, Wilderbuer et al. 2002). The negative shifts in intercepts are an indication of lower recruitment success for all groups, generally corroborated by observed negative derivatives from average recruitment seen in many groundfish species (NPFMC 2003). With the available data, it appears that environment had greater influence on the community as a whole as well as nontarget fish species. Zwanenburg (2000) found on the eastern Scotian shelf that slope of the CSS was not correlated with effort, but was positively correlated with bottom temperature (slope steeper with colder bottom temp), whereas on the western shelf, slope was negatively correlated with effort but not temperature. He concluded that lack of correlation with effort argues for greater influences of temperature. The increasing (less negative) slope with increasing effort found in our analyses is reflected in the increasing trend in the CSS over time in the number of larger fish. Decreased recruitment over time, as reflected in the negative trend in CSS intercepts, are occurring despite increases in the number of larger fish. This might reflect environmental influences on recruitment success.

In systems dominated by a few species, a very strong year class would initially increase the intercept and thus make the slope steeper as the species recruit to the community, and make the slope less steep as the yearclass moves through the larger size classes (Bianchi et al. 2000). Walleye pollock are the dominant species in this community, composing up to 50% of the total annual CPUE. This species had a strong year class in 1978 and experienced a drop in exploitation rates from 30-40% in the mid-1970s to <10% in the early 1980s (NPFMC in Conners et al. 2002). Being such a large percentage of overall fish community, this species alone

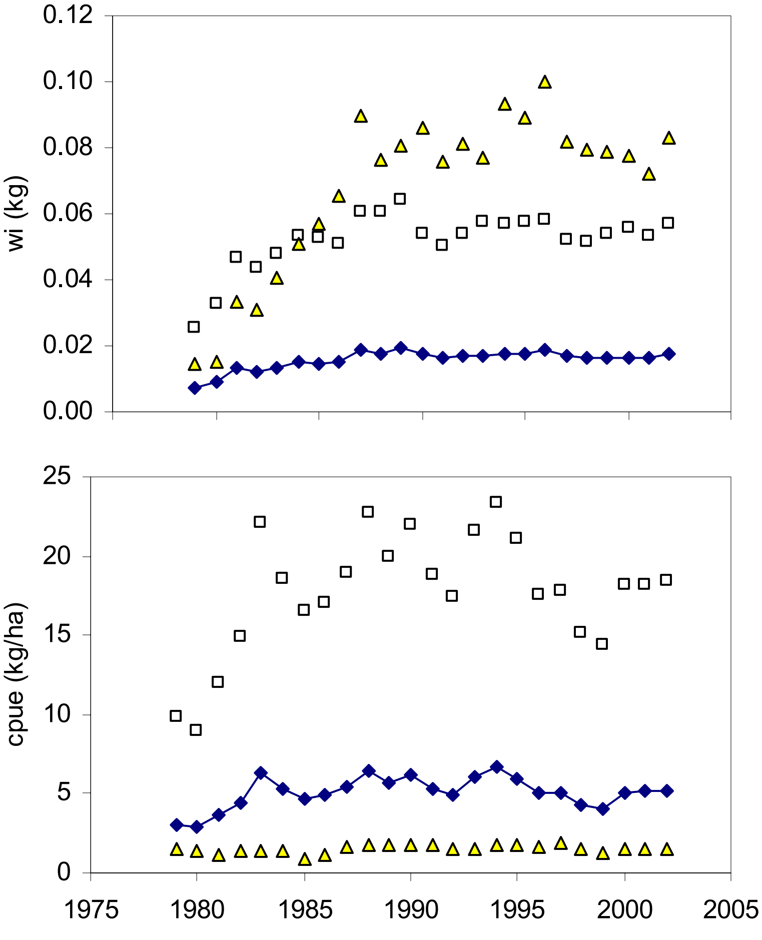

Figure 5. Annual mean individual weight (w_i) and Catch Per Unit Effort for fish species in the eastern Bering Sea, weighted by species abundance. Key: ♦ = All fish species; □ = Commercial fish species; Δ = nontarget species.

might drive the overall pattern of increasing slope and decreasing intercept of the overall fish CSS. But in addition, there were low exploitation rates of commercially important flatfish, which may have led to an additional increase in larger sized fish. The only commercial fish species to decline significantly in mean individual weight and biomass from 1982-2002 was Pacific cod. The decline in Pacific cod w_i may be due to the large 1977 year class attaining large adult weight during the mid-1980's. The increases in other fish species w_i over time may be due to a lack of young fish, especially among Greenland turbot and Pacific halibut. Three nontarget fish species showed positive relationships for w_i and negative trends in CPUE (yellow Irish lord, warty sculpin, and plain sculpin), further indicating poor recruitment in this system. While the increase in mean individual weight of nontarget fish is undoubtedly important, commercial fish overshadow them in the overall analyses.

There appear to be no major changes in community composition over time. While flathead sole and rock sole increased in CPUE and consequently percent contribution over time, yellowfin sole, Alaska plaice, and Pacific cod declined. Yet there were no differences in k-dominance curves between year groups. Had there been a significant change in dominant species, or elimination of less common species, the curves would reflect these changes.

Factors other than fishing, such as the regime shift affecting the North Pacific and eastern Bering Sea during the time period under consideration, may have had an influence on the community size spectrum. Lower recruitment of commercial fish and a decrease in top predators contributed to an increase in overall slope and decrease in intercept. Bianchi et al. (2000) wrote that size spectra are affected by different histories of fishing intensity, and therefore interpretation within an area is not straightforward. Further, the snapshots of community state may not be informative in respect to the state of exploitation. Fishing effort and environment are far from uniform across the Bering Sea, and different conclusions may be drawn when strata and species groups are analyzed separately.

Acknowledgements

We would like to thank Bob McConnaughey for providing bottom trawl effort data, and Geoff Lang for essential data support.

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Ecosystem Goal: Humans are part of ecosystems

Fishing overcapacity programs

Updated 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. Overcapacity can, under certain conditions, have grave implications for conservation as well.

The North Pacific Fishery Management Council has developed several programs to address overcapacity in the Alaskan fisheries. For scallops and most groundfish and crab species, management programs (such as a moratorium and a license limitation program [LLP]) limit the number of harvesting vessels that may be deployed off Alaska. However, rights-based management is increasingly being used to “rationalize” fisheries.

An Individual Fishing Quota (IFQ) program is used to manage the halibut and fixed gear sablefish fisheries. 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 for the Bering Sea and Aleutian Islands (BSAI) crab fisheries would include quota shares for processors and harvesters (including vessel captains) and community protection measures (a so-called “three-pie” program). Some features of this crab program would need to be authorized by Congressional action. The Council is also currently considering an IFQ program for the Gulf of Alaska groundfish fisheries.

Congress, too, has provided 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. And, a program to retire licenses, vessels, and vessel histories from the BSAI crab fisheries has been authorized by Congress and is under development by NMFS.

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' 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 vessel numbers and 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% (down to 350 licenses) relative to the vessel moratorium. The number of vessels eligible for groundfish licenses (N = 1,837) is only slightly less than the number that held moratorium permits (while the LLP carries stricter qualification standards, many moratorium permits were never claimed). 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), for which regulations are under development, also 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 2002, 3,556 persons held halibut QS and 888 held sablefish QS. The number of vessels landing halibut in the IFQ fishery declined from 3,450 in 1994 to 1,385 at the end of 2002; the number landing sablefish in the IFQ fishery declined from 1,191 in 1994 to 415 in 2002.

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. Vessel size of participating vessels has ranged from 201- 376 ft length overall LOA.

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 authorizes also 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, the number of catcher vessels delivering to motherships dropped 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 has since dropped to 17 in 2002.

In 1998, there were 107 inshore catcher vessels that 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 86 in 2002.

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

Groundfish fleet composition

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

Fishing vessels participating in the groundfish fisheries in the EEZ 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 less than 1,097 in 1998, and is currently 1,006 in 2002 (Figure 1). Hook and line vessels accounted for about 1,114 and 675 of these vessels in 1994 and 2002, respectively. The number of vessels using trawl gear has tended to decrease, during this eight-year period it decreased from 255 to 231 vessels. During the same period, the number of vessels using pot gear peaked in 2000 at 316, but decreased to 175 in 2002.

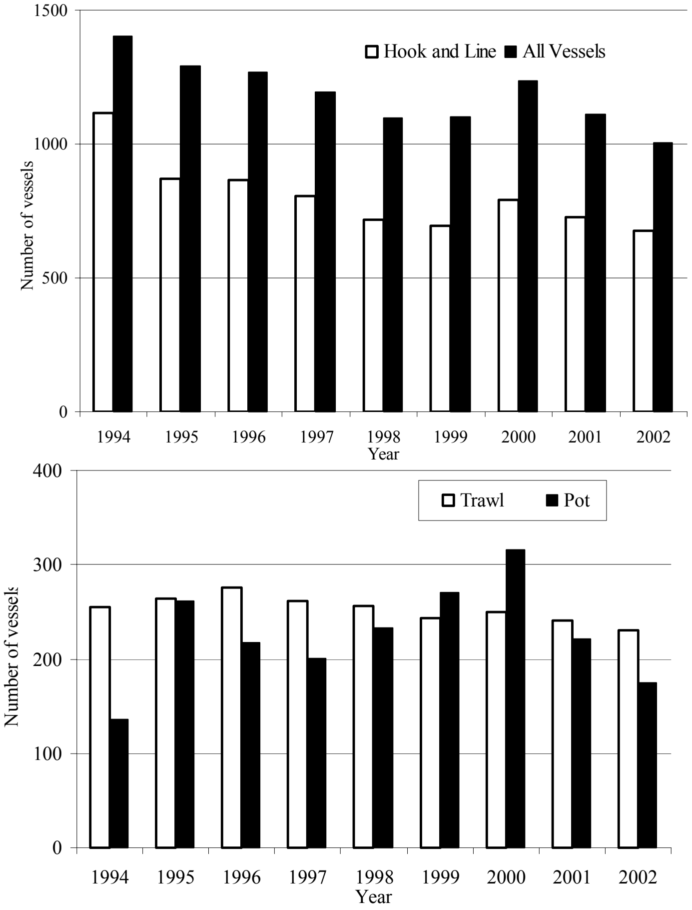

Figure 1. Number of vessels participating in the groundfish fisheries in the EEZ off Alaska by gear type, 1994-2002.

Ecosystem Assessment of the Bering Sea/Aleutian Islands and Gulf of Alaska Management Regions

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Summary

The primary intent of this assessment is to summarize historical climate and fishing effects on the shelf and slope regions of the eastern Bering Sea/Aleutian Islands and Gulf of Alaska from an ecosystem perspective and to provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function. The Ecosystem Considerations section of the Groundfish SAFE's provides the historical perspective of status and trends of ecosystem components and ecosystem-level attributes using an indicator approach. Multispecies and ecosystem models provide the tools for prediction of possible future effects and form the basis for assessment of the possible future effects of fishing on BSAI and GOA ecosystems. Multispecies bycatch model predictions of catch, bycatch, and characteristics of various fishing strategies provide future predictions of realistic fishing mortalities expected for groundfish stocks and the bycatch of nontarget species in groundfish fisheries given the present bycatch and OY constraints of the groundfish fisheries of the BSAI and GOA. Fishing mortalities from the multispecies bycatch model can be used to drive multispecies and ecosystem predator/prey simulations to evaluate the predator/prey implications of these fishing strategies. These predator-prey models are not used for year-to-year management advice but provide a method for assessing the possible medium and long-term implications of fishing strategies on predator/prey relationships and energy flow in these systems.

This is the first year that this assessment strategy is being used and not all of the modeling tools are ready for use in projections. Evaluation of the assumptions behind the forecasting methods of the models is presented and results from the multispecies bycatch model projections are used for assessing future ecosystem effects. Recommendations are made for improving the multispecies and ecosystem predator/prey model forecasts for future use in this chapter. As noted by Carpenter (2002), a limitation of ecological forecasts includes the uncertainty of predictions because the future probability distributions of drivers such as climate may be unknown or unknowable. Development of possible future scenarios, expansion of our forecasting capabilities within the space/time constraints that are relevant to human action, and identification of management choices that are robust to a wide range of future states are possible ways this assessment can be broadened in the future.

Introduction

Fish are only one component of a complex marine ecosystem. Removing fish for human consumption can potentially have broad impacts on the marine ecosystem unless safeguards are incorporated into fishery management plans. Fisheries can impact fish and ecosystems by the selectivity, magnitude, timing, location, and methods of fish removals. Fisheries can also impact ecosystems by vessel disturbance, nutrient cycling, introduction of exotic species, pollution, unobserved mortality, and habitat alteration.

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

Methods

Assessment Approach: Effects categories, indicators, thresholds

Ecosystems consist of populations and communities of interacting organisms and their physical environment that form a functional unit and have some characteristic trophic structure and material cycles (i.e., how energy or mass moves among the groups). Evaluation of the effects of fishing on ecosystems should include these characteristics of ecosystems: populations, communities, physical environment, trophic structure and material (or energy) cycles. Previous ecosystem analyses for the draft groundfish FMP environmental impact statements categorized effects into three main classes: predator/prey, energy flow and removal, and diversity. This report summarizes potential ecosystem impacts based on 2003 harvest recommendations. Unlike the Draft Programmatic Supplemental Environmental Impact Statement (DPSEIS) (NMFS 2003), which evaluated a whole suite of management alternatives, this analysis considers only fishing mortality changes encompassed by the TAC Environmental Assessment alternatives and OY cap constraints.

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

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

A great deal of literature has been written on possible indicators of ecosystem status in response to perturbations (eg., Odum 1985, Pauly et al. 1998, Rice and Gislason 1996, Murawski 2000). These indices can show changes in energy cycling and community structure that might occur due to some external stress such as climate or fishing. For example, fisheries might selectively remove older, more predatory individuals. Therefore, we would expect to see changes in the size spectrum (the proportion of animals of various size groups in the system), mean age, or proportion of r-strategists (faster growing, more fecund species such as pollock) in the system. These changes can increase nutrient turnover rates because of the shift towards younger, smaller organisms with higher turnover rates. Total fishing removals and discards also provide a measure of the loss and re-direction of energy in the system due to human influences. Total fishing removals relative to total ecosystem energy could indicate the importance of fishing removals as a source of energy removal in an ecosystem. Changes in scavenger populations that show the same direction of change as discards could be an indicator of the degree of influence discards have on the system. Discards as a proportion of total natural detritus would also be a measure that could indicate how large discards are relative to other natural fluxes of dead organic material. Levels of total fishing removal or fishing effort could also indicate the potential for introduction of non-native species through ballast water in fishing vessels. Fishing practices can selectively remove predators or prey. Tracking the change in trophic level of the catch may provide information about the extent to which this is occurring (eg., Pauly et al. 1998). Thus, we will use measures of total catch, total discard, and changes in trophic level of the catch to indicate the potential of fishing to impact ecosystem energy flow and turnover.

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

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

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

Issue	Effect	Significance Threshold	Indicators
Predator-prey relationships	Pelagic forage availability	Fishery induced changes outside the natural level of abundance or variability for a prey species relative to predator demands	Population trends in pelagic forage biomass (quantitative - pollock, Atka mackerel, catch/bycatch trends of forage species, squid and herring)
	Spatial and temporal concentration of fishery impact on forage	Fishery concentration levels high enough to impair the long term viability of ecologically important, nonresource species such as marine mammals and birds	Degree of spatial/temporal concentration of fishery on pollock, Atka mackerel, herring, squid and forage species (qualitative)

	Removal of top predators	Catch levels high enough to cause the biomass of one or more top level predator species to fall below minimum biologically acceptable limits	Trophic level of the catch Sensitive top predator bycatch levels (quantitative: sharks, birds; qualitative: pinnipeds) Population status of top predator species (whales, pinnipeds, seabirds) relative to minimum biologically acceptable limits
	Introduction of nonnative species	Fishery vessel ballast water and hull fouling organism exchange levels high enough to cause viable introduction of one or more nonnative species, invasive species	Total catch levels
Energy flow and balance	Energy re-direction	Long-term changes in system biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery discarding and offal production practices	Trends in discard and offal production levels (quantitative for discards) Scavenger population trends relative to discard and offal production levels (qualitative) Bottom gear effort (qualitative measure of unobserved gear mortality particularly on bottom organisms)
	Energy removal	Long-term changes in system-level biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery removals of energy	Trends in total retained catch levels (quantitative)

Diversity	Species diversity	Catch removals high enough to cause the biomass of one or more species (target, nontarget) to fall below or to be kept from recovering from levels below minimum biologically acceptable limits	Population levels of target, nontarget species relative to MSST or ESA listing thresholds, linked to fishing removals (qualitative) Bycatch amounts of sensitive (low potential population turnover rates) species that lack population estimates (quantitative: sharks, birds, HAPC biota) Number of ESA listed marine species Area closures
	Functional (trophic, structural habitat) diversity	Catch removals high enough to cause a change in functional diversity outside the range of natural variability observed for the system	Guild diversity or size diversity changes linked to fishing removals (qualitative) Bottom gear effort (measure of benthic guild disturbance) HAPC biota bycatch
	Genetic diversity	Catch removals high enough to cause a loss or change in one or more genetic components of a stock that would cause the stock biomass to fall below minimum biologically acceptable limits	Degree of fishing on spawning aggregations or larger fish (qualitative) Older age group abundances of target groundfish stocks

Data Sources and Models

Quantitative measures of some of the indicators mentioned above in a historical sense are derived from the Ecosystem Considerations for 2004 section (Boldt 2003). Predictions of the future ecosystem status based on these indicators will be derived from three modeling approaches in future assessments. These model approaches include: 1) multispecies bycatch model, 2) age-structured multispecies predator/prey forecast, and 3) biomass dynamics predator/prey forecast. The first approach was used in the NMFS Programmatic Supplemental Alaska Groundfish EIS (NMFS 2003) to forecast dynamics of target groundfish species and bycatch amounts of other species. The latter two approaches are being presented here for the first time with respect to the assumptions and methodology of the models. There are still some methodological problems with doing forecasts with these models that need to be resolved before their use in this assessment. Some of the issues that require further work include properly modeling prohibited species bycatch and the OY cap constraints along with target species catches. The other main issue that needs resolution is standardizing the way recruitment is handled in all three of these modeling approaches. These issues will be worked on in the coming year.

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

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

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

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

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

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

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

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

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

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

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

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

Fishing Scenarios

The following fishing scenarios are proposed to evaluate the present TAC-setting strategy of groundfish fisheries within the context of the PSC bycatch limits and OY cap that constrain these fisheries. These fishing scenarios will be run using the multispecies bycatch model from 2003 through 2023. These scenarios are similar to those alternatives considered in the TAC EA. Some differences are that we consider some scenarios with and without the OY cap to highlight the effect of that cap in constraining catch in the BSAI and to provide an evaluation of the implications of this constraint from a multispecies and ecosystem point of view. This evaluation was recommended by the NPFMC F40 review panel. Also, TAC EA alternative 4 is not modeled here because that alternative is an attempt to mimic the constraints that the multispecies bycatch model explicitly considers. There may not be much contrast between alt 1 and alt2.2. Note that for the GOA, Alts 2.1 and 2.2 are identical (since the OY cap doesn't typically constrain TAC). Also, the difference between Alt 1 and 2.2 is only the author's adjustment.

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

Results

The following is a summary of key ecosystem indicators in the baseline, obtained primarily from the Ecosystem Considerations Section, and the model predictions of these indicators from the multispecies bycatch model (Tables 2 and 3) for the TAC alternatives listed above. As mentioned in the Methods Section, predictions from the multispecies and ecosystem predator/prey models are not yet available because methods for forecasting using the same bycatch and OY constraints and recruitment assumptions as the multispecies bycatch model are still being derived. As these models and the forecasting methodology are verified, these results will be included in future assessments.

1.) Climate indicators of PDO or El Nino status

The Pacific Decadal Oscillation (PDO), an indicator of the North Pacific climate, shifted from positive to negative in 1999 and remained negative until 2002 (Mantua and Hare 2003). This indicated that a shift to a cool, pre-1977-type regime may have occurred in 1998/99. In August 2002, however, the index shifted back to positive and has remained positive through July 2003, introducing uncertainty into the hypothesis that a regime shift occurred in the late 1990's (Mantua and Hare 2003). One confounding factor is the occurrence of El Nino and La Nina events. An extended La Nina occurred from 1999-2001 and then an El Nino occurred in the winter of 2003, which resulted in conditions similar to that of a positive PDO (Rodionov et al. 2003).

Bond et al. (in review) suggest that the PDO should not be the only index examined to determine the state of the North Pacific. Spatial patterns of sea surface temperature anomalies (SSTA) and sea level pressure anomalies (SLPA) during winters of 1999-2002 did not resemble those of the pre- or post-1977 conditions (Bond et al. in review; Rodionov et al. 2003). During 1999-2002, there was a dipole of pressure, with a positive pressure anomaly centered over the eastern subtropical Pacific, and a negative pressure anomaly centered over the Bering Sea and eastern Alaska (Rodionov et al. 2003). This resulted in cold sea surface temperatures in the eastern Pacific and warm temperatures in the central Pacific and the Bering Sea (Rodionov et al. 2003). Oceanographic conditions in the Bering Sea and Gulf of Alaska therefore continue to resemble the post-1976/77 regime; whereas, conditions in the Pacific Northwest currently resemble the pre-1977 regime (Bond et al. in review; Peterson and Schwing 2003). Current conditions are near average and neither a La Niña nor an El Niño are expected to develop in the fall of 2003 (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/, October 2, 2003).

Predictions: Reasonably foreseeable future effects of climate change and regime shifts on BSAI and GOA ecosystems are not well-known. Individual species may respond favorably to a particular regime while others may experience declines. Prediction of future climate effects on these ecosystems is complex and requires better understanding of the probability of certain climate states in the near-term and longer term and the effects of this variability on individual species production and distribution and food webs. Future ecosystem assessments may integrate various climate scenarios into the multispecies and ecosystem forecasting models by using assumptions about the effects of climate on average recruitment of target species.

2.) Population trends in pelagic forage biomass

GOA walleye pollock population status and trends

In 2002, GOA walleye pollock (177,070 t) were estimated to be at 28% of the unfished stock size and below $B_{40\%}$ (240,000 t) (Dorn et al. 2002). The 1999 year class strength is above average and strongly influences estimates of spawning stock (Dorn et al. 2002). The EIT survey in Shelikof Strait in 2002 indicated that there was a 38% decline in total abundance and a 62% decrease in adult biomass (Dorn et al. 2002). This may indicate reduced utilization of Shelikof Strait by spawning pollock (Dorn et al. 2002). In 2003, biomass estimates in the 2003 Shelikof Strait EIT survey and the 2003 NMFS bottom trawl survey were higher than in 2002; however, the ADFG trawl survey showed a 30% decline in biomass (Dorn et al. 2003).

Predictions: The multispecies bycatch model predicts that GOA pollock biomass will increase in the long-term in all the TAC EA alternatives. Preferred alternative 2.1 shows a predicted increase of about 74% that relies heavily on the recruitment of the above-average 1999 year class. Climate-induced recruitment changes have the potential to cause large deviations from these predictions.

AI Atka mackerel population status and trends
Total biomass of Atka mackerel was high in the early 1980's and again in the early 1990's (Lowe et al. 2002). Stock size decreased by 43% from 1991 to 1999, and then increased in 2001 (Lowe et al. 2002). The 2002 trawl survey estimates indicate a 50% increase in biomass (Lowe et al. 2002). The 1998 year class appears to be very strong. Female spawning biomass is above $B_{35\%,}$ therefore the stock is not considered overfished nor approaching an overfished condition (Lowe et al. 2002).

BS walleye pollock population status and trends
Bottom trawl and EIT survey biomass estimates for 2002 were 16% and 18% higher than estimates in the previous year (2001 for bottom trawl surveys and 2000 for the EIT survey) (Ianelli et al. 2002). Exploitable biomass (ages 3 and older) of EBS pollock increased since 1991 and has been variable at about 10 million tons (Ianelli et al. 2002). Currently, the biomass is high and decreasing (Ianelli et al. 2002). Female spawning biomass is well above B40% and B35% (Ianelli et al. 2002).

Predictions: Multispecies bycatch model predictions of changes in total of BS pollock and AI Atka mackerel biomass indicate positive changes ranging from 10 to about 70% in each of the TAC alternatives. Status quo alternative indicates a possible increase of about 15% in the biomass of forage that are targets of groundfish fisheries. These results rely heavily on the estimates of average recruitment from 1978-2001 to drive the projections. Climate-induced recruitment changes have the potential to cause large deviations from these predictions.

Herring
Herring bycatch in BSAI and GOA federally- managed FMP groundfish fisheries decreased in 2002 and is at the lowest value since 1994 (Hiatt and Terry 2003). Bycatch estimates range from 1823.4 metric tonnes (mt) in 1994 to 132.7 mt in 2002 (Hiatt and Terry 2003). Bycatch in the BSAI (130.5 to 1723.3 mt) is higher than that in the GOA (2.2 to 100.2 mt) (T. Hiatt, Alaska Fisheries Science Center, personal communication). BSAI herring bycatch estimates represent between 0.1% and 1.0% of the Togiak herring biomass estimates and between 0.1% and 0.7% of the total estimated herring biomass in 4 managed areas of the Bering Sea: Togiak, Norton Sound, Cape Romanzof district, and the Kuskokwim area (West 2003; Lingnau and Salomone 2003; Menard et al. 2003; Estensen and Bue 2003). Bycatch of herring relative to assessed populations in the GOA range from 2.4% (in 2000) to 11.5% (in 1994) of the PWS biomass and 0.1% (in 2002) to 0.5% (in 1994) of the Southeast AK biomass (Sharp et al. 2000; Carlile 2003). Overall, bycatch as a percent of assessed population biomass is small; however, spatial overlap of groundfish fisheries with these populations has not been examined here.

Squid
Most squid catch is incidental to the pollock fisheries. Squid bycatch in groundfish fisheries of the GOA decreased from 1997 to 2000 (97.5 to 18.6 t) and then increased in 2001 (90.8 t) due to very high catches in area 620 and increased catches in areas 610 and 630 (Gaichas 2002; Gaichas and Boldt 2003). Bycatch of squid in the BSAI decreased from a high of 9000 t in 1978 to a few

hundred tons in 1987-95 (Gaichas 2002). Squid bycatch in the BS also decreased from 1997 to 2000 (1,573.4 to 412.9 t) and increased in 2001 (1,810.4 t) due to high catches in areas 517 and 519 (Gaichas 2002; Gaichas and Boldt 2003).

Forage species

The bycatch of forage species in the GOA increased considerably in 2001 (540.8 t) compared to 1997-2000 (27.2-124.9 t), primarily due to a large increase in the catches of smelts in area 620 (128.8 t) (Gaichas and Boldt 2003; Nelson 2003). The bycatch decreased to 158.3 t in 2002 (Nelson 2003). In 2001, catch of Sticheidae fish (4.66 t) was also higher than in previous years (0.03 -3.53 t) due to catches in areas 610, 620, and 630, but then decreased to 0.1 t in 2002 (Gaichas and Boldt 2003; Nelson 2003).

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

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

Predictions: Multispecies bycatch model projections of forage species (including squid, herring, forage species category) bycatch in target groundfish fisheries by TAC alternative show large percent increases in the bycatch amounts in the GOA, amounting to about 250% increase from the baseline. Bycatch of pelagic forage in the BSAI are projected to decrease by about 1 to 20% in the alternatives, with the preferred alternative of 2.1 showing about a 8% long term decrease in bycatch amounts of non-target species forage. Although the bycatch increases in the GOA are large on a percent change basis, these likely will not impact forage species populations, given the low exploitation rates of around 1% estimated in the baseline.

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

GOA Walleye pollock

Winter fishing effort is usually concentrated in Shelikof Strait and near the Shumagin Islands, and targets pre-spawning pollock (Dorn et al. 2002). Observer-recorded catches in winter 2001 were concentrated in Shelikof Strait and on the northeast side of Kodiak Island. Summer and fall 2001 fishing effort was concentrated on the southeast side of Kodiak Island and south of Unimak Pass (Dorn et al. 2002).

Most recommended TACs for 2003 (from the 2002 assessment) were similar or slightly lower than those recommended for 2002 in most areas and seasons (Dorn et al. 2002). Exceptions included the A season near Kodiak where the 2003 TAC was twice the 2002 TAC, Chirikof where the 2003 TAC was about 25% less than the 2002 TAC, and West Yakutat where there was no 2003 TAC in A, B, or C seasons (Dorn et al. 2002).

Atka mackerel

The distribution of biomass in the Western, Central, and Eastern Aleutians, and the southern Bering Sea shifted between each of the 1991, 1994, 1997, 2000 and 2002 surveys, and most dramatically in area 541 in the 2000 survey (Lowe et al. 2003). In 1994 for the first time since the initiation of the Aleutian triennial surveys, a significant concentration of biomass was detected in the southern Bering Sea area (66,600 t) (Lowe et al. 2003). This occurred again in 1997 (95,700 t) and most recently in 2002 (59,883 t). These biomass estimates are a result of large catches from a single haul encountered north of Akun Island in all three surveys. In both 1991 and 1994, the Western area contributed approximately half of the total estimated Aleutian biomass, but dropped to 37% in 1997 (Lowe et al. 2003). The proportion of biomass in the Western area has remained fairly stable since 1997. In 1994, 14% of the Aleutian biomass was found in the Central area compared to 40% in 1991 and up to 65% 2000 survey. The most recent 2002 survey showed the Central area contributing 42% of the Aleutian biomass (Lowe et al. 2003).

A four-year schedule from 1999-2002 was proposed to disperse fishing both temporally and spatially within Steller sea lion critical habitat in the BSAI (Lowe et al. 2003). The TAC was divided equally between two seasons, January 1 to April 15 and September 1 to November 1 (Lowe et al. 2002). Spatial dispersion of fishing was accomplished by dividing catch between areas within and outside of critical habitat. This four-year plan was in addition to bans on trawling within 10 nm of all sea lion rookeries in the Aleutian district and within 20 nm of the rookeries on Seguam and Agligadak Islands (in area 541), which were instituted in 1992 (Lowe et al. 2003). The goal of spatial dispersion was to reduce the proportion of each seasonal allowance caught within CH to no more than 40% by the year 2002. No CH allowance was established in the Eastern subarea because of the year-round 20 nm trawl exclusion zone around the sea lion rookeries on Seguam and Agligadak Islands that minimized effort within CH (Lowe et al. 2003). The regulations implementing this four-year phased-in change to Atka mackerel fishery management became effective on 22 January 1999 and lasted only 3 years (through 2001). In 2002, new regulations affecting management of the Atka mackerel, pollock, and Pacific cod fisheries went into effect. Furthermore, all trawling was prohibited in CH from 8 August 2000 through 30 November 2000 by the Western District of the Federal Court because of violations of the Endangered Species Act (ESA) (Lowe et al. 2003).

BS walleye pollock

The fishery that occurs in January to March (A season) is primarily concentrated north and west of Unimak Island and along the 100m isobath of the Bering Sea shelf (Ianelli et al. 2002). The B-season fishery (September to October) shifted to areas west of 170° W after 1992, when the Catcher Vessel Operational Area was implemented. The trend of increasing catches west of 170° W has continued in the past few years, acting to disperse the fishery spatially (Ianelli et al. 2002). Also catches within sea lion conservation areas has continued to decrease, with the exception of the latter parts of 2001 and 2002. In 1999 additional sea lion critical habitat was closed to pollock fishing around sea lion haulouts in the GOA and BS. In 2000, the entire Aleutian Islands region was closed to pollock fishing. The proportion of pollock caught within SCA in 2002 was higher than in 1999-2001 (Ianelli et al. 2002).

Herring
In 2003, the herring food/bait fishery in PWS was cancelled and no commercial sac roe or spawn-on-kelp fisheries occurred because the threshold spawning biomass was not attained (Bristol Bay area staff, http://www.cf.adfg.state.ak.us/region2/finfish/herring/pws/pwsupd03.htm). The PWS herring spawning biomass is not expected to increase for several years.

The number of purse seine sets made in the Togiak herring fishery has declined. In 2003 it declined again because lower numbers of permit holders participated in the fishery due to its decreased value (http://www.cf.adfg.state.ak.us/region2/finfish/herring/togiak/togpos03.htm).

Predictions: The TAC alternatives do not change any area closures or quarterly allocations of TAC. Spatial/temporal concentration of the catch would change in the alternatives due to more aggressive or less aggressive harvesting policies embodied in each TAC alternative. The preferred alternative retains the same harvesting policy as the baseline and is not anticipated to change the degree of spatial/temporal allocation of the catch on forage species and possible indirect effects on species competing with fisheries for forage.

Indirect effects of groundfish fisheries on pinnipeds may include competition, such as overlap in pinniped prey and fishery target species or size classes, or overlap in pinniped foraging areas and commercial fishing zones. Since it is difficult to measure these indirect effects, Steller sea lion rookery and haul-out trend sites are monitored in seven areas of Alaska during June and July aerial surveys. Counts of adult and juvenile animals provide an index of the population status. Populations from the Eastern GOA to the Central AI increased slightly in 2002; the Western AI population continued to decline (Sinclair 2003). The number of Northern fur seal pups born on the Pribilof Islands provides an index of the population status there. The number of pups born on St. Paul and St. George Islands has continued to decrease in 2002. Understanding and prediction of fishery competition with marine mammals for prey is the intense focus of research in Alaska. Improvements in understanding species movements, distribution, and prey requirements in a seasonal sense and bycatch characteristics of groundfish fisheries on finer spatial/temporal scales are needed to develop and improve predictive models of catch and bycatch composition in a spatial and seasonal sense.

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

Groundfish catch biomass in the BS is dominated by walleye pollock. Catches of pollock increased in 2002. Catch biomass in the AI was dominated by walleye pollock from about 1980 to 1991; after which Atka mackerel, Pacific cod, and rockfish became the dominant catch. Pollock comprised the majority of catch in the GOA from about 1976 to 1985, after which it represented approximately 1/3 to 1/2 of the catches up until 2002. After 1985, Pacific cod, sablefish, halibut, and rockfish represented the other 1/2 to 2/3 of the catch.

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

Predictions: Small percent changes in the trophic level of the catch are predicted by the multispecies bycatch model for each of the TAC alternatives, ranging from 1.3-1.8% in the GOA and less than 1% in the BSAI. This is not a very sensitive indicator. It may be more prudent to evaluate exploitation rates and population trends of top level predators to determine if loss of top trophic level species through fishing is occurring.

5.) Removal of top predators

Groundfish fishery bycatch of:

Sharks

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

In the GOA, sleeper shark bycatch in NMFS observer data is concentrated in the central and western GOA; whereas, the IPHC survey caught sleeper sharks along the entire coastal GOA (Boldt et al. 2003). There was no apparent temporal pattern in sleeper shark bycatch in the GOA or PWS. Bycatch in the BS was lower and concentrated along the BS shelf. BS sleeper shark bycatch in 2001 was the highest since 1997 (Boldt et al. 2003).

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

Birds

The average annual bycatch of seabirds is comprised of 59% fulmars, 20% gulls, 12% unidentified birds, 4% albatross, 3% shearwaters, 2% all other birds. Most seabird bycatch is taken with longline gear (65-94%), although some bycatch is taken with trawls (6-35%) or pots (1%). Pots catch primarily Northern fulmars, trawl and longline fisheries catch a wider variety of seabirds. In 2002, total catch of seabirds was 3,835 in the BSAI and 259 in the GOA (Fitzgerald et al. 2003). This represents a continued decline in bycatch in both areas. The decline in BSAI longline bycatch was primarily due to reduced numbers of Northern fulmars, gulls, shearwaters, unidentified tubenoses, and unidentified seabirds. The decline in GOA longline bycatch was due to a reduction in catch of all bird groups, except unidentified seabirds.

Pinnipeds

Incidental mortality of pinnipeds in groundfish fisheries has been low from 1998-2002, did not exceed PBRs, and is not expected to have a direct effect on the ecosystem (Sinclair 2003). Between 1998 and 2002, an average of 36 harbor seals was taken annually in fisheries in both SEAK and the GOA, and 31 were taken in the BS (Sinclair 2003). An annual average of 3.4 and

29.5 Steller sea lions were taken in the Eastern and Western Pacific (Sinclair 2003). Fifteen Northern fur seals on average were taken in the East North Pacific annually (Sinclair 2003).

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

BS Greenland Turbot

CPUE and AFSC bottom trawl surveys on the slope and shelf of the BS indicate that Greenland turbot abundance decreased from 1979-85, declined moderately from 1985-91, and continued to decline in 1993-2001 (Ianelli et al. 2002). Both the 2001 and 2002 assessments indicate a declining trend in age 1+ biomass of Greenland turbot (Ianelli et al. 2002).

BS and GOA ATF

Arrowtooth flounder (ATF) are the most abundant groundfish in the GOA; however, they are not a major target of commercial fisheries (Turnock et al. 2002). The biomass of age3+ ATF in the GOA changed dramatically between the 1960/70's and the present. From 1961 to 1970, the estimated biomass of ATF ranged from 320,430 to 339,190 metric tonnes (Turnock et al. 2002). After the early 1970's, biomass began to increase and, in 2002, was 1.8 million metric tonnes (Turnock et al. 2002).

In the BSAI, ATF are not the most abundant groundfish. They represented 3% to 8% of the total groundfish biomass in the 1980's and between 8% and 12% of total groundfish biomass from 1990 to 2002 (Wilderbuer and Sample 2002). ATF biomass increased from 156,296 t, in 1980, to 817,700 t in 1996, after which, biomass decreased to 638,000 t in 2002 (Wilderbuer and Sample 2002).

Sablefish

Sablefish abundance increased in the mid-1960's, declined in the 1970's due to heavy fishing, increased in the late 1970's and 1980's, and has since decreased. The relative abundance of sablefish decreased faster in the Eastern BS, AI, and Western GOA than in Central and Eastern GOA, the center of sablefish abundance (Sigler et al. 2003). This has been attributed to size-dependent migration, since small sablefish migrate westward and large sablefish migrate eastward (Heifetz and Fujioka 1991). The 1995 and 1997 yearclasses are two recent strong yearclasses of sablefish which may have reversed the declining sablefish abundance in the Central and Eastern GOA (Sigler et al. 2003). Currently, sablefish abundance appears to be moderate, but is projected to decrease in the short-term future (Sigler et al. 2003).

Halibut

Halibut biomass in the GOA varied from 164,253 t to 271,142 t between 1935 and 1980 (S. Hare, International Pacific Halibut Commission, personal communication). After 1980, halibut biomass increased substantially to a high of 763,784 t in 1996. Biomass decreased slightly in the late 1990's but was still at 717,823 t in 2000 (S. Hare, International Pacific Halibut Commission, personal communication).

Predictions: Multispecies bycatch model predictions of the bycatch trends of top predator species show relatively low percent changes in bycatch rates for sharks and birds in the BSAI are expected (<1%) in the preferred alternative while relatively high percent increases (about 25%) are predicted in the GOA, although the absolute value of the increases are not large in the GOA (about a 200t increase from the baseline in the preferred alternative). The population-level impacts of these catches are unknown for shark species although fishery-independent indicators of shark abundance in the baseline do not show a temporal pattern that might be linked to fishery-induced declines. However, more research to better understand and quantify species-specific bycatch rates of sharks in groundfish fisheries and better independent estimates of shark population abundance are needed.

6.) Introduction of non-native species

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

Total groundfish catch in the AI is much lower than in the BS and has been more variable (from 50,000 to 175,000 t). Total groundfish catch peaked in 1989, comprised mainly of pollock, and in the early 1990's, comprised of pollock, Pacific cod, Atka mackerel, and rockfish. Pollock were a large proportion of catches from the late 1970's to the early 1990's. Currently, the AI is closed to pollock fishing, therefore total catch has decreased; however, the catch of Atka mackerel, Pacific cod, and rockfish have increased and total catch is about 100,000 t.

In the GOA, total groundfish catch has ranged from less than 50,000 t in the 1950's to highs of almost 400,000 t in the mid-1960's, which was associated with high rockfish catches, and mid-1980's, which was associated with high pollock catches. Since the mid-1980's total catch has varied between approximately 150,000 t (in 2002) and 300,000 t (in 1991). The catch of pollock and Pacific cod determine the major patterns in catch variability.

Predictions: Multispecies bycatch model predictions of changes in total catch by TAC alternative show about a 6% decline in total catch in the BSAI and 73% increase in the GOA for the preferred alternative. The potential for nonnative species introduction through ballast water and hull fouling organisms of fishing vessels in the BSAI remains unchanged from the baseline while it has increased potential in the GOA. More research is needed on the potential for survivability of nonnative organisms in the ballast water and hulls of fishing vessels coming from the lower-48. Coordination with ADF&G, which has devised a management plan for Alaska aquatic nuisance species, may be necessary to better understand and mitigate possible threats to Alaskan marine food webs due to invasive species introductions via fishing vessels.

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

Discards of Target Species

Discards of target groundfish decreased after 1997 in both the GOA and BSAI, after which it has been relatively stable (Hiatt and Terry 2003). From 1998 to 2002, the biomass of groundfish discarded was higher in the BSAI (approximately 125,000 t) than in the GOA (approximately

25,000 t); however, the percent of groundfish discarded was higher in the GOA (approximately 12%) than in the BSAI (approximately 8%) (Hiatt and Terry 2003).

Discards of Non-Target Species

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

Scavenger Species in the GOA and BSAI:

Birds

Overall, in 2000, seabirds nested earlier than average in the SE BS, AI, GOA, and SEAK. The one exception is the Middleton Island colony of black-legged kittiwakes (Kuletz and Rivera 2002). Productivity in 2000 was average or equal throughout most of Alaska except for murres at Kasatochi Island in the Central AI. Increased productivity was most often seen in piscivorous seabirds and equal productivity was seen in planktivorous seabirds. In 2000, 12 populations had increased, 8 decreased, and 7 showed no change (Kuletz and Rivera 2002).

Gulls

No discernable trends in glaucous-winged gull populations were apparent in the BS or in SEAK, as of 2000 (Kuletz and Rivera 2002).

Kittiwakes

In 2000, Black-legged kittiwake populations in the North Bering and Chukchi Seas were increasing, but were decreasing in the SE BS (Kuletz and Rivera 2002). Populations at three colonies (Chiniak Bay, Gull Island, and PWS) of the GOA were increasing, and the population at one colony (Middleton Island) was decreasing (Kuletz and Rivera 2002).

Red-legged kittiwakes continued to decline at Koniuji Island in 2000 and declined at the Pribilof Islands in 1999 (Kuletz and Rivera 2002).

Fulmars

Approximately 440,000 fulmars nest at the Semidi Islands in the GOA, 500,000 on Chagulak Island in the AI, 80,000 on the Pribilofs in Central BS, and 450,000 on St. Matthew/Hall Islands in northern BS (Kuletz and Rivera 2002). The population on St. Paul Island (a Pribilof Island) increased from 1990 to 1996, whereas the population on St. George Island decreased between 1992 and 1999 (Kuletz and Rivera 2002). The fulmar population in the Semidi Islands decreased between 1995 and 2001 (Kuletz and Rivera 2002).

Skates

Skates are caught incidentally in many groundfish fisheries, especially the hook and line fishery for Pacific cod and in trawl fisheries for pollock, rock sole, and yellowfin sole. The catch of skates in the GOA has varied from 1828 t (in 2002) to 4476 t (in 1998). Estimated skate biomass in the EBS increased after 1985, peaked in 1990 (at 534,556 t), and has varied between 325,000 - 419,508 t since (Gaichas 2002). Skate biomass in the AI increased from 10,123 t (in 1980) to 34,412 t in 2002.

Sablefish

See #5.)

Cod

In the GOA the estimated biomass of Pacific cod increased in the early 1980's (approximately 800,000t), was high until the early 1990's, and then decreased through the present (Thompson, et al. 2002). In 2002, the biomass of cod was 454,000 t, the lowest biomass estimated in the time series (1978 to present) (Thompson et al. 2002).

The biomass of Pacific cod in the BSAI has declined from a high of 2,627,000 t in 1987, through to the present, with upturns in 1995 (1,692,000 t), 2000 (1,270,000 t), and 2002 (1,315,000 t) (Thompson and Dorn 2002).

Predictions: Changes in the amount of total discards as predicted by the multispecies bycatch model are not anticipated to be large in the BSAI, with about a 1.3% decline in the preferred alternative in the long-term. Total discards are anticipated to increase about 13.6% in the GOA preferred alternative. However, these increases still result in discard amounts that are lower than those observed historically in the baseline in which no scavenger population increases were linked to discarding or offal release practices. Closer examination of the spatial/temporal nature of discarding and offal production practices may be needed to better understand the possible impacts on scavenger species.

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

Bottom trawl effort in the GOA and AI has decreased since 1990 due to reduced pollock and Pacific cod TACs (Coon 2003a). In the BS, bottom trawl effort peaked in 1997 and then declined. Currently, the bottom trawl effort in the BS is relatively stable, and is approximately four times higher than that in the AI or GOA (Coon 2003a). Both bottom trawl and longline effort in the BS is also more concentrated than in the AI or GOA (Coon 2003b). Most fishing effort in the BS is north of False Pass and along the shelf edge. Fishing effort is concentrated along the shelf edge in the AI and along the shelf edge of the GOA with small areas of effort near Chirikov, Cape Barnabus, Cape Chiniak, and Marmot Flats (Coon 2003a).

Predictions: Bottom gear effort is predicted to change less than 1% in the BSAI and about 1.2% in the GOA in the preferred TAC alternative as predicted by the multispecies bycatch model. This is essentially no change from the baseline amounts of bottom gear inducing unobserved mortality on bottom organisms. Additional indicators of benthic infauna and epifauna abundance are needed from independent samples such as benthic grabs to understand the actual abundance trends of this community that is not well-sampled by bottom trawl surveys.

9.) Diversity measures – Species diversity

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

Marine Mammal and Bird Status
Short-tailed albatross are considered endangered; their population is increasing, and is currently estimated at 1,700 (Fitzgerald et al. 2003). Three short-tailed albatross were recorded in observer bycatch data from 1993 to 2002 in the BSAI longline fishery and none were recorded in the GOA longline fishery (Fizgerald et al. 2003).

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

The western stock of Steller sea lions (Cape Suckling to Russia and Japan) are considered endangered (Sinclair 2003). The Eastern stock of Steller sea lions (from southeast Alaska to California) are classified as threatened (Sinclair 2003). See #5.) for population status.

There are two stocks of Northern fur seals in U.S. waters: Eastern Pacific and San Miguel Island (Sinclair 2003). Northern fur seals are considered depleted. See #5.) for population status.

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

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

Sharks

Most sharks are caught as bycatch in the midwater trawl pollock fishery and the hook and line fisheries for sablefish, Greenland turbot, and Pacific cod (Gaichas 2002). See #5.) for catch trends.

HAPC biota

HAPC biota caught in groundfish fisheries includes seapens/whips, sponges, anemones, tunicates, and corals. Bycatch of HAPC biota in the BSAI has ranged from 922.8 t (in 1999) to 2548.3 t (in 1997), comprising up to 4.6% of all non-target species caught. Bycatch of HAPC biota is substantially lower in the GOA (27.4-35.1 t), and represents up to 0.09% of total non-target catch (Gaichas and Boldt 2003). Sponges, anemones, and some corals represented the majority of the HAPC biota caught in the GOA; whereas, tunicates and sponges, with some anemones, were the dominant HAPC biota caught in the BSAI. There was no apparent temporal trend in catches of any HAPC biota in the GOA. The catch of seapens/whips increased in the BSAI from 1997 to 2001. The lowest bycatch in the BSAI occurred in 1999 due to decreased catches of tunicates.

HAPC biota are also caught in the NMFS trawl surveys; however, these surveys are not designed to sample these organisms and may not represent true population trends (Brown 2003). In 2001, catches of seapens and anemones increased in Western and Central GOA, and catches of sponges and stony corals increased in eastern GOA (Brown 2003). In 2003, catches of seapens in the BS were the highest in the time series (beginning in 1982) and catches of sponges in the BS continued to decline from 2000 to 2003 (Walters 2003). In the Eastern AI, catches of seapens were the highest in the time series in 2002 (Walters 2003).

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

In 2001, over 90,000 nmi of the EEZ were closed to trawling all year, and 40,000 nmi were closed seasonally (Coon 2003). Most state waters (0-3 nmi) are closed to bottom trawling (Coon 2003). The closures in effect in 2003 were the same as those in 2002 for both the BSAI and GOA (Coon 2003). Closures in 2002 were similar to the previous 7 years, however, included additional closures around Steller sea lion haulouts (Coon 2003).

Predictions: Target species abundance is not predicted to fall below overfished levels by 2023 in preferred alternative 2.1 and some dominant species are predicted to increase. Although bycatch of sensitive species (sharks and birds) are predicted to increase in the future for the preferred alternative, the change is relatively small in terms of absolute amounts in the BSAI and GOA. As previously mentioned in the top predator species section, better understanding of shark bycatch rates of sharks in groundfish fisheries and better independent estimates of shark population abundance are needed. Bycatch rates of some nontarget species are not well-estimated at the species level and instituting a program for prioritizing species-level information needs for nontarget species would provide additional security against unintended species-level extinctions due to fishery bycatch. HAPC biota bycatch is not predicted to change much in the BSAI but is predicted to increase by over 10% in the GOA in the preferred alternative 2.1. Improved mapping of sensitive HAPC biota distributions (i.e., coral) may be needed along with closed-area protection for these sensitive species.

Community diversity measures

The diversity of all fish combined in the BSAI and GOA from 1990 to the present peaked in 1999 and was near the long-term average in 2001 and 2002 in the GOA and BSAI, respectively

(Mueter 2003a). Total catch of all groundfish and invertebrate taxa in the same time period peaked in 1993 in both the Western GOA and BS (Mueter 2003b).

Biodiversity measures (richness and evenness) of two guilds of fish in the Bering Sea reflected the late 1980's climate change (Hoff 2003), when the Arctic Oscillation index, an indicator of sea level pressure, became positive (Rodionov et al. 2003). The richness and evenness of the pleuronectiform guild increased until the late 1980's and then leveled off; whereas, the roundfish guild (all other fish except Walleye pollock and Pacific cod) decreased until the late 1980's and then leveled off (Hoff 2003). The change in biodiversity of roundfish was primarily due to an increase in skates on the inner and middle domains of the BS and a decrease of many other roundfish species, such as eelpouts and sculpins (Hoff, unpublished). The increased biodiversity of pleuronectiforms was due to an increase in some species, such as ATF, Kamchatka flounder, flathead sole, and rock sole, and a decrease in other species, such as yellowfin sole and Greenland turbot (Hoff, unpublished).

Combined standardized indices of recruitment and survival of major demersal and pelagic stocks in the BS and GOA also reflected climate changes (Mueter 2003c). Recruitment indices of demersal species reflect the 1976/77 and 1989/90 shifts in climate in both the BS and GOA. The 1976/77 climate shift was reflected in improved recruitment and survival indices for both demersal (assessed groundfish species) and pelagic (salmon and herring) fish in both the BS and GOA, with the exception of BS demersal stocks (Mueter 2003c). The lack of increased survival of BS demersal fish indicates increased spawner abundance rather than improved recruit survival associated with the 1976/77 climate shift (Mueter 2003c). The 1989/90 climate shift was reflected in demersal, not pelagic stocks in both the BS and GOA (Mueter 2003c).

Predictions: The multispecies bycatch model predicts changes in target species biomass and diversity. Dominant species in the BSAI and GOA, such as walleye pollock and Atka mackerel, are predicted to increase, thus decreasing diversity measures that include these species. Climate-driven recruitment changes appear to drive much of the diversity measures of fish communities and further research is needed to understand and predict climate effects on individual species production.

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

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

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

In the BSAI, female rock sole in spawning condition are desirable; therefore, fishing has focused on winter spawning concentrations north of the Alaska Peninsula (Turnock et al. 2002b; NMFS Technical team for essential fish habitat of groundfish in the Bering Sea and Aleutian Islands 1998).

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

Community size spectrum analysis of the eastern Bering Sea fish community (Bartkiw et al. 2003) indicates there has not been a systematic decline in the amount of large fish from 1979 to 2002.

Predictions: The multispecies bycatch model retains preferred time/area fishing measures and the TAC EA alternatives do not consider any changes in time/area fishing measures that might alter the degree to which genetic diversity would be altered due to increases in fishing pressure on spawning aggregations or large fish. At least with regard to large fish, the baseline and preferred alternative indicates that the present level of TACs has not caused declines in the total amount of large fish over time. However, further research on the genetic differences between local spawning stocks may be important to ensure that irreversible loss of genetic components of a stock does not occur.

Table 2. Ecosystem indicators of the possible future effects of various TAC alternatives on predator/prey relationships, energy flow and balance, and diversity in the GOA from the multispecies bycatch model. Baseline is 2003 for target species and nontarget species catch baseline is the average of 1997-2001. Projected values are for the year 2023.

Indicator	**Baseline 2003**	**Alt. 1 2023**	**Alt. 2.1 2023**	**Alt. 2.2 2023**	**Alt. 3 2023**	**Alt. 5 2023**
GOA	1000 t	1000 t (top value), percent change from baseline (bottom value)				
Pelagic forage biomass (total biomass GOA pollock)	801.4	1,378.7 72.0	1,397.4 74.4	1,397.4 74.4	1,590.2 98.4	2,094.4 161.3
Bycatch of pelagic forage species (squid, herring, forage species)	0.117	0.418 257.3	0.410 250.4	0.410 250.4	0.292 149.6	-
Trophic level of the catch	3.81	3.86 1.3	3.86 1.3	3.86 1.3	3.88 1.8	-
Bycatch of top predator species (Sharks, birds)	0.89	1.10 23.6	1.11 24.7	1.11 24.7	0.72 -19.1	-
Biomass of top predator species (total biomass target groundfish: arrowtooth flounder, cod, sablefish)	2,644.5	3,351.9 26.7	3,373.4 27.5	3,373.4 27.6	3,572.4 35.1	3,997.3 51.2
Total catch (target, nontarget)	191.1	338.0 76.8	329.8 72.6	329.8 72.6	232.4 21.6	-
Total bottom trawl catch	319.9	315.0 -1.5	323.8 1.2	323.8 1.2	140.0 -56.2	
Total discards (target, nontarget)	47.8	54.4 13.8	54.3 13.6	54.3 13.6	36.3 -24.2	-
Total retained catch	143.3	283.6 97.9	275.5 92.3	275.5 92.3	196.1 36.8	-
Bycatch of HAPC biota (sea pens/whips, anemone, sponge, corals)	0.027	0.031 14.8	0.030 11.1	0.030 11.1	0.017 -37.0	

Table 3. Ecosystem indicators of the possible future effects of various alternatives on predator/prey relationships, energy flow and balance, and diversity in the BSAI from the multispecies bycatch model. Baseline is 2003 for target species and nontarget species catch baseline is the average of 1997-2001. Projected values are for the year 2023.

Indicator	**Baseline 2003**	**Alt. 1 2023**	**Alt. 2.1 2023**	**Alt. 2.2 2023**	**Alt. 3 2023**	**Alt. 5 2023**
BSAI	1000 t	1000 t (top value), percent change from baseline (bottom value)				
Pelagic forage biomass (total biomass BS pollock, AI Atka mackerel)	12,237.2	13,969.4 10.1	14,119.1 15.4	13,727.7 12.1	15,236.5 24.5	20,933.4 71.1
Bycatch of pelagic forage species (squid, herring, forage species)	3.19	3.17 -0.6	2.94 -7.8	3.07 -3.8	2.55 -20.1	-
Trophic level of the catch	3.68	3.68 0.0	3.68 0.0	3.68 0.0	3.69 0.3	-
Bycatch of top predator species (Sharks, birds)	0.715	0.793 10.9	0.721 0.8	0.769 7.6	0.512 -28.4	-
Biomass of top predator species (total biomass managed groundfish: arrowtooth flounder, Greenland turbot, cod, sablefish)	3,016.6	3,458.5 14.7	3,561.1 18.1	3,489.7 15.7	3,934.0 30.4	4,765.6 58.0
Total catch (target, nontarget)	2,003.	2,041. 1.9	1,884. -5.9	1,992. -0.5	1,552. -22.5	-
Total bottom trawl catch	364.0	401.0 10.2	367.0 0.8	402.0 10.4	220.0 -39.6	
Total discards (target, nontarget)	151.	156. 3.3	149. -1.3	155. 2.6	94. -37.7	-
Total retained catch	1,853.	1,885. 1.7	1,735. -6.4	1,837. -0.9	1,458 -21.3	-
Bycatch of HAPC biota (sea pens/whips, anemone, sponge, corals)	0.651	0.707 8.6	0.643 -1.2	0.705 8.3	0.509 -21.8	-

Conclusions

Climate indicators do not yet provide a clear signal regarding the PDO status. There had been an indication of a shift to a cool, pre-1977 regime until the recent El Niño. However, this El Niño event has produced conditions similar to those of a positive PDO.

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

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

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APPENDIX: MODEL DESCRIPTIONS

MSVPA/MSFOR Model

By Jesus Jurado-Molina and Pat Livingston

In the present work the MSVPA and the MSFOR models are used to simulate the population dynamics of eight species from the eastern Bering Sea using fishing mortalities from J. Ianelli's multispecies bycatch model. In these models we used the assemblage of species from previous work (Livingston and Jurado-Molina 2000; Jurado-Molina and Livingston 2002a; Jurado-Molina and Livingston 200b) including walleye pollock **(***Theragra chalcogramma***)**, Pacific cod (*Gadus macrocephalus*), Greenland turbot (*Reinhardtius hippoglossoides*) and yellowfin sole (*Pleuronectes asper*) played the role of both predator and prey. Rock sole (*Lepidopsetta bilineata*) and Pacific herring, were considered only as prey. Arrowtooth flounder (*Atheresthes stomias***)** and northern fur seal (*Callorhinus ursinus*), were considered external predators.

MSVPA is an extension of the VPA model (Gulland 1965) that estimates fishing mortality, recruitment, stock size and the predation mortality *M2* based on catch at age, predator ration and predator diet information. In addition to the assumptions and equations from VPA, MSVPA assumes that the natural mortality *M* is separated in two components, the residual mortality *M1* and the predation mortality *M2*. *M1* involves several causes of mortality such as aging, starvation, and diseases and is assumed to be constant for each age class of each species. MSVPA assumes no predation upon age-0 organisms in the two first quarters of their first year of life by MSVPA predators. The predation mortality of the prey *p* of age *a* is estimated iteratively within the MSVPA with the following equation:

$$(1) \qquad M2_{p,a} = \sum_i \sum_j \frac{\overline{N}_{i,j} R_{i,j} S_{p,a,i,j}}{\sum_{p,a} \overline{N}_{p,a} W_{p,a} S_{p,a,i,j}} .$$

$\overline{N}_{i,j}$ 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. The suitability coefficient reflects the diet composition of the predators relative to the available food (Sparre 1991). The denominator of Equation (1) 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 its weight at age in the stomach of the predator. The suitabilities are estimated iteratively in the MSVPA model with the following equation:

$$(2) \qquad S_{p,a,i,j} = \frac{U_{p,a,i,j} / \left(\overline{N}_{p,a} W_{p,a}\right)}{\sum_p \sum_a U_{p,a,i,j} / \left(\overline{N}_{p,a} W_{p,a}\right)}$$

where $U_{p,a,i,j}$ represents the food composition that is assumed to be equal to the observed stomach content. In the estimation of *M2*, MSVPA uses a weighted average suitability coefficient with the sample size as weight. The number of suitabilities is numerous because there is a value for each age class-predator-prey combination. The MSVPA model was set up in a quarterly form and it was updated to 2002 data.

The MSFOR is the predictive counterpart of the MSVPA and also uses Equation (1) to estimate *M2*. The average suitability coefficients and the terminal stock sizes, residual mortalities, weight of the prey in the stomach of the predator and annual ration of the predator are transferred from the MSVPA to MSFOR to carry out the simulation of the future dynamics of the species (Gislason 1991). MSFOR also uses assumptions about the future recruitment. We explored two scenarios, in the first one we assumed a log-normal distribution and in the second scenario we assumed that recruitment depended on the spawning biomass using the Ricker's equation for walleye pollock and the Beverton and Holt for the rest of the species. The fishing mortalities used in the simulations were those from the scenarios proposed in the J. Ianelli's multispecies bycatch model. The simulations were run from 2003 to 2042, when the populations reached equilibrium.

Data

The input data of the MSVPA included: catch-at-age data, maturity-at-age, weight-at-age, stomach content data, weight-at-age of the prey in the stomach contents of the predator, annual ration of the predator and residual natural mortality. The fish food habits database from the Alaska Fisheries Science Center (AFSC) contains stomach content information of several groundfish predators collected annually since 1985 (over 40 000 stomach samples).

The Multispecies forecasting model was set up in annual form and used some outputs from MSVPA as input, including the initial population in 2003 and the average suitability coefficients. The average suitabilities were estimated as the weighted average of the quarterly suitabilities from MSVPA using the ration of the predator as weight. MSFOR also uses the residual mortality and the annual consumption of the predator from MSVPA. The values of full fishing mortality by year for all species were obtained for each scenario from the outputs of the bycatch model. The parameters from the Ricker and the Beverton and Holt models were estimated by fitting the estimates of recruitment (age 0 third quarter) from the MSVPA.

Several indicators of performance were chosen to assess the potential consequences of fishing associated to each scenario including the temporal trend of the spawning biomass, adult population and the juvenile population. We also choose the equilibrium values in the long term of the spawning biomass, the spawning biomass ratio, the percentage change of biomass with respect to the biomass equilibrium value from the scenario 2.1 and the predation mortality.

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Estimates of N3+ obtained with the MSVPA and the single-species stock assessment models were similar, although some differences were seen for Pacific herring. The MSVPA was not able to replicate the trend observed in the estimates of the Alaska Department of Fish & Game stock assessment during the mid 1980s estimating greater N3+ estimates for the years

1982 to 1987. However, the N3+ trajectories for the rest of the species were similar between the multispecies and the corresponding single-species model as shown below (Figure 1):

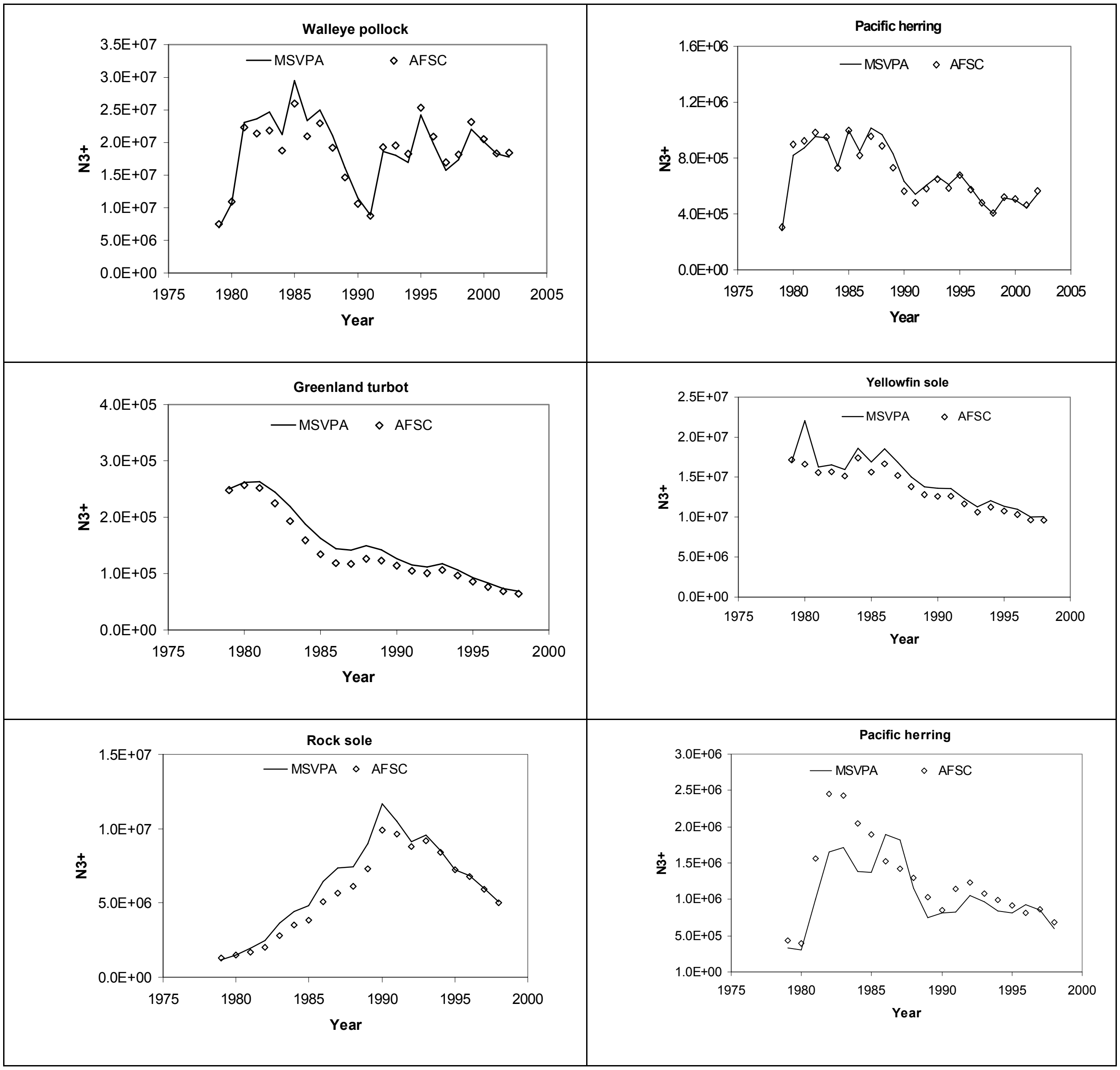

Figure 1. Comparison of the estimates of N3+ (except for herring N4+) from the multispecies VPA and the corresponding single-species stock assessment models.

The average MSVPA estimates of predation mortality for younger ages were higher than the ones used in the single-species stock assessment models. In particular, the highest average predation mortality (1.37) corresponded to age-1 walleye pollock (Figure 2). For this age class, cannibalism is an important component of the predation mortality; however predation produced by other species (Pacific cod, Greenland turbot, northern fur seal and arrowtooth flounder) also play an important role in this parameter (Livingston and Jurado 2000).

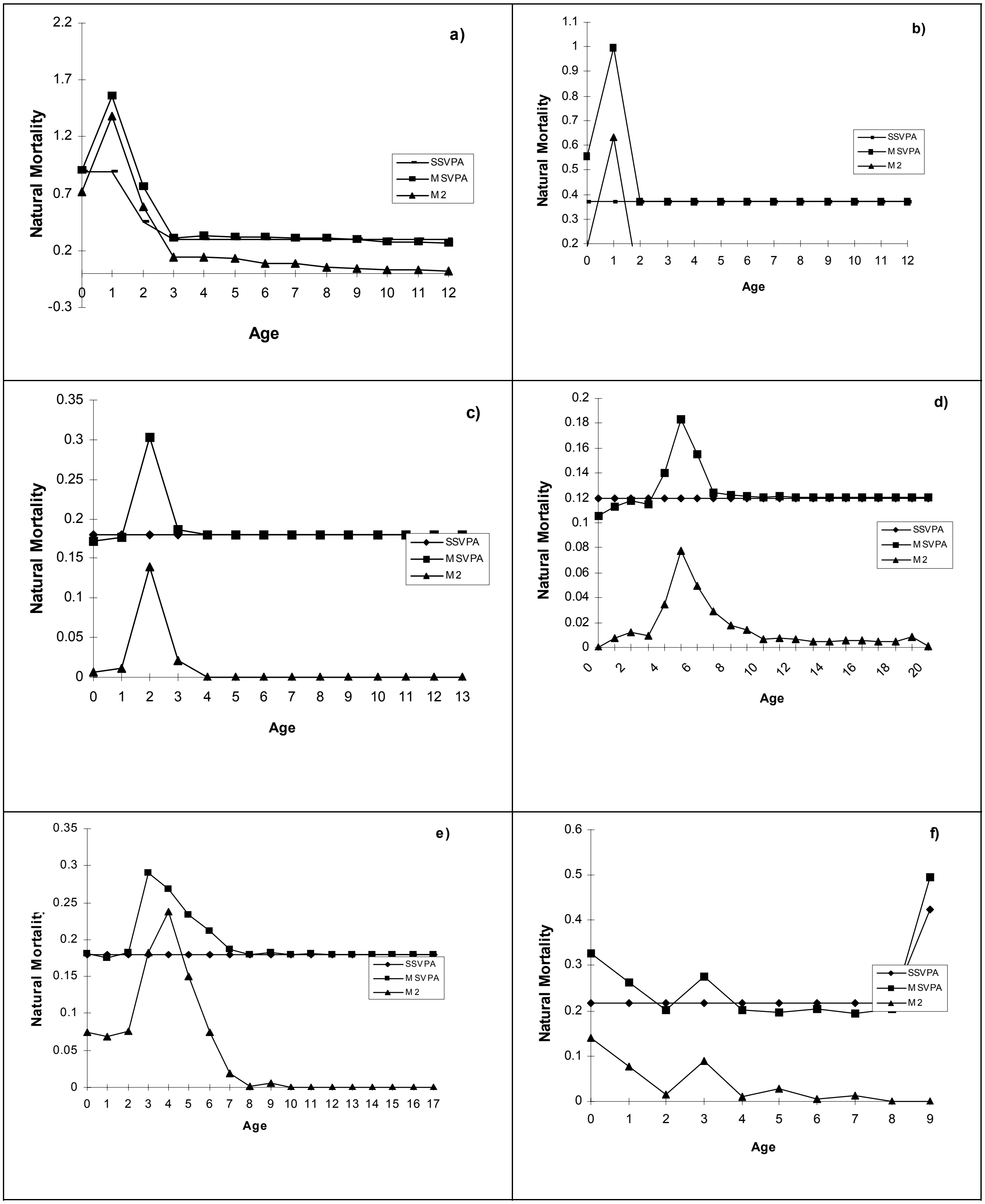

Figure 2. Estimates of natural mortality(MSVPA), predation mortality (M2) from the Multispecies VPA and natural mortality used in single species models (SSVPA). A) walleye pollock, b) Pacific cod, c)Greenland turbot, d)yellowfin sole, e) rock sole and f) Pacific herring.

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Whole food-web models

By Kerim Aydin, Sarah Gaichas, and Ivonne Ortiz

Introduction

Modeling food webs for use in large marine ecosystem (LME) fisheries management has been identified as a key element of an "ecosystem-based" approach to management (EPAP 1998). Such models provide a complement rather than a replacement for single-species approaches (Hollowed et al. 2000) as they may identify key shifts in marine populations that arise out of changes in prey availability, predation mortality, or may identify climatic changes as they appear through shifts in these parameters.

Moreover, such models, updated on an annual basis, may provide a basis for: (1) the calculation of indicators specific to energy flow through modeled ecosystems; (2) an evaluation of sensitivity of species to perturbations in their predators or prey; (3) targeting research on ecologically important but poorly understood species; or (4) evaluation of management alternatives as they may affect long-term changes in food web structure.

Here we present the preliminary results of food web models for the Bering Sea and Gulf of Alaska fisheries management regions. A complementary model for the Aleutian Islands region is under development. A brief description of the Aleutian Islands model is given here, but full results are not presented.

The mass-balance modeling methodology used for these food webs was initially developed for the eastern Bering Sea region (Laevastu and Favorite 1979). This initial work, was generalized and extended by Polovina (1985) into a set of Microsoft Visual Basic routines, Ecopath, which allow for the consistent estimation and comparison of mass-balance results between multiple fisheries ecosystems.

This generalization and cross-comparison was critical, as it provided a tool for evaluating the ecological meaning of indicators produced by these models by comparing results across ecosystems. Ecopath was updated and made available through the world-wide web by V. Christensen, D. Pauly and C. Walters (Christensen and Pauly 1992; Christensen et al. 2000). The current packaged software version, Ecopath with Ecosim (EwE), and documentation is available free for download at www.ecopath.org.

Ecopath is designed to make extensive use of data as it is already collected for single-species fisheries management; for base parameters, survey biomass estimates, age, weight, and mortality studies are supplemented with consumption rate data either from laboratory or shipboard experiments, to determine production and consumption rates for each species.

For the eastern Bering Sea, Ecopath has previously been used to reconstruct food webs of the region as they existed in the early 1980s (Trites et al. 1999; Aydin et al. 2002). The current models represent a redesign of this initial work to include greater species and geographic resolution as well as an update to the present-day.

Data for this modeling has been supplied from multiple agencies and programs, including the Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE), Resource Ecology and Fisheries Management (REFM) and National Marine Mammal Laboratory (NMML) divisions. Additional data were collected from the Alaska Department of Fish and Game (ADF&G) and the US Fish and Wildlife Service (USFWS). Further, the Ecopath algorithms are being re-implemented by the authors in such a way as to automate model updates from existing Alaska Center databases.

To coordinate the extensive data resources available from multiple agencies and programs into a consistent format for ecosystem-level modeling, AFSC has contracted a one-year ecosystems database manager position through the Pacific States Marine Fisheries Commission (PSMFC). It is expected that the results of this coordination will be made publicly available in a convenient web-based format; the continuation of this position will be critical for making timely updates to the ecosystem-wide models.

The most central parameter set for food web models are diet composition matrices, obtainable through stomach sampling or other analyses. In particular, the elaboration of these food web models with respect to fished species depends heavily on the analysis of 250,000+ stomachs collected by the Resource Ecology and Ecosystem Management (REEM) program. Continuation of this collection will allow for a regular update and improvement of these models. Due to the high resolution and coverage of this diet data, we were able to model species at a relatively high resolution: over 120 species are specifically and separately accounted with survey strata-level resolution, with specific juvenile and adult accounting for several of the commercial groundfish, crab, and pinniped species.

Ecopath has been associated and packaged with a biomass dynamics/age structured simulation tool, Ecosim (Walters et al. 1997), which provides a theoretical framework for providing dynamic deterministic projections of changes in species and fisheries in response to changes in fishing or natural predation mortality. However, use of this tool requires a more formal statistical estimation procedure of parameters than is currently available in EwE. Ecosim in its packaged form is only recommended for use in hypothesis exploration or first-order perturbation and sensitivity analyses as a supplement to other forecasting methods.

Recent publications suggest that the importance of predator prey interactions may shift in time as ecosystems adjust to shifts in climate (Bailey 2000, Hunt et al. 2002). Ecosim models may be useful in understanding and evaluating hypotheses regarding the shifting control of marine fish production from bottom up to predator control. This evaluation must include the consideration of dynamic projections across the ecosystem, including sensitive species and undersampled species. The thermodynamic constraints imposed by Ecopath have the effect of bounding the estimation problem for species about which too little data is available for incorporation in multispecies virtual population analysis (MSVPA) forecast methods (MSFOR): this procedure may add information to dynamic projections in a formal sense.

To this end, we also present a proposed method for incorporating Ecopath thermodynamic constraints and model structure into dynamic projections, as a Bayesian Synthesis (e.g. Givens et al. 1993). An outline of this method, Ecosense, was previously published for a simplified case in the subarctic Pacific gyres, in which model structure provides the only additional information to the model (Aydin et al. 2003). Here, this method is expanded to include the addition of survey time series data for parameter estimation.

It should be noted that as a whole, Ecopath, Ecosim, and Ecosense are tools designed to examine explicit predator/prey relationships and their affect on changes in mortality throughout each modeled ecosystem. Accounting for this food web variability is an important component of ecosystem management, but should not be seen as a complete view: habitat, life-history, climate, and other non predator/prey interactions are not directly captured by the use of these models.

Methods

Model description

Data overview

The base time period for the initial models was taken to be 1990-1994, with data included from adjacent time periods as necessary. This time period was selected to represent a recent time period covering several surveys, but with enough years between the base model and the present year to tune dynamic forward projections. Cetacean and seabird estimates, not available as time series from this earlier period, were included as “most recent” (1997-2002) estimates.

The modeling framework described below is designed to make primary use of data collected for the purposes of single-species management, either from fisheries or mammal, bird, or lower trophic level monitoring programs. Full details of the references for each parameter for each species are found in Appendix A (*in preparation*).

Groundfish biomass levels are taken from RACE trawl surveys 1979-2002 and, in the case of roundfish with low catchability to trawls, supplemented by stock assessment estimates. Production and consumption rate estimates combine mortality estimates from literature and stock assessments with growth ranges measured from available REFM age-length or age-weight data. Shellfish parameters were estimated from Alaska Department of Fish and Game (ADF&G) records listed in the Appendix. Bird estimations were taken from colony counts provided by USFWS, with birds not nesting in the region being extrapolated from North Pacific-wide estimations. A full description of these methods by species is found in the Appendix.

Mammal estimations were performed in conjunction with researchers in the National Marine Mammal Laboratory (NMML) and represent their best current information on stock size and mortality rates for each species as provided by N. Friday (NMML) and D. Kinzey (University of Washington). Consumption and growth rates were calculated with a general marine mammal bioenergetics model detailed in the Appendix; for pinnipeds these models were compared to more recent laboratory investigations.

Lower trophic level biomass and production estimates were primarily derived from literature values (specific to region) and supplemented with plankton models and data provided by Fisheries Oceanography Coordinated Investigations (FOCI) researchers and the results of several broad research programs including PROBES and SEBSCC, as detailed in the Appendix.

Diet data for groundfish was calculated from a detailed analysis of the REEM food habits database which included bootstrap estimation of diet uncertainty, as outlined in the Appendix. Pinniped diets were supplied from literature with additional information contributed by E. Sinclair, while cetacean diet estimates were obtained from a NMML review conducted by S. Harkness. Diet for other species was provided from literature values obtained by the authors.

In many cases, especially for birds and mammals, literature diet data was only available to indicate predator preference between broad groups (between "roundfish" and "cephalopods" for example). In these cases, predators were assumed to consume the indicated percentages of each of these broader categories, but with neutral preference within each category (diet proportional to the relative biomasses of the indicated prey). This method required an iterative estimation process: initial estimation of prey availability within categories was calculated from the groundfish diet database; in the second iteration the prey for which the detailed diets were unavailable were assumed to forage within each category in proportion to the availability of prey to the total groundfish biomass (preference equations for this method are detailed in the Appendix).

Fisheries catch and bycatch statistics were primarily derived from the NPFMC Blend database 1991-2002, with supplemental information included from state fisheries records (including indigenous catches), International Pacific Halibut Commission records, and bycatch analysis conducted for NMFS groundfish fisheries in its Draft Programmatic Supplemental Environmental Impact Statement (DPSEIS; NMFS 2003).

The model is considered an "annual" model and growth and consumption rates are scaled to yearly totals. However, fish diet data is primarily derived from summer collections (May-September)—it is assumed that while annual averages are used for consumption rates, most of this consumption occurs during the summer. The exception to this rule is for ice-edge following species that overwinter in the Bering Sea, whose consumption is in wintertime only. Extension of diet collection into spring and fall months would be a valuable addition for this model.

The three geographically separate food web models, one for each of the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands, were based on the current definitions of these management regions (Figure 1). This was selected as a primary division so as to model stocks on the same scale as the management of major commercial groundfish species. In general, these divisions correspond with the understood geographic ranges of many stocks.

All individually modeled species are listed in Table 1: not all indicated species occur in all modeled regions. Species were categorizes as one of either migratory (moving specifically across model boundaries), stock (primarily contained within each model's boundaries), complexes (stocks consisting of multiple species) or local (subpopulation/different species may occur in different subdomains of each of the three models). Further, species were modeled as either biomass pools or aged (initially split into juvenile and adult biomass accounting; this is elaborated into a fully age-structured model during dynamic simulations).

The food web models described in this document are based on a mass-balance approach; that is, the flows of biomass between functional components in the food web (species or aggregated species compartments) are accounted for in such a way that any imbalance (positive or negative) between input and output of a compartment may be considered either indication of data uncertainty or true energy loss/gain between the compartment and the remainder of the system. The ideal methodology provides relatively independent estimates of input (bottom-up supply) and output (top-down removal) so that the relative consistency of the multiple sources of data may be assessed.

For such an analysis, each ecosystem is considered to be a homogenous system in which species mix freely, with the geographic boundaries of the system set large enough so that migration across the model boundaries is minimal, and yet small enough so that processes throughout the ecosystem are relatively uniform.

However, within each of these regions are multiple biogeographic subareas delineated by oceanography or bathymetry (e.g. NRC 1996). While a given stock may range across several of these subareas, the critical processes controlling production may vary between the subareas. Therefore, each of the three models was divided into subareas based on RACE survey strata and the actual geographic area was limited to the continental shelf and slope (<1000m depth). Functional groups considered to be “local” are considered to consist of different populations in each modeled subregion. This effectively encodes predator habitat preference into the diet matrix; a species consuming copepods in one subregion alone shall be considered limited by the production in that subregion.

On a larger scale, many species, especially marine mammals but also commercial fish such as sablefish, move between regions or spend a significant portion of the year or their life cycle outside of a given model region. For the purposes of mass-balance modeling, rather than explicitly modeling immigration and emigration rates, biomass levels were weighted by the amount of time each such stock spends in each modeled region. Fisheries were included as they occur in the modeled regions. While this accounting is sufficient for building mass-balance models, further specification of imported diet and external fishing (feeding and fishing of species outside the model’s geographic boundaries) will be required for dynamic simulations.

Pacific salmon (*Oncorhychus* spp.) are a special case, as a large proportion of the critical stages in their life cycle occur outside of modeled areas, and their presence occurs in compressed bursts of migration throughout the year. These bursts represent a large component of both food supply and predation, and yet their temporal compression prevents scaling their brief in-system growth rates to the remainder of their life cycle. Therefore, outmigrating and immigrating salmon are considered to be separate (unlinked) species and treated as an input parameter rather than a state variable for dynamic simulations. Salmon fisheries are not included in the models.

Modeling framework

Ecopath is a food web analysis tool that has gained broad recognition as a methodology for assembling and exploring data on marine food webs (Polovina 1985; Christensen and Pauly 1992; Christensen et al. 2000). The implementation used to prepare these models, Ecosense, was written by the authors (Aydin) based on Ecopath and Ecosim code provided by V. Christensen, which was reviewed by the authors and modified for formal parameter estimation in Microsoft Excel, Visual Basic, and C++ development environments. The modifications were focused on (1) automating links between AFSC survey and assessment databases to allow consistent updating of the regional submodels on an annual basis; (2) implementing formal parameter estimation procedures.

Ecopath is a mass-balance model, built by solving a simple set of linear equations which quantify the amount of material (measured in biomass, energy or tracer elements) moving in and out of each compartment (functional group) in a modeled food web. A single functional group (food web compartment) may be a single species or a set of trophically similar species. The master Ecopath equation is, for each functional group (i) with predators (j):

$$B_i\left(\frac{P}{B}\right)_i * EE_i + IM_i + BA_i = \sum_j \left[B_j * \left(\frac{Q}{B}\right)_j * DC_{ij} \right] + EM_i + C_i$$

The definition of the parameters in the above equation, and the general methods used to derive each parameter, are given in Table 2.

The preferred method for using the Ecopath model is to input all parameters from independent data sources, except for ecotrophic efficiency (EE) for each functional group. Ecopath will estimate a vector EE values by solving the resulting set of linear equations, with EE as the unknown for each functional group, utilizing the generalized inverse method (Mackay 1981) to guarantee a solution. The estimation of EE is the primary tool for data calibration in Ecopath: independent estimates of consumption and production of different species often lead to initial conclusions that species are being preyed upon more than they are produced (EE>1.0), which is impossible under the mass-balance assumption (Christensen et al. 2000).

By using an EE greater than 1.0 as a diagnostic tool for error, it is then possible to assess the relative quality of each piece of input data to adjust inputs to a self-consistent whole. This process is known as “balancing” the model: it does not imply that the true ecosystem is in equilibrium but rather quantifies the uncertainty contained in the estimates of supply and demand present in the system. It should be noted that this is a “one way” criterion. If specified mortality on a species is greater than its production, the species is flagged as containing an error (EE>1.0), while if production is greater than specified mortality this is considered acceptable. This reflects the fact that it is possible and likely, even in a closed system, to have unspecified energy loss from a given compartment (such as due to disease or senescence for top predators) but it should not be assumed that there is unspecified energy gain.

In cases where biomass is unknown for a functional group, the EE for the group may be fixed (usually at a value between 0.8-1.0) and used to estimate the minimum biomass or production rate required to satisfy the consumption rates of the group’s predators, this is known as a “top-down” balance. In our study, this “minimum production” method was used only in cases where no reasonable estimate of biomass was available for a group. A fixed value of 0.8 was selected for all such species.

As detailed in the Appendix [in preparation], the top-down balance was used on 30-35 of the functional groups, primarily the less dominant species of plankton, zoobenthos, and forage fish. Additionally approximately 10 of the juvenile compartments used to model age-structured species were balanced in this manner. Dominant species in the lowest trophic levels (phytoplankton, copepods and euphausiids) were modeled with direct production estimates, so as to prevent this top-down method from merely creating sufficient supply in the model to satisfy any indicated demand within the food web.

However, due to current data limitations, this method may create a bias in the models for forage fish and juvenile production estimates, specifically with respect to species such as sandlance, capelin, and myctophidae, and some crab and flatfish juveniles. While the constraints placed on the lowest trophic levels prevent the model estimates from exceeding total possible population production, the resulting modeled biomass of each of these species individually represents the minimum amount required to sustainably satisfy the predators' demand for these species. This result does not in itself guarantee that such biomass levels exist in the system.

The mass-balance constraints of Ecopath do not in themselves require or assume that the modeled ecosystem is in equilibrium, but rather require that any directional component (known increase or decrease of biomass) be included in the mass-balance accounting through the biomass accumulation (BA) term. For these food webs, this term is used only in cases where known historical decreases in the biomass of species are required to provide sufficient energy for measured consumption and fishing in the rest of the ecosystem.

Within a modeled regime, it is assumed that the components of the ecosystem either (a) lie close (within the range of short-term process noise) to an attractive and relatively stable equilibrium for the given biomass levels and mortality rates, or (b) are subject to an explicitly specified directional trend as captured by inclusion of a Biomass Accumulation parameter. For species close to equilibrium, the system is not assumed to exist in this state in any given instant; rather, like a carrying capacity for an individual species, it is the state towards which the ecosystem would tend in the absence of driving perturbations (changes in fishing rates, climate, or other process-related noise). For extensions of these assumptions to non-equilibrium estimation see the section on dynamic modeling, below.

Balancing procedure

An ecosystem is never frozen in a true equilibrium. A considerable body of literature suggests that variability in marine fish production and growth is influenced by oceanographic conditions (Francis et al. 1998). When available, the input data for the model includes year-specific estimates of production and recruitment, as measured by retrospective stock assessments and growth studies. As such, the starting conditions of the model, for stocks with good data coverage, are an implicit snapshot of the oceanographic variability and compensatory responses that contributed to each stock's current biomass within the food web.

However, given this background variability, thermodynamic limitations on production require that a mass-balance of materials between ecosystem components exists on some scale. Balancing the model, to ensure that EE values are less than 1.0 for each functional group, provides a powerful method for ensuring that data collected from species in an ecosystem, when assembled into a whole, satisfies fundamental thermodynamic constrains. It may be argued that this procedure requires model developers to force a changing ecosystem into an inappropriate static mould; however, in practice care is taken to avoid this.

We performed the model balancing by proceeding from the greatest EE values to the least that were greater than one; it was not uncommon for the initial estimation to produce EE's of 100 or greater. If EE values of this range were assumed to represent actual biological shifts, it would imply species being reduced by a factor of 100 or more in a single year, which is biologically unreasonable in most cases.

The full changes made for the purposes of balance are detailed in the Appendix. Much of the initial balancing indicated in the Appendix served to confirm whether sampling methodologies undersampled prey items. Other balancing issues focused on "edge" species, for example Atka mackerel exist in small quantities on the edge of the Bering Sea model region, so in reference to the dominant flows a trace diet consumption of Atka may scale into an "unbalanced" result. To facilitate decisions on which parameters to adjust, a grading scheme was used (Table 3) to rank the quality of the input data. Parameters with lower quality rankings were adjusted as necessary (minimized or maximized to balance constraints) before parameters of higher data quality were considered for adjustment.

After these corrections, only a few unbalanced species remained in each system; in these cases a decline in these species over time had been noted from the data and was included as a Biomass Accumulation term.

When run as a dynamic model, Ecosim and Ecosense contain built-in compensatory density-dependent responses in recruitment and production. These responses may be fit with time series data, and Ecosense will allow for formal model selection between alternate density-dependent formulations. External variability, such as oceanographic change, will not be explicitly modeled in the initial formulation. However, hypotheses of external control mechanisms derived from other sources may be explicitly included for exploration or by examining the residuals of these responses.

Analysis of mass-balanced models

Ecosystem indicator trends

Ecosystem indicator trends over time, such as the annual energy flow through each trophic level and trophic level of the catch, will be calculated by two methods. The first method is to fix the diet matrix (assume constant) and calculate each indicator based on yearly input biomass reflected by available survey trends, using the base year to calculate catchability coefficients between the survey and model biomass estimates. The second method is similar to the first except that the diet matrix will be recalculated using predator/prey functional responses. At the moment, evaluation of the sensitivity of each of these methods, and the sensitivity of these results to initial assumptions, is under way.

Dynamic simulations

Ecopath has been associated and packaged with a biomass dynamics/age structured simulation tool, Ecosim (Walters et al. 1997), which does provide a theoretical framework for providing deterministic projections of changes in species and fisheries in response to changes in fishing or natural predation mortality. However, the current versions of this tool, while providing methods for tuning to time series data, require a more rigorous evaluation of parameters than is currently available.

At this stage, Ecosim in its published form Ecopath with Ecosim (EwE; Walters et al. 1997 or see www.ecopath.org for the latest available software) is only recommended for use in hypothesis exploration or first-order perturbation and sensitivity analyses as a supplement to other forecasting methods (single-species models or MSFOR). However, using Ecosim as a starting point it is possible to frame thermodynamic constraints into a formal fitting procedure (ECOSENSE) as described here.

The assumption of relative stability becomes a formal constraint in the extension of the Ecopath model to dynamic predictions through the use of Ecosim. Ecosim uses the mass-balance solution to the Ecopath master equations to calibrate the following biomass dynamics model:

$$\frac{dB_i}{dt} = GE_i \sum_{j \in prey} \left[f_{ij}(\overline{B}) \right] - \sum_{k \in pred} \left[f_{ki}(\overline{B}) \right] + PP(B_i) + IM(B_i) + BA(B_i) - EM(B_i) - F_{i,} B_i - M_{0i} B_i$$

More specific information on each of the above functions, and their calculation from Ecopath parameters, is found in Table 4.

This general model as written does not automatically assume that an equilibrium state exists for all functional groups in the ecosystem. In particular, the predator/prey interaction functions f(B) are set from consumption, production, and diet parameters plus an additional term, vulnerability, which represents the relative strength of top-down (Lotka-Volterra) interactions and bottom-up (density-dependent ratio) interactions. Further, the relative importance of foraging time limitation or handling time may be included as tunable parameters. In theory the use of these functions does not guarantee that the system has an equilibrium state, and the above formulae may include oscillatory or chaotic dynamics.

However, as coded and used in practice as a transition between Ecopath and Ecosim, the parameter M0 ("other" mortality) for each functional group is set after all of the other parameters in the rate equation have been calculated. It is set from Ecotrophic Efficiency (EE) values so that, in the absence of a nonzero Biomass Accumulation (BA), the Ecopath system of mass-balance equations also represents the equilibrium state of the dynamic equations for all functional groups. The fact that other parameters were adjusted in the Ecopath stage to ensure that all EEs<1.0 guarantees that a stable equilibrium exists in the model, although this equilibrium may approach an oscillatory or chaotic state if vulnerability settings are set for strong top-down (Lotka-Volterra) interactions.

The practice also guarantees that only a single equilibrium state exists: it is not possible for "state flips" or multiple equilibria to exist as emergent properties of changes in state space. Regime shifts are thus only modeled as input (hypothesized) changes in external forcing parameters that persist throughout the regime, and not as internal ecosystem reorganizations. While diet switching occurs in a modeled predator as differing prey species change in biomass, "preferences" remain constant and thus overall transitions remain smooth and reversible.

Discussion of the uncertainty, and in particular the overcompensation of Ecosim prey species to perturbation under the default assumptions (resulting in a possible overestimation of sustainable fishing rates) is discussed elsewhere (Aydin and Friday 2001). In practice, it is possible and necessary to tune Ecosim with historical data to remove such overcompensation. By allowing the model to "spin up" from a hypothetical stable state to a far-from-equilibrium state, large scale changes and the effect of permanent loss of component functional groups may be considered.

The EE term performs a "double duty" in the Ecopath approach as it represents model uncertainty in Ecopath yet is used as a dynamic equilibrium-creating term in Ecosim. The relative stability of this equilibrium is determined by all of the parameters in the system; but in particular, by adjusting the vulnerability parameter for each predator prey link. Additionally, a "low but positive" threshold is assumed for each biomass that ensures that no biomass may permanently be removed from the ecosystem.

The resulting set of differential equations are run forward in time using standard numerical integration routines (Runge-Kutta order 4 or Adams-Basforth) which allow for the input of time varying forcing functions in fishing mortality rates (F's) or primary production rate (PP's). Other possible forcing functions, such as time-varying growth efficiencies (GE's) as an interaction between temperature and biology, are possible.

To incorporate both the information in the input data (initial model state and parameters) and model information gained by thermodynamic bounding, the following procedure is suggested to estimate M0 values and select between alternative compensation formulations of the consumption equation f(B), and therefore remove the assumption of initial equilibrium specification while maintaining thermodynamic constraints. This procedure is a form of the Bayesian Synthesis approach (Givens et al. 1993):

(1) For each of the models, N simulated ecosystems are created using a Monte Carlo process. Each ecosystem consisted of a set of parameters for the Ecosim dynamic equations and a vector of initial biomass values and were not necessarily in initial equilibrium. Distributions of parameters are based on confidence ranges of Ecopath inputs (Table 3) and are taken to have distributions with variance indexed by this data grading. See Aydin et al. (2003) for a discussion on the appropriate prior distributions for each parameter, especially diet composition.

(2) Each generated ecosystem is tested for relative thermodynamic consistency, to discard perceived "impossible" states and to impose the likely existence of an equilibrium state containing positive biomass for all functional groups without explicitly specifying the equilibrium as in EwE. In a previous test (Aydin et al. 2003) this constraint eliminated over 90% of generated ecosystems, and introduced significant covariance structure between surviving parameter sets.

The resulting distributions and covariance structures are used in conjunction with time series data to find parameter profiles for M0 and consumption values over time. In addition, alternate functional responses (such as Holling Type II) may be tested and subject to model selection. An implementation of this method is currently underway for the eastern Bering Sea.

Scope for dynamic projections

As mentioned above, the predator/prey interaction function f(B) is set for each predator/prey interaction from consumption, production, and diet parameters. The full equation for any given predator/prey pair may be written:

$$F(\mathrm{B}_{\mathrm{pred}}\mathrm{B}_{\mathrm{prey}}) = \frac{(Q^{*}_{pred} \cdot DC^{*}_{predprey}) \cdot X^{*}_{predprey} \cdot \frac{\mathrm{B}_{\mathrm{prey}}}{B^{*}_{prey}} \cdot \frac{\mathrm{B}_{\mathrm{pred}}}{B^{*}_{pred}}}{(X^{*}_{predprey} - 1) + \frac{\mathrm{B}_{\mathrm{pred}}}{B^{*}_{pred}}}$$

where $\mathrm{B}_{\mathrm{pred}}$ and $\mathrm{B}_{\mathrm{prey}}$ are the current biomasses of the predator and prey, respectively, Q* is the total consumption of the predator at the reference (Ecopath) starting point, DC* the diet proportion of the prey in the predator's diet at that starting point, and $\mathrm{B}^{*}_{\mathrm{pred}}$ and $\mathrm{B}^{*}_{\mathrm{prey}}$ are the biomasses of the predator and prey at the reference point. This reference point need not be an equilibrium state of the model.

$X^*_{predprey}$, called the “vulnerability multiplier” in Ecosim, is a measure of the density-dependent compensation of predator consumption, and therefore a measure of a predator’s instantaneous production response to changes in predator density. In this equation X ranges from 1 to infinity. Note that some confusion exists in the literature, as the term “vulnerability” is also applied to a log-scaled version of this multiplier which ranges between 0 and 1 (for use in EwE spreadsheet entry) and to a parameter ‘v’ in an alternative parameterization of this equation (Christensen et al. 2000).

If X is equal to 1 for a given predator/prey pair, density-dependent consumption compensation is strong and production per unit biomass increases for predators as their populations decrease; prey populations exert strong “bottom-up” control on predator production this is considered a relatively stable system in the absence of bottom-up (environmental) forcing. For high values for X, consumption and production per unit biomass of predator change little as predator populations change: high values of X imply that predators exert strong “top-down” control on prey. High values for X multipliers throughout all species results in a system which is considerably less stable. Note that the value of X is situational, and is calculated in reference to the starting (Ecopath) biomass levels for each predator/prey pair.

Walters et al. (1997) derives the vulnerability term theoretically from assumptions of the changes in prey risk avoidance in response to predator populations (the Arena hypothesis), yet empirically this term may be a descriptor of compensation reflected through shifts age-class composition (increases in recruitment and younger, more active foragers that occur with depressions in predator population size; Aydin MS in prep).

As such, Ecosim implicitly parameterizes the empirical aspects of age compensation and thus allows for the examination of the potential effects of changes in food resources on this compensation. This comes at the cost of assuming fixed (less precise than age-structured models) partitioning of resources between reproduction and growth, although in species in which juvenile and adult accounting is performed separately (Table 1), an additional pair of parameters allows for the explicit partitioning of compensation between reproduction and growth and models compensatory changes in this partitioning with changes in prey supply.

Multispecies methods such as MSVPA and the resulting MSFOR projection models also provide methods for explicitly modeling changes in predation mortality between assessed species, and where data is available contain greater detail on age-structure and particularly spawning biomass levels than does Ecosim. However, MSFOR still relies on the assumption of fixed processes for recruitment of each species, while the explicit f(B) link in Ecopath between available forage and production (especially on lower trophic levels) allows for examining these links; in particular, the Ecosim method explicitly limits recruitment and growth compensation to the amount of energy available for that species within the system.

Ecosim, as a whole, offers a reasonable method for exploring the effects of both changing predation mortality and changing available production on alternative management scenarios, although this comes at the cost of losing some resolution on the explicit specification of age-structured compensation.

However, it is important to note that, as with single-species and MSVPA methods, confidence in these results may only be evaluated by examination of the results of formal parameter fitting, as being implemented through Ecosense. Through the fitting process, the sensitivity of these results to parameter variance shall need to be examined before results are applied. In the process key areas of importance for future predator/prey research may be identified and recommended.

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Table 1. (Page 1 of 2) Species groups in EBS, GOA, and ALU food web models. Spatial modeling methods: M=Migratory, S=Stock, L=Local subarea. Life-history modeling methods; Bio=Biomass; Com=Biomass of complex; Age=Age structured; Fixed=used as reference level only. Some age-structured groups are not modeled as aged-structured in all models.

Category	Group	Method
Marine Mammals	Trans Killer	M_Bio
	Sperm whales	M_Bio
	Resident Killers	S_Bio
	Porpoises	S_Bio
	Belugas	M_Bio
	Gray Whales	M_Bio
	Humpbacks	M_Bio
	Fin Whales	M_Bio
	Sei whales	M_Bio
	Right whales	M_Bio
	Minke whales	M_Bio
	Bowhead Whales	M_Bio
	Sea Otters	S_Bio
	Walrus Bd Seals	M_Bio
	N. Fur. Seal	M_Aged
	Steller S.L.	S_Aged
	Resident seals	S_Com
	Wintering seals	M_Com
Birds	Shearwater	M_Bio
	Murre	M_Bio
	Kittiwake	M_Bio
	Auklet	M_Bio
	Puffin	M_Bio
	Fulmar	M_Bio
	Storm Petrel	M_Bio
	Cormorants	M_Bio
	Gulls	S_Bio
	Albatross Jaeger	M_Bio
Rockfish	POP	S_Aged
	Sharpchin Rock	S_Bio
	Northern Rock	S_Bio
	Dusky Rock	S_Bio
	Shortraker Rock	S_Bio
	Rougheye Rock	S_Bio
	Shortspine Thorns	S_Aged
	Other Sebastes	S_Com
Misc. groundfish	Greenlings	S_Com
	Bigmouth myox Irish Ld	S_Com
	Other sculpins	S_Com
	Misc. roundfish	S_Com
Cephalopods	Octopi	S_Cin
	Squids	L_Com
Forage Fish	Salmon returning	see text
	Salmon outgoing	see text
	Bathylagidae	L_Com
	Myctophidae	L_Com
	Capelin	L_Bio
	Sandlance	L_Bio
	Eulachon	L_Bio
	Managed Forage	L_Com
	Oth pel. smelt	L_Com
Shellfish	Bairdi	S_Aged
	King Crab	S_Aged
	Opilio	S_Aged
	Pandalidae	L_Com
	NP shrimp	L_Com

Table 1. (Page 2 of 2) Species groups in EBS, GOA, and ALU food web models. Spatial modeling methods: M=Migratory, S=Stock, L=Local subarea. Life-history modeling methods; Bio=Biomass; Com=Biomass of complex; Age=Age structured; Fixed=used as reference level only. Some age-structured groups are not modeled as aged-structured in all models.

Category	Group	Method
Elasmo-branchs	Sleeper Sharks	S_Bio
	Salmon Sharks	S_Bio
	Dogfish	S_Bio
Major Roundfish	W. Pollock	S_Aged
	P. Cod	S_Aged
	Herring	S_Aged
	Atka	S_Aged
Large Flatfish	Arrowtooth	S_Aged
	Kamchatka	S_Aged
	Gr. Turbot	S_Aged
	P. Halibut	S_Aged
Small Flatfish	YF. Sole	S_Aged
	FH. Sole	S_Aged
	N. Rock sole	S_Aged
	S. Rock sole	S_Bio
	AK Plaice	S_Bio
	Dover Sole	S_Bio
	Rex Sole	S_Bio
	Misc. Flatfish	S_Com
Skates	AK skate	S_Bio
	Bering skate	S_Bio
	Aleutian skate	S_Bio
	Whiteblotched	S_Bio
	Mud skate	S_Bio
	Longnosed skate	S_Bio
	Big skate	S_Bio
	Black Skate	S_Bio
Slope groundfish	Sablefish	M_Aged
	Eelpouts	L_Com
	Giant Grenadier	S_Bio
	Pacific Grenadier	S_Bio
	Other Macruids	S_Com
	Misc. deep fish	S_Com
Motile epifauna	Sea Star	L_Com
	Brittle Star	L_Com
	Urchins dollars cucumbers	L_Com
	Snail	L_Com
	Hermit crabs	L_Com
	Misc crabs	L_Com
	Misc. Crustacean	L_Com
	Benth. Amph.	L_Com
Sessile epifauna	Anemones	L_Com
	Corals	L_Com
	Benth. Hydroid	L_Com
	Benth. Urochordata	L_Com
	Sea Pens	L_Com
	Sponge	L_Com
Infauna	Clam	L_Com
	Polychaete	L_Com
	Misc. Worm. Etc.	L_Com
Pelagic planktonic	Scypho Jellies	L_Bio
	Fish Larvae	L_Com
	Chaeteg etc.	L_Com
	Euphausiid	L_Com
	Mysid	L_Com
	Pel Amph	L_Com
	Pel. Gel. Filter Feeder	L_Com
	Pteropod	L_Com
	Copepod	L_Com
	Microzooplankton	L_Com
	Algae	L_Com
	Lg Phytoplankton	L_Com
	Sm Phytoplankton	L_Com
Detritus	Discards	L_Bio
	Offal	L_Bio
	Pelagic Detritus	L_Bio
	Benth Detritus	L_Bio

Table 2. Parameters and parameter calculation methods for the Ecopath master equation.

Parameter	**Abbreviation And units**	**Calculation methods used**
Biomass	B (t/km^2)	Survey estimates, sampling programs, stock assessments
Production/ Biomass	P/B (1/year)	Mortality rates, growth rates, bioenergetics models
Consumption/ Biomass	Q/B (1/year)	Bioenergetics models, gut content analysis
Diet composition	DC (proportion by biomass/wet weight)	Gut content analysis
Fisheries Catch	C (t/km^2)	Fisheries statistics
Biomass Accumulation	BA (t/km^2)	Biomass trend data (only used if energetic demand requires it)
Immigration and Emigration	IM and EM (t/km^2)	Used to specify annual net migration imbalance (not used in these models)
Ecotrophic Efficiency	EE (proportion)	Estimated by Ecopath or set at standard level to estimate biomass

Table 3. Criteria for grading data quality (pedigree) for biomass, P/B, Q/B, Catch, and Diet input parameters.

Rank

1. Data is established and substantial, includes more than one independent method (from which best method is selected) with resolution on multiple spatial scales.

2. Data is direct estimate but with limited coverage/corroboration, or established regional estimate is available while subregional resolution is poor.

3. Data is proxy, proxy may have known but consistent bias.

4. Direct estimate or proxy with high variation/limited confidence or incomplete coverage.

Biomass and Catch	**PB, QB, and Diet**
5. Estimate requires inclusion of highly uncertain scaling factors or extrapolation.	5. Estimation based on same species but in “historical” time period, or a general model specific to the area.
6. Historical and/or single study only, not overlapping in area or time.	6. Same species in neighboring region, or similar species in same region.
7. Requires selection between multiple incomplete sources with wide range.	7. Proxy from general literature review or model of clade, or outside of region.
8. No estimate available (estimated by Ecopath)	8. Functional group represents multiple species with diverse life history traits.

Table 4. Terms in the Ecosim dynamic equations.

Parameter	Abbreviation	Notes
Growth efficiency	GE	Constant for each predator, calculated as (P/B)/(Q/B) from Ecopath balance, may be subject to time forcing.
Consumption equation	*F(B)*	As documented in Walters et al. (1997), independent terms for each predator/prey link include predator density dependence. Calibrated from Ecopath Q/B and diet composition. Handling time (dependent on sum of prey) and other adjustments or forcing are possible as documented in the EwE manual.
Primary production rate	PP	Simple density-dependent half-saturation curve for all primary producers.
Immigration	IM	Constant yearly rate independent of biomass (assumed determined by outside dynamics). Determined from input Ecopath immigration.
Emigration	EM	Per-biomass rate determined from input Ecopath emigration.
Biomass Accumulation	BA	Per-biomass rate determined from input Ecopath Biomass Accumulation.
Fishing mortality	F	Per-biomass rate determined from input Ecopath fisheries catch and biomass.
"Other" (not predation) natural mortality	M_o	Determined by Ecopath Ecotrophic Efficiency and used to ensure equilibrium in the absence of biomass accumulation.

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