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Fisheries and the Environment: Ecosystem Indicators for the North Pacific and Their Implications for Stock Assessment

May 2005

Fisheries and the Environment: Ecosystem Indicators for the North Pacific and Their Implications for Stock Assessment

Proceedings of the First Annual Meeting of the National Marine Fisheries Service's Ecological Indicators Research Program

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EXECUTIVE SUMMARY

The goal of the National Marine Fisheries Service's Fisheries and the Environment research initiative, referred to as the Ecological Indicators (EI) program in this report, is to develop ecosystem indicators for use in stock assessment. The initiative is based on the premise that the state of knowledge of ocean processes and their potential impact on production, growth, and/or distribution of marine fish has matured to a level where the information can, and should be, incorporated into stock assessment advice and harvest policy. Investigators who are funded by the program meet on an annual basis to compare their observations and share innovations. This report summarizes the proceedings of the 2003 EI program meeting. The meeting focused on recent shifts in climatic conditions and their influence on the growth, distribution or production of marine fish and invertebrates.

The meeting was broken into six major focus sessions. Sessions 1 and 2 focused on physical and lower trophic level indicators of decadal variability (Session 1) and El Niño Southern Oscillation (ENSO)-related variability (Session 2). Session 3 focused on evidence of temporal shifts in recruitment variability of fish and invertebrate production. Session 4 reviewed evidence for climate forcing on fish and invertebrate geographic distributions. In Session 5, investigators compared recruitment patterns of marine fish in an effort to identify synchronous patterns of fish and invertebrate production. Session 6 was devoted to a review of the data needs and present tools for incorporating ecosystem indicators into stock assessments.

This report provides short 2-3 page summaries of presentations made by participants. The meeting served as a forum for exchange of information and analysis techniques amongst EI investigators and NMFS stock assessment scientists. Future meetings could be improved if stock assessment scientists from regional laboratories outside of the meeting location were able to attend. Key findings from each session include the following:

1. Evaluation of physical climate forcing data across the North Pacific reveals that the Bering Sea and West Coast exhibit different modes of forcing. Evidence of temporal shifts in physical and biological indicators was detected in the eastern Bering Sea (EBS) and along the West Coast in 1977, 1989, and 1997. Temporal shifts in Pacific Island ecosystem indicators were detected in 1977 and 1998. Key indicators include: Empirical Orthogonal Function (EOF) analysis of sea surface temperature (SST), sea level pressure (SLP), and sea surface height (SSH), and location of the Transition Zone Chlorophyll Front (TZCF) from satellite images.

2. It is difficult to distinguish whether shifts in ocean conditions resulted from an extended La Niña condition or from a decadal scale shift in atmospheric forcing. The winter position of the TZCF tracks the influence of atmospheric forcing in the Central Pacific. Beginning in late 2002, the central North Pacific began to return to pre-1999 observations. This finding is consistent with the conclusion that

the central North Pacific underwent a natural oscillation back to baseline conditions after an extended La Niña from 1999 to 2002. Comprehensive Ocean Atmospheric Database (COADS) data along the West Coast and central Pacific provide a useful index for tracking the time signature and northern extent of ENSO-related forcing.

3. Evaluation of ENSO forcing shows ENSO effects on the North Pacific vary by region. The most recent ENSO event of 2002-2003 was weak along the West Coast but strong in the Gulf of Alaska (GOA) and central Pacific.

4. Investigators from throughout the Pacific contributed evidence of impacts of climate forcing (decadal or ENSO-related). Time series of annual recruitment and production rates (recruits per spawner) were used to identify temporal shifts in fish and invertebrate production. Annual production of Pacific sardine, West Coast sablefish and hake, West Coast and Alaskan rockfish and Alaskan flatfish exhibited shifts consistent with decadal scale changes in climate forcing throughout the North Pacific. Time trends in the production of Pacific herring, Atka mackerel, walleye pollock, and Pacific cod were not statistically related to decadal shifts in physical and lower trophic level forcing. Pacific herring, Pacific cod, walleye pollock, sablefish, Atka mackerel and Pacific hake all exhibit recruitment time series punctuated by strong recruitment events. Of these, GOA Pacific cod, GOA walleye pollock and Pacific hake have a higher probability of an exceptional recruitment event in years of Niño North, the northern manifestation of El Niño. Market squid exhibit a marked decline in abundance that appears to be associated with Niño North events. The mechanism underlying this shift appears to be temperature-dependent growth.

5. If post-1998 conditions persist, production of commercial groundfish and salmon is expected to increase in the California Current, and groundfish production in the eastern Bering Sea (EBS) is expected to remain productive with a notable drop in winter spawning flatfish abundance.

6. Review of interannual variability in year-class strength revealed distinct patterns of synchrony among several stocks suggesting a common local response to large-scale forcing. For example, synchronous year-class strengths are observed for Pacific cod and walleye pollock in the EBS, for Pacific cod and walleye pollock in the GOA, and for Atka mackerel and walleye pollock in the Aleutian Islands. Cluster analysis of interannual variability in Alaskan groundfish and salmon and West Coast rockfish recruitment revealed synchrony in several stocks with distinct regional patterns. These regional patterns were consistent with regional partitions in oceanographic domains. Abundance indices from 10 West Coast rockfish species revealed marked similarities in the time trend of abundance. Investigators from the Southwest Fisheries Science Center (SWFSC) Santa Cruz laboratory attempted to develop regional stock assessments for West Coast rockfish. This technique showed that winter spawning rockfish exhibited marked

synchrony in the production all along the coast suggesting that survival is influenced by large-scale forcing.

7. Acoustic trawl and bottom trawl survey data indexed shifts in fish distribution in response to interannual variations in ocean temperature. Collection of underway information during surveys is highly recommended.

8. Examples of mesoscale shifts in fish or invertebrate distributions were indexed by spatial patterns of ocean color (index of chlorophyll-a) from satellite photos and underway collections of water column properties during surveys. In the Pacific Islands, satellite images identified frontal systems that may play important roles in defining habitat boundaries and niche partitioning between competing species at the local scale. Review of spatial patterns in fish distribution on the eastside of Kodiak Island revealed that shifts in the location or intensity of these fronts may be important for predator prey interactions and measures of competition for limited resources.

9. The final session of the meeting was devoted to a review of techniques for incorporating environmental information in assessments. Of the available techniques, immediate progress can be made in incorporating climate influences on growth and availability. In one notable case, temperature and spawning biomass are used to forecast reproductive success in Pacific sardine.

The presentations made at this meeting provide compelling evidence of recent shifts in biological communities throughout the North Pacific. Detecting change, identifying its temporal and spatial signature, and understanding the processes underlying the changes is a first step towards the EI Research Program's goal of developing ecosystem indicators for use in stock assessments. Ecological Indicators investigators acknowledged that several groups currently compile annual summaries of selected ecosystem indicators for their region (e.g., the state of the California Current report produced by California Cooperative Oceanic Fisheries Investigations (CalCOFI), and the Ecosystem Considerations Chapter of the North Pacific Fishery Management Council's Stock Assessment and Fishery Evaluation Report). Ecological Indicators investigators do not seek to replicate the efforts of other organizations. The EI program is designed to provide new indices for regional reports and to promote the use of these indices in stock assessments.

Meeting participants provided the following recommendations for future research. Stock assessment scientists should consider predicting future recruitment scenarios by drawing recruitment distributions from three different time periods: pre-1977, 1977-88, and 1989 to present. These recruitment forecasts could be used to assess the sustainability of the stock under alternative regimes. Ecological Indicators investigators could not reach a consensus regarding treatment of El Niños as events or as extremes in a continuum. While climatologists recognize El Niños as discrete, well-defined events, evidence of the expression of Niño North influences on marine fish is mixed. The EI program encourages laboratories to enhance ocean monitoring during surveys to identify factors

influencing the spatial distribution of fish. Evidence of synchrony in production patterns of selected groups of species provided a rationale for applying key vital rates for a well-studied species to a species where information is lacking. This application has direct use for developing management advice for species in data poor situations.

GLOSSARY

AFSC –	Alaska Fisheries Science Center
B.C. –	British Columbia
BEUTI –	Biologically Effective Upwelling Transport Index
BS –	Bering Sea
BSAI –	Bering Sea/ Aleutian Islands
CalCOFI –	California Cooperative Oceanic Fisheries Investigations
CCS –	California Current System
COADS –	Comprehensive Ocean Atmospheric Database
CPUE –	Catch per unit effort
CSL –	Coastal sea level
CTD –	Conductivity, temperature, and depth recorder
EBS –	Eastern Bering Sea
EBS POP –	Eastern Bering Sea Pacific ocean perch
EI –	Ecological Indicators
ENSO –	El Niño Southern Oscillation
EOF –	Empirical Orthogonal Function
GLOBEC –	Global Ocean Ecosystem Dynamics Program
GOA –	Gulf of Alaska
IOOS –	Integrated Ocean Observing Systems
IPHC –	International Pacific Halibut Commission
MEI -	Multivariate El Niño - Southern Oscillation Index
NMFS –	National Marine Fisheries Service
NOAA –	National Oceanic and Atmospheric Administration
NOI -	Northern Oscillation Index
NWHI –	Northwest Hawaii
OSCURS -	Ocean Surface Current Simulator
PDO –	Pacific Decadal Oscillation
PWS –	Prince William Sound
SEAK -	Southeast Alaska
SLP -	Sea level pressure
SSH –	Sea surface height
SST –	Sea surface temperature
SWFSC –	Southwest Fisheries Science Center
TZCF –	Transition Zone Chlorophyll Front

CONTENTS

I. INTRODUCTION

The National Marine Fisheries Service's (NMFS) Fisheries and the Environment research initiative, referred to as the Ecological Indicators (EI) program in this report, strives to develop methods to incorporate ecosystem indicators in stock assessment and harvest strategy evaluation. The initiative is based on the premise that the state of knowledge of ocean processes and their potential impact on production, growth, and/or distribution of marine fish has matured to a level where the information can and should be incorporated into stock assessment advice and harvest policy. Incorporating indicators of ecosystem status in stock assessments is a fundamental step towards developing ecosystem-based fisheries management.

The EI program is proceeding along a phased implementation time frame where modest funds support full-time equivalents (FTE) and post-doctoral appointees at NMFS regional science centers and satellite laboratories in the Pacific. These researchers work closely with stock assessment scientists and fisheries oceanographers and endeavor to develop prototype examples of methods for incorporating ecological indicators into stock assessments. NMFS envisions an expanded program where candidate mechanisms will be indexed by enhanced monitoring programs in the field. At current funding levels, the goal of this initiative is to develop ecological indicators based on value-added programs that utilize existing data, or new data derived from the field by augmenting existing surveys with new equipment. The indicators derived from the EI program may be synthesized products such as "Biologically Effective Upwelling Transport Index" (BEUTI) or direct observations such as the adult salmon habitat/growth/survival index.

A unique element of this program is that investigators are housed at different institutions. This is a new approach to staffing within NMFS. Housing scientists with a common objective in different institutions is expected to facilitate the development of cross-cutting projects that will expedite comparisons of fisheries responses to ecosystem change in different oceanographic conditions. The comparative approach has been the cornerstone of research focused on identifying the impact of climate forcing on marine fish populations.

The EI investigators meet on an annual basis to compare their observations and share innovations in modeling techniques. This report summarizes the proceedings of an EI program meeting hosted in Seattle on 22-23 September 2003. The purpose of this meeting was to bring scientists together to discuss evidence regarding ecological change across the North Pacific. Scientists attending the meeting were asked to provide data to evaluate the evidence regarding changes in oceanographic conditions that may affect fisheries and fish populations. Conveners were interested in information regarding decadal, interannual, or El Niño Southern Oscillation (ENSO) scale events and the evidence of these on growth, distribution or production of marine ecosystems. Participants hoped to render the long list of candidate mechanisms linking fish distribution, growth, or production to ecosystem indicators (Table 1) to a manageable list of core processes. We hoped to accomplish this task by searching for commonalities between species or species that share common life histories.

Table 1. -- Summary of studies of oceanic influences on recruitment of commercially exploited fish and shellfish stocks in the northeast Pacific Ocean.

Species	Reference	Hypothesized Mechanisms	Variable
Arrowtooth flounder	Bailey and Picquelle 2002	On-shore transport	El Niño – Southern Oscillation
	Wilderbuer et al. 2002	On-shore transport	Ocean Surface Current Simulator (OSCURS) winter transport
Bluefin tuna	Mysak 1986	Alteration of migration routes.	El Niño – Southern Oscillation
Coho salmon	Nickelson 1986	Reduced predation offshore, increased upwelling during spring and summer enhances prey availability leading to accelerated growth	Upwelling
	Logerwell et al. 2003	Winter preconditioning, spring production, spring advection, growth	Sea Surface Temperature (SST), transition date, sea level
	Mackas et al. 2001	Match mismatch	Timing of zooplankton bloom
	Beamish and Mahnken 2001	Critical period, Critical size	Timing of zooplankton bloom, sustained summer production
	Gargett 1997	Optimal stability window	Stratification
Dover sole	Hayman and Tyler 1980	Prey concentrations, location of settling	Upwelling
Dungeness crab	Johnson et al. 1986	Transport of zoea	Wind stress
	Jamieson et al. 1989	Transport	Current patterns
	McConnaughey et al. 1992	Larval transport and settlement	Geostrophic transport
English sole	Kruse and Tyler 1983	Alteration of spawning period, change in rate of gonadal development	Temperature
	Hayman and Tyler 1980	Prey concentration	High storm frequency, low mean wind speed
	Botsford et al. 1989	Prey concentrations	Production
	Forrester 1977	Egg viability	Temperature
	Ketchen 1956	Pelagic stage duration and transport	Temperature
Jack mackerel	Zwiefel and Lasker 1976	Incubation period, larval growth	Temperature
	Theilacker 1986	Larval starvation, predation	Production
	Hewitt et al. 1985	Larval starvation, predation	Production

Table 1. -- Continued.

Species	Reference	Hypothesized Mechanisms	Variable
Northern anchovy	Lasker 1975, 1981	Prey concentration	Wind-driven turbulence
	Peterman and Bradford 1987	Prey concentration	Wind-driven turbulence
	Husby and Nelson 1982	Transport and prey concentration	Turbulence, upwelling, strength of thermocline
	Power 1986	Larval Transport	Upwelling
	Fiedler 1984	Extension of spawning range	El Niño - Southern oscillation
	Zweifel and Lasker 1976	Incubation period, larval growth	Temperature
	Methot 1986	Maturity schedule	Temperature
Pacific cod	Tyler and Westerheim 1986	Larval transport, survival of eggs and larvae	Transport and temperature
Pacific hake	Bailey 1981	Larval transport	Upwelling, temperature
	Zweifel and Lasker 1976	Incubation period, larval growth	Temperature
	Bailey and Francis 1985	Larval transport, growth, spawning location	Upwelling and temperature
	Hollowed and Bailey 1989	Larval transport, growth, prey availability	Upwelling, spring transition
	Horne and Smith 1997	Spawning location, location of nursery grounds	Larval distribution, temperature
	Sakuma and Ralston 1997	Vertical distribution, advection	Stratification, upwelling
	Cass-Calay 1997	Growth dependent on prey size	Zooplankton samples
Pacific halibut	Parker 1989	Larval transport	Wind
	Clark et al. 1999	Transport, growth	Pacific Decadal Oscillation (PDO)
	Bailey and Picquelle 2002	Transport	El Niño - Southern Oscillation
Pacific herring	Alderdice and Hourston 1985	Embryonic and larval survival	Temperature, salinity
	Stocker et al. 1985	Physiological effect, prey production	River discharge, temperature
	Schweigert and Noakes 1991	Transport	Ekman transport, upwelling

Table 1. -- Continued.

Species	Reference	Hypothesized Mechanisms	Variable
Pacific herring continued	Tanasichuk and Ware 1987	Ovary weight and fecundity	Temperature
	Foy and Paul 1999	Overwintering success, accumulation of fat, sustained summer feeding	Timing of spring bloom, growth rate, production
	Cooney 1993	Zooplankton abundance determines rate of predation	Zooplankton abundance and pollock abundance
Pacific sardine	MacCall 1996	Habitat quality and quantity	Spatial distribution of temperature
	Bakun 2001	School mix and schooling behavior modulates predation	Distribution of adults and juveniles
Rock sole	Fargo and McKinnell 1989	Year-class strength modulated by temperature	Temperature
Rockfish	Larson et al. 1994	Larval transport	Upwelling, larval distribution
Walleye pollock	Bailey and Macklin 1994	Wind mixing influences on larval feeding	Wind mixing
	Dwyer et al. 1987, Livingston and Methot 1998, Hollowed et al. 2000a, Bailey 2000	Juvenile predation	Predator abundance
	Hinckley et al. 1991, Kendall et al. 1996	Transport to nursery grounds	Advection
	Paul and Paul 1999	Overwintering success	Growth
	Megrey et al. 1996	Eddy concentration of prey	Precipitation
	Brodeur et al. 1996	Feeding success in frontal regions	Strength and location of fronts
	Wespestad et al. 2000	Transport away from predators	Advection

II. REGIONAL EVIDENCE FOR A LATE 1990s REGIME SHIFT

Shifts in climate forcing and their associated shifts in ocean conditions have important impacts on marine fish populations. The National Oceanic and Atmospheric Administration's (NOAA) National Standard Guidelines for implementation of the Magnuson-Stevens Fishery Conservation and Management Act include a provision to allow re-setting biological reference points if there is compelling evidence of a natural shift in the reproductive characteristics of the stock. In practice, biological reference points reflect a long-term productive regime and they are seldom reset. There is a need within the agency for guidance regarding the circumstances that constitute a compelling case for re-setting biological reference points. Three crucial steps should occur to enable assessment scientists to make this determination:

1. Scientists should be able to characterize the state of the system in terms that will distinguish the new state from natural variability.

2. Scientists should be able to identify the temporal signature of climate shifts in an unambiguous way such that shifts to new ecosystem states can be readily detected.

3. Scientists should be able to identify the mechanisms underlying shifts in fish production.

In this session, meeting participants presented evidence of decadal shifts in climate forcing. Participants were asked to consider their regional findings with respect to the three steps identified above.

Identifying and characterizing decadal shifts in atmospheric forcing is an active area of research. Opinions differ on the duration and signature of such shifts. For example, the Pacific Decadal Oscillation (PDO) represents a change in the distribution of sea surface temperature across the Pacific (Mantua et al. 1997). This index tracks low frequency variability as shifts between two phases (positive and negative) with recent shifts in 1976-77 and perhaps a new event in 1999. In contrast, Overland et al. (1999) identifies climate variability across a spectrum of climate variability marked by strong events occurring in association with the PDO and several minor events of short (3-7 year) duration. More recent studies revealed that the temporal signature of atmospheric forcing differs by region. Overland et al. (1999) and Hare and Mantua (2000) documented a marked shift in the Arctic Oscillation in 1988-89. This shift influenced the Bering Sea ecosystem. Ecosystem effects of the 1989 shift were also detected in shifts in salmon catch, zooplankton community structure off the coast of British Columbia and zooplankton abundance in the California Current ecosystem.

Recent studies identify a shift in atmospheric forcing in 1998-99 (Peterson and Schwing 2003, Chavez et al. 2003). The time signature of the PDO showed a sharp transition in 1976-77 and with shifts of short duration in 1988-89 and 1999-2000 (Fig. 1). This shift occurred in conjunction with one of the largest El Niño events of the century and was followed by a strong La Niña. The recent 1999-2000 of the PDO index extended for 4 years, was interrupted by a positive PDO index in September 2002 because of the El Niño event and is expected to become negative again. Bond and Overland (IIA) and Howell and Polovina (IIB) present compelling evidence that support the hypothesis that climate forcing may be shifting.

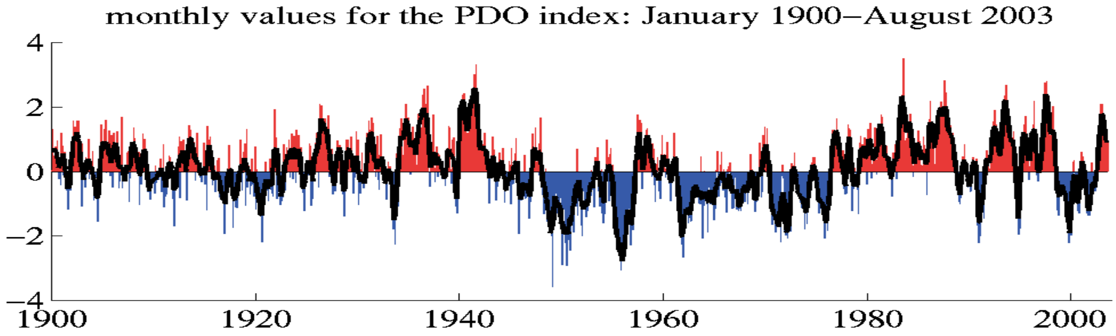


Figure 1. -- Time series of the Pacific Decadal Oscillation (source: http://www.jisao.washington.edu/pdo/, Retrieved 1 August 2003).

IIA. North Pacific (N.A. Bond and J.E. Overland)

A shift in the PDO index in 1998 led scientists to question whether we experienced a climate shift. The winters of 1972-76 were typical of the negative PDO phase, with anomalously high pressure over the east-central north Pacific and the Bering Sea (Bond et al. 2003; Fig. 2a). There was warm water in the east-central Pacific and cold water along the west coast of North America (Bond et al. 2003; Fig. 2b). From 1976-77 to the mid-1990s, the North Pacific was characterized by a generally positive PDO (Mantua et al. 1997) (e.g., enhanced salmon production in Alaska and depressed salmon production off Oregon and Washington). In 1998 there was a shift towards negative PDO initially suggesting conditions may have returned to a pre-1977 state; however, there was no clear shift in the Aleutian Low index in 1998 and it has remained at relatively large negative values for most of this time. During 1999-2002, there was also 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 (Fig. 2a). This resulted in cold sea surface temperatures in the eastern Pacific and warm temperatures in the central Pacific and the Bering Sea (Fig. 2b). Therefore, conditions have not returned to the pre-1977 state, rather the North Pacific is in a new state that has not been previously observed and is not adequately described by the PDO index (Bond et al. 2003).

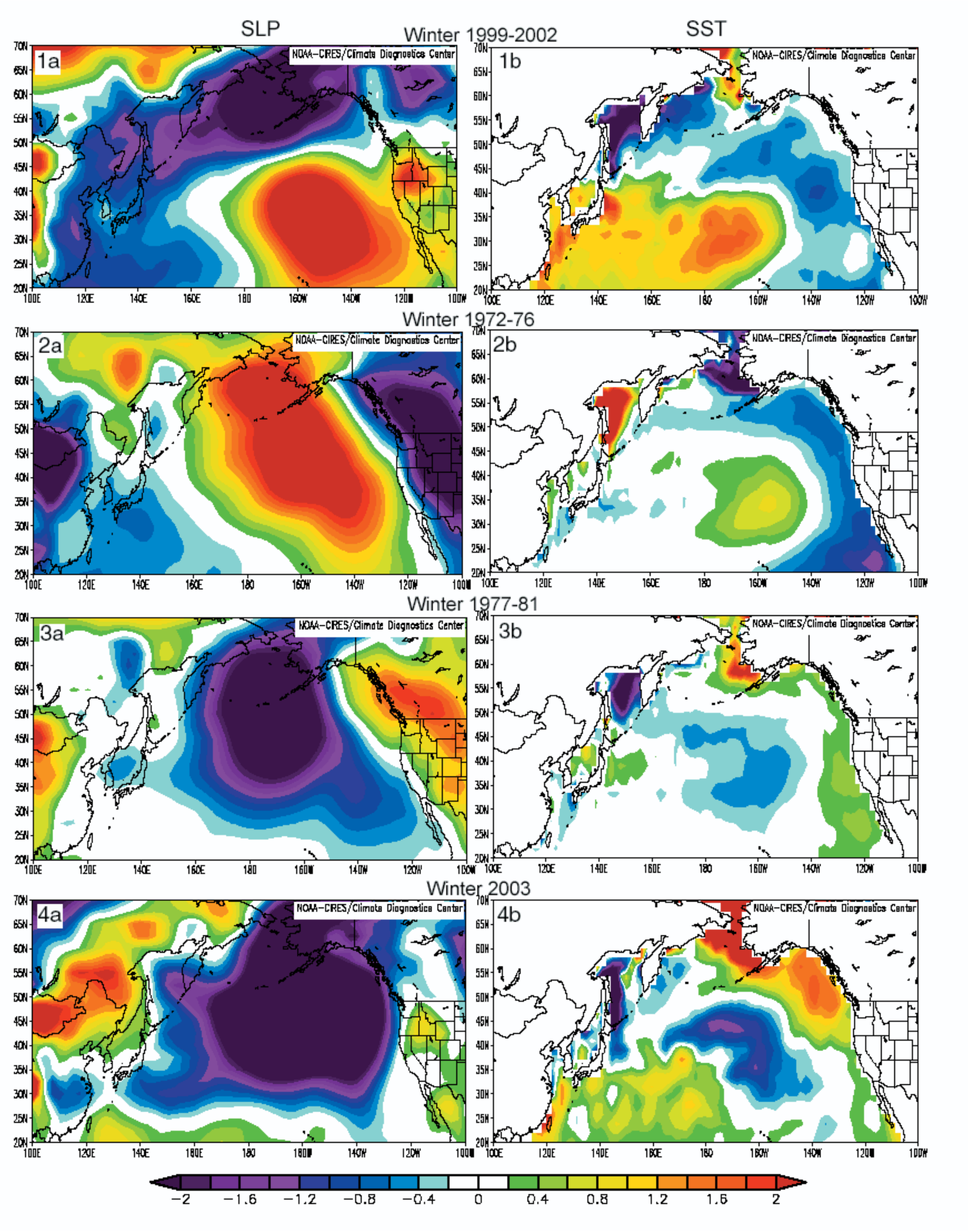


Figure 2. -- Maps of: a) sea level pressure, and b) sea surface temperature for winter (November – March) 1999–2003, 2003, 1972-76, 1977-81 from Bond et al. (2003).

IIB. Central North Pacific (E. Howell and J. Polovina)

Introduction

Early observations of recent changes in the mean state of several environmental and climatological parameters in the central North Pacific since 1999 were thought to be indicative of a regime shift. A rapid increase in sea surface height (SSH) and sea surface temperature (SST) in the subtropical gyre has been detected since 1999. Changes on the scales observed can affect ecosystems in the central North Pacific ranging from the area surrounding the northwestern Hawaiian Islands (NWHI) to large-scale changes in the basin-wide Transition Zone Chlorophyll Front (TZCF). The deviations observed remained strong in the period from 1999 to 2002, but they have appeared to return to a mean climatological state following the weak El Niño event of 2002-2003.

Environmental Changes Observed in the Central North Pacific

The largest changes in the central North Pacific were centered in the area between the subtropical and subpolar gyres, which is commonly referred to as the Transition Zone (Roden 1991, Roden 1977). There was a rise in SSH and SST in this zone centered close to Midway Island (180°W, 29°N) from 1999 to 2002. An Empirical Orthogonal Function (EOF) analysis of detrended altimetry data can provide the modes of low frequency variability in the central North Pacific observed during this period. The first mode of the EOF analysis accounts for 11.6% of the total variability (Fig. 3). The spatial pattern of the first mode is representative of the largest variation in the central North Pacific with seasonality removed. The first principal component (Fig. 3a) of this spatial pattern shows a definite shift in 1999, which is indicative of a reversal in the spatial pattern (Fig. 3b). The magnitude of the change in sea surface height as estimated from the first principle component has a maximum of 10-12 cm from 1999 to 2002 with a drop back towards pre-1999 conditions during the weak El Niño event of 2002-2003.

The variability exhibited by the observed SST is very similar but does not directly mirror the changes observed in the SSH (Fig. 4). The largest change observed is again in the central North Pacific, with temperatures rising to 1.5° C in the time period from 1999 to 2002. The changes observed show a complete reversal of sea state. In the time period before 1999, the central North Pacific had lower sea surface heights, with corresponding cooler temperatures. This state of lower height and cooler waters is indicative of a subsurface region with less stratification and greater mixing. These conditions are also indicative of a shallower thermocline and increased upwelling, mechanisms which can infuse nutrients to the mixed layer and increase primary productivity.

The reversal of sea state in 1999 is accompanied by an increase in SSH and a rise in the water temperature. These signals are indicative of a convergent zone with increased stratification, a decrease in mixing, and a depression of the mixed layer. The depression of the mixed layer in conjunction with the increase in stratification has an adverse effect on primary productivity that may carry negative repercussions throughout the food web. The change in state also affects another major component of the central North Pacific, the TZCF. The TZCF is a basin-wide chlorophyll front that occurs along the interface between the low-surface chlorophyll subtropical gyre and the high surface chlorophyll subarctic gyre. The TZCF has a natural meridional oscillation pattern with a latitudinal minimum in January-February and a latitudinal maximum in

July-August (Polovina et al. 2001). The position of the TZCF appears to be directly connected to the SSH and corresponding subsurface conditions. In the pre-1999 time period, the TZCF reached a southern latitudinal minimum below 28°N, directly influencing the waters close to and including the NWHI (Fig. 5). From 1999 to 2002, the southern latitudinal minimum was constrained north of 30°N, with no interaction with the NWHI. The TZCF did reach farther south during the El Niño year of 2003, but it was still constrained north of the NWHI. The observed northern containment of the TZCF in the winter may have negative effects on the habitat of the NWHI. The intrusion of the TZCF during winter brings an infusion of phytoplankton to the system. Non-infusion at this low trophic level may have negative impacts throughout the food chain.

This northern restriction of the transition zone may also be directly dependent on the magnitude of the wind stress curl in the area. Wind stress curl is commonly used as a proxy for describing areas in terms of vertical movement of water. Areas of high positive (negative) wind stress curl produce upwelling (downwelling) of water in that area. There appears to be a relationship in the transition zone between the maximum of the negative wind stress curl signal and the position of the TZCF (Fig. 6). Comparisons of the wind stress curl along a meridional line (Fig. 7) for the periods 1991 to 1998 and 1999 to 2003 show a latitudinal increase in the negative wind stress curl maximum. This is indicative of a northern restriction of the area of highest convergence in the central region of the transition zone.

Another interesting feature that has been observed since 1998 is the appearance of large chlorophyll a blooms around the Hawaiian Archipelago. These blooms have emerged on an interannual basis with major events occurring in July or August of 1998, 2000, and 2002. At this time not much is understood about the importance of these blooms, but it is hypothesized that they are comprised of nitrogen-fixing diatoms and are nontoxic. It is also believed that these diatoms thrive in warm, stratified waters as a result of low winds. The main difference observed is that, in 1998, two bloom events occurred to the west of the island chain near French Frigate Shoals, whereas in 2000 and 2002, the blooms appeared to the north/northeast of the main Hawaiian Islands.

Conclusions

A basin-wide change in the mean sea state of the central North Pacific to La Niña conditions occurred from 1998 to 2002. This shift in state was observed in several environmental parameters across multiple satellite platforms. A 10-12 cm rise in SSH in the central North Pacific was observed with a 1-2°C warming of the sea surface. These observed changes also affected the winter position of the TZCF and its interaction with the NWHI. Beginning in late 2002, the central North Pacific began to return to pre-1999 observations. This would allow the conclusion that the central North Pacific underwent a natural oscillation back to baseline conditions after and extended La Niña from 1999 to 2002.

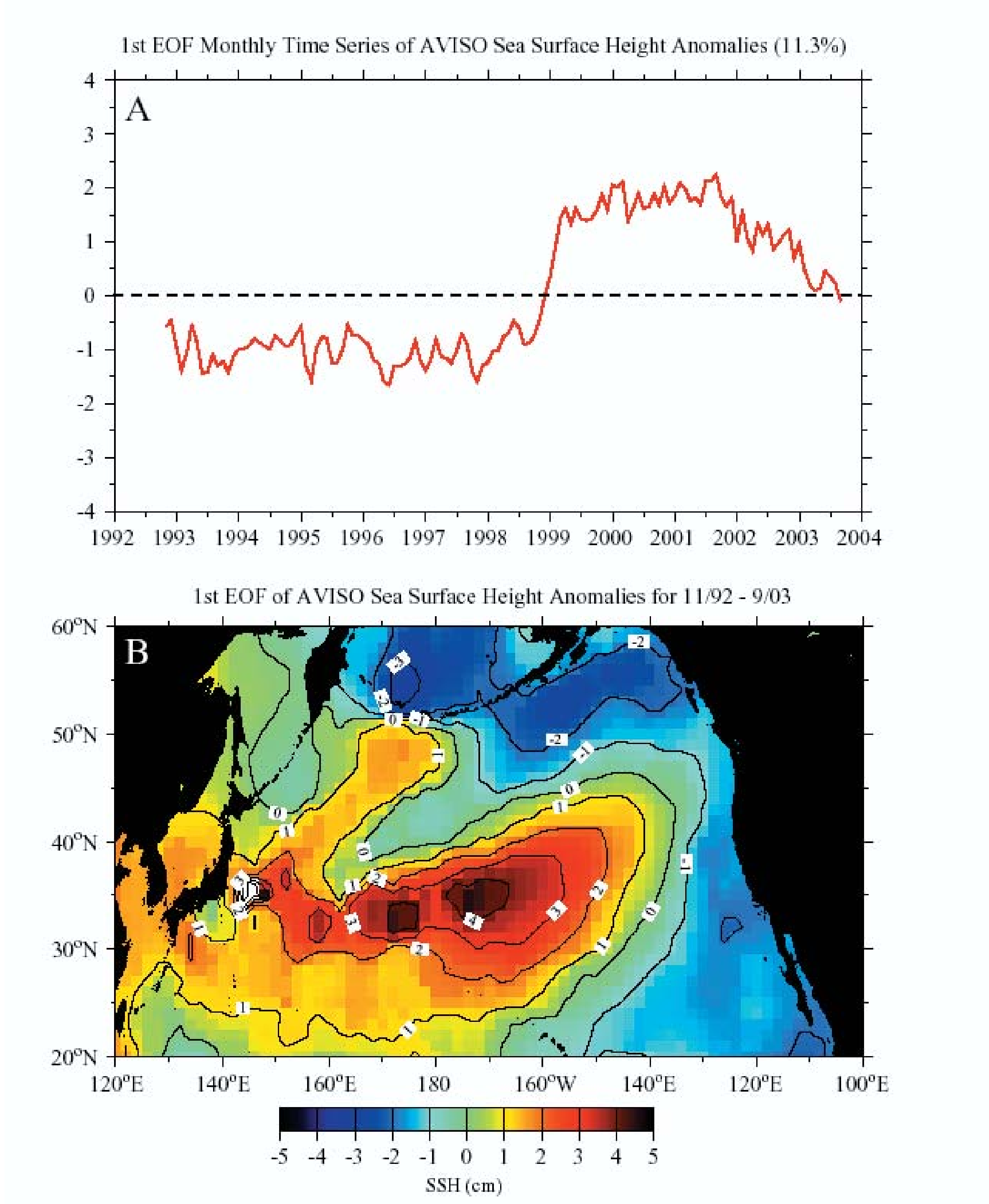


Figure 3. -- The first mode of the Empirical Orthogonal Function (EOF) analysis of sea surface height. The top portion (A) represents the magnitude of the detrended variation. The bottom portion (B) is the first eigenvector which is equal to spatial pattern of the variation. The product of the two yields the total change in height.

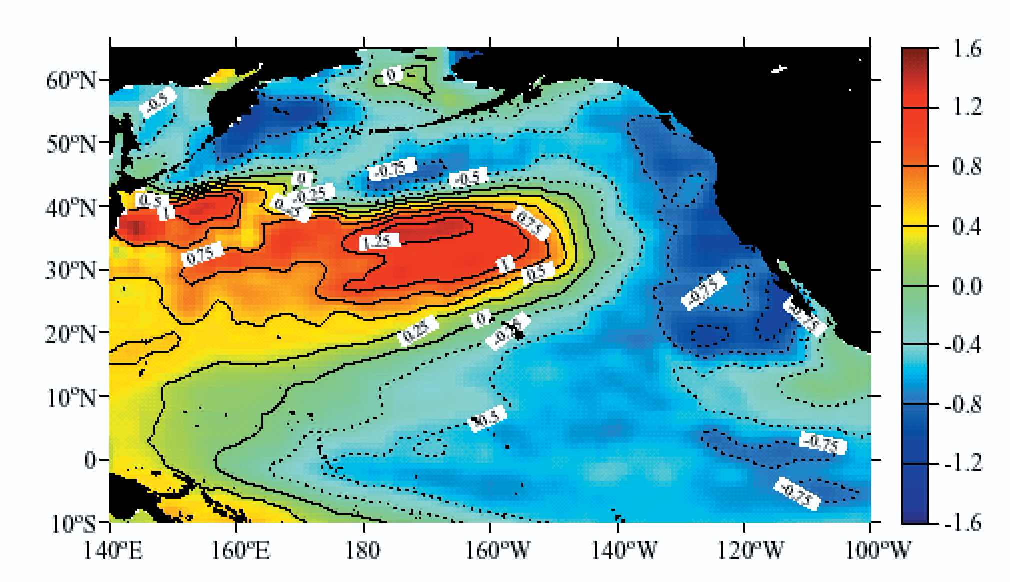


Figure 4. -- The difference in sea surface temperature (SST) anomalies of Period 1 (1993-98) subtracted from Period 2 (1999-2002). The scale of the image is in degrees Celsius.

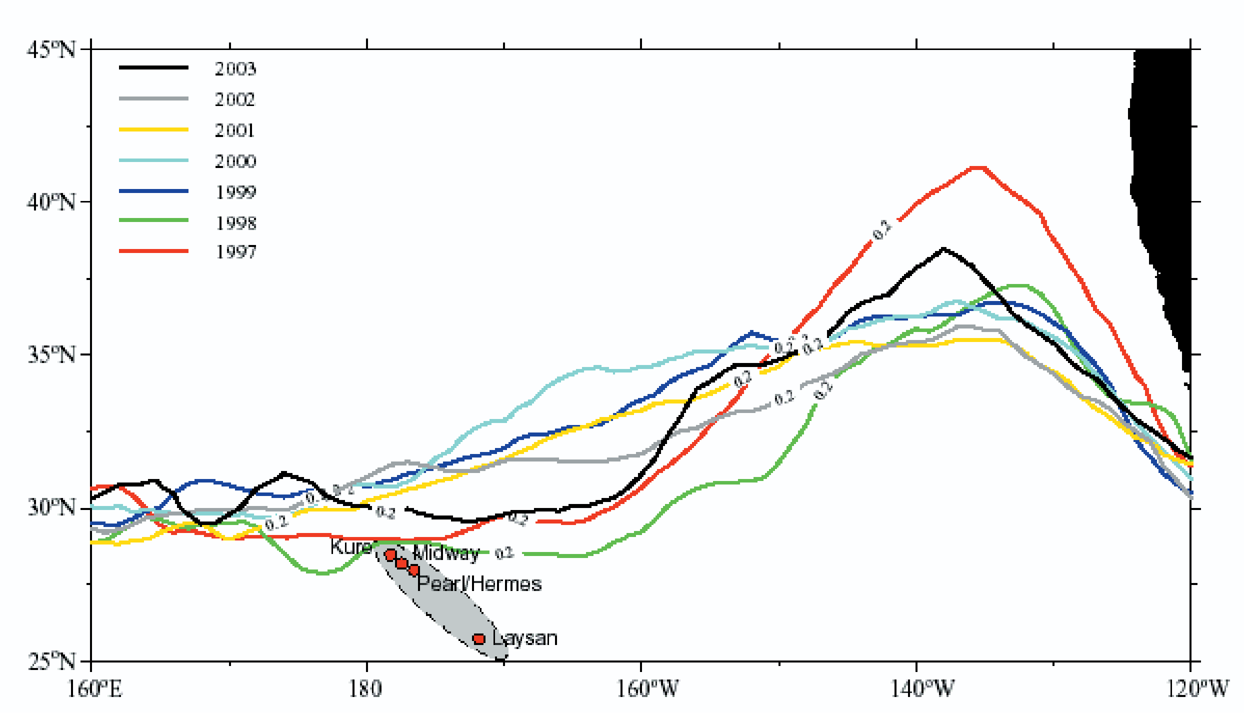


Figure 5. -- The position of the Transition Zone Chlorophyll front at its southern minimum each year. The front is described as the 0.2 mg m^{-3} contour line. Each line is the average of the values for January and February for each year.

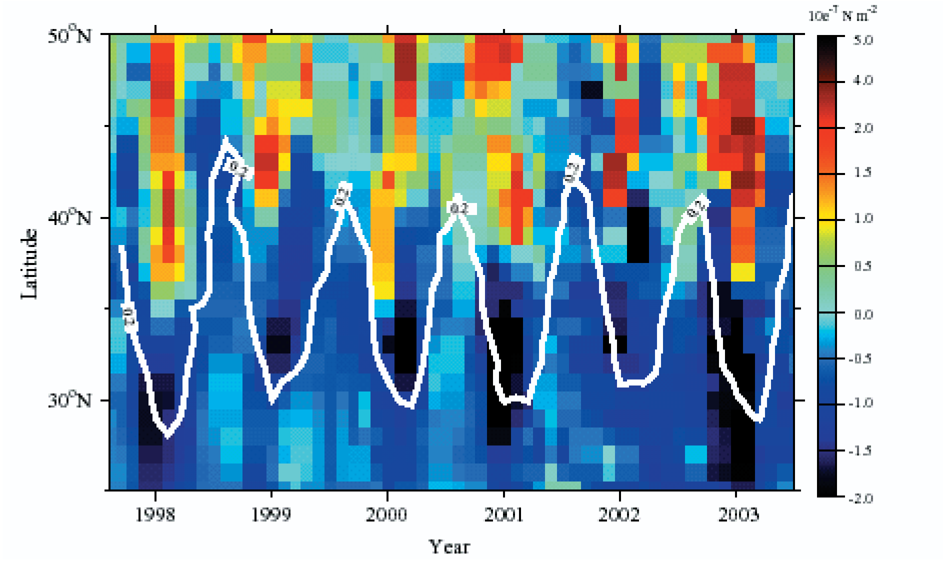


Figure 6. -- A time series of meriodonal slices of ERS-1,2 and QUIKScat wind stress curl averaged over 5 degrees (178°E-177°W). The white line represents the 0.2 mg chl *a* m^{-3} Transition Zone Chlorophyll Front.

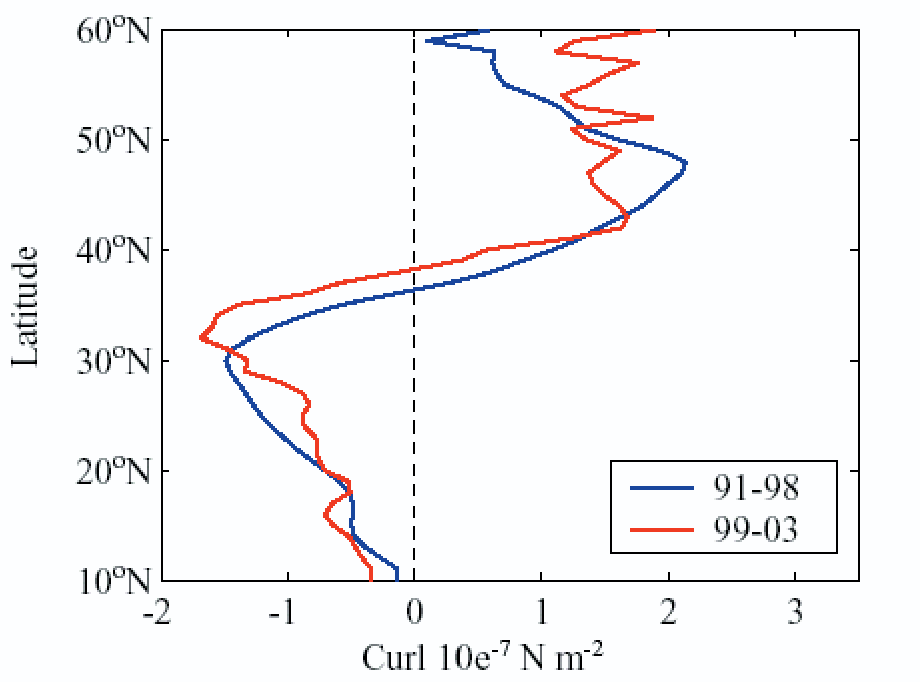


Figure 7. -- Meridional slices of ERS-1,2 and QUIKScat wind stress curl averaged over 5 degrees (178°E-177°W) during the two temporal regions of interest (1991-98, 1999-2003) in the winter (January-March).

III. Regional Evidence for 1997-98 and 2002-03 El Niño Effects

There is a rich amount of literature documenting influences of El Niño /La Niña and its northern manifestation Niño North/ Niña North on the distribution, growth and production of phytoplankton, zooplankton, and marine fish. Stock assessment scientists use this information to reduce uncertainty in their assessments. Three steps must occur to enable assessment scientists to facilitate the incorporation of El Niño Southern Oscillation (ENSO) type forcing in stock assessments:

1. Scientists should be able to identify the temporal signature of climate shifts in an unambiguous way such that Niño / Niña North influences can be readily detected;

2. Scientists should be able to distinguish whether conditions represent a Niño / Niña North event that is unique or whether the events represent a condition that is within the range of natural variability. (Addresses the question of whether we treat the years as events or as time series of predictor variables).

3. Scientists should be able to identify the mechanisms underlying the shifts in productivity. If Niño / Niña North influences a process indexed by a local variable, it would be preferable to use the local index.

Participants were asked to consider their regional findings with respect to the three steps identified above.

Analysis of sea surface temperature (SST) anomalies along the coast of North America reveals that the regional influence of ENSO events in the North Pacific is not identical for all events (Hollowed et al. 2001, Peterson and Keister 2003). Hollowed et al. (2001) used this information to document Niño North conditions in the coastal regions of the North Pacific (Table 2). In some years (1973), ENSO effects are only observed off the coast of California (Fig. 8). In other years (1957-58, 1982-83 and 1997), warm ocean temperatures are observed throughout the region (Fig. 8). Similar figures for meridional slices of Reynolds SST (reconstructed from 1950 to 1981, optimal interpolation from 1982 to 2003) data in the central North Pacific (178°E-176°W) by latitude also show the evidence of ENSO events (Fig. 9).

The transition in oceanographic conditions following the strong El Niño event of 1997-98 was possibly the most dramatic and rapid episode of climatic change ever recorded in the California Current Ecosystem (Schwing et al. 2002, Greene 2002). This event was characterized by substantially cooler coastal waters along the west coast of North America (Schwing and Moore 2000, Schwing et al. 2000), likely the result of anomalously strong upwelling-favorable winds, and/or greater than normal southward transport in the California Current (Strub and James 2003). Satellite data have revealed a basin-wide increase in sea level slope, resulting in some of the lowest sea level readings observed in at least 65 years along the west coast of North America (Chavez et al. 2003, Peterson and Schwing 2003). These observations correspond with a clear shift in a variety of climate indices (i.e., Northern Oscillation Index (NOI), Multivariate El Niño - Southern Oscillation Index (MEI)), including a shift to negative ("cool phase") values of the

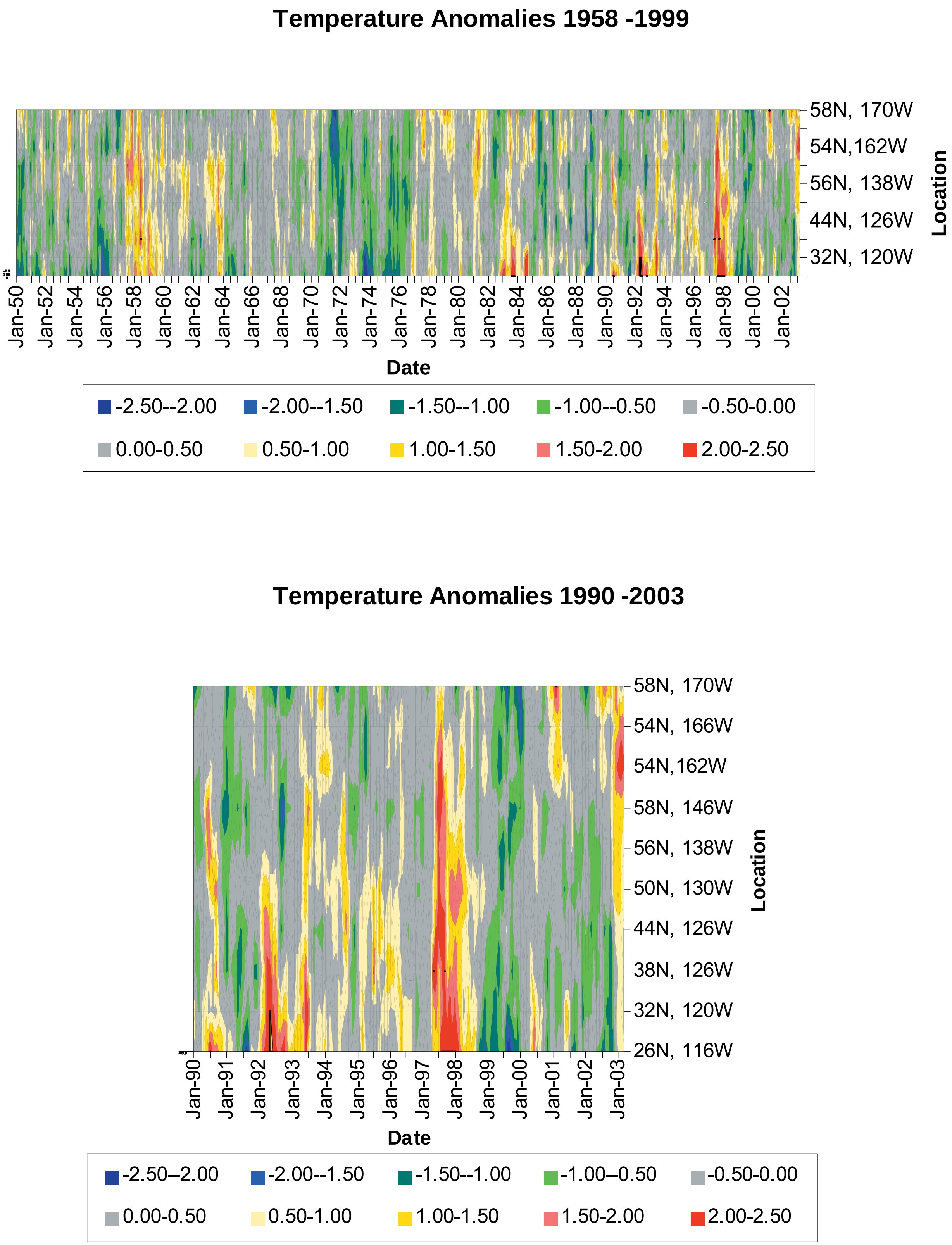
PDO beginning in August 1998 (Fig. 1). These negative PDO conditions persisted for 4 years until the onset of moderate El Niño-like conditions in late 2002.

The information presented here updates the Niño North time series with the most recent ENSO event which occurred in 2002-03. The coastal temperature signature of this event differed from previous events with a marked positive sea level anomaly apparent along the Alaskan coast with only a minor level of warming along the West coast (Figs. 2b and 8). This signature is clearly observed in global sea surface temperature anomalies for January 2003 (Rodionov et al. 2003) (Fig. 10). The 2002 ENSO event is clearly evident in the central Pacific and in the northern latitudes (Figs. 8 and 9)

Table 2. -- Timing and duration of anomalous warm conditions related to tropical El Niño events. Tropical events are identified in the first column. The year and month when warming was identified for each region using the format MM/YY, the duration of the event in months is in parentheses.

Equatorial Region B	West Coast	Eastern GOA	Western GOA and EBS	Lag WC	Lag GOA	Lag EBS
6/51-2/52(9)		9/51-12/51(4)			3	
4-9/53(6)			7/53-9/53(3)			3
4/57-4/58(13)	6/57-9/59 (28)	5/57-8/58 (16)	6/57-6/58(13)**	2	1	2
6/63-1/64(8)	9/63-1/64(5)	10/62-2/64(17)		3	-8	
4/65-2/66(11)	11//65-12/65(2)*			7		
11/68-1/70(15)	12/69-3/70 (4)		1/70-4/70(4)	13		14
4/72-2/73(11)	10/72-1/73(4)			6		
6/76-3/77(10)	11/76-2/77(4)		6/77-10/77(5)	5		12
7/77-1/78(7)+	12/77-6/78(6)		2/78-5/78** 12/78-9/79(10)	5		7
10/79-4/80(7)+	1/80-3/80 (3)			3		
5/82-9/83(17)	1/83-3/84 (15)	3/83-8/83 (6)	5/83-8/83(4), 12/83-1/84(2)!	8	10	12
9/86-1/88(17)			10/86-12/86 (3), 3/87-5/87(3)	7		1; 6
5/91-6/92(14)	2/92-11/92(10)			9		
3-7/93(5)	2/93-7/93(6)	5/93-8/93 (4)	11/93-12/93(2)!	-1	2	8
10/94-2/95(5)	2/95-4/95 (3), 7/95-9/95 (3), 12/95-9/96(10)			4		
[5/97-]	5/97 - 8/98 (16)	6/97-4/98(11)	6/97-8/97(3)	0	1	1

* only 2 month duration, ** includes a 2 month gap, + evident in Trenberth's analysis only.


Temperature Anomalies 1958 -1999

Temperature Anomalies 1990 -2003

Figure 8. -- Sea surface temperature anomalies (top) as measured from Comprehensive Ocean Atmospheric Database (COADs) in regions along the coast of North America 1950-2003 and the same (bottom) for the 1990 – 2003.

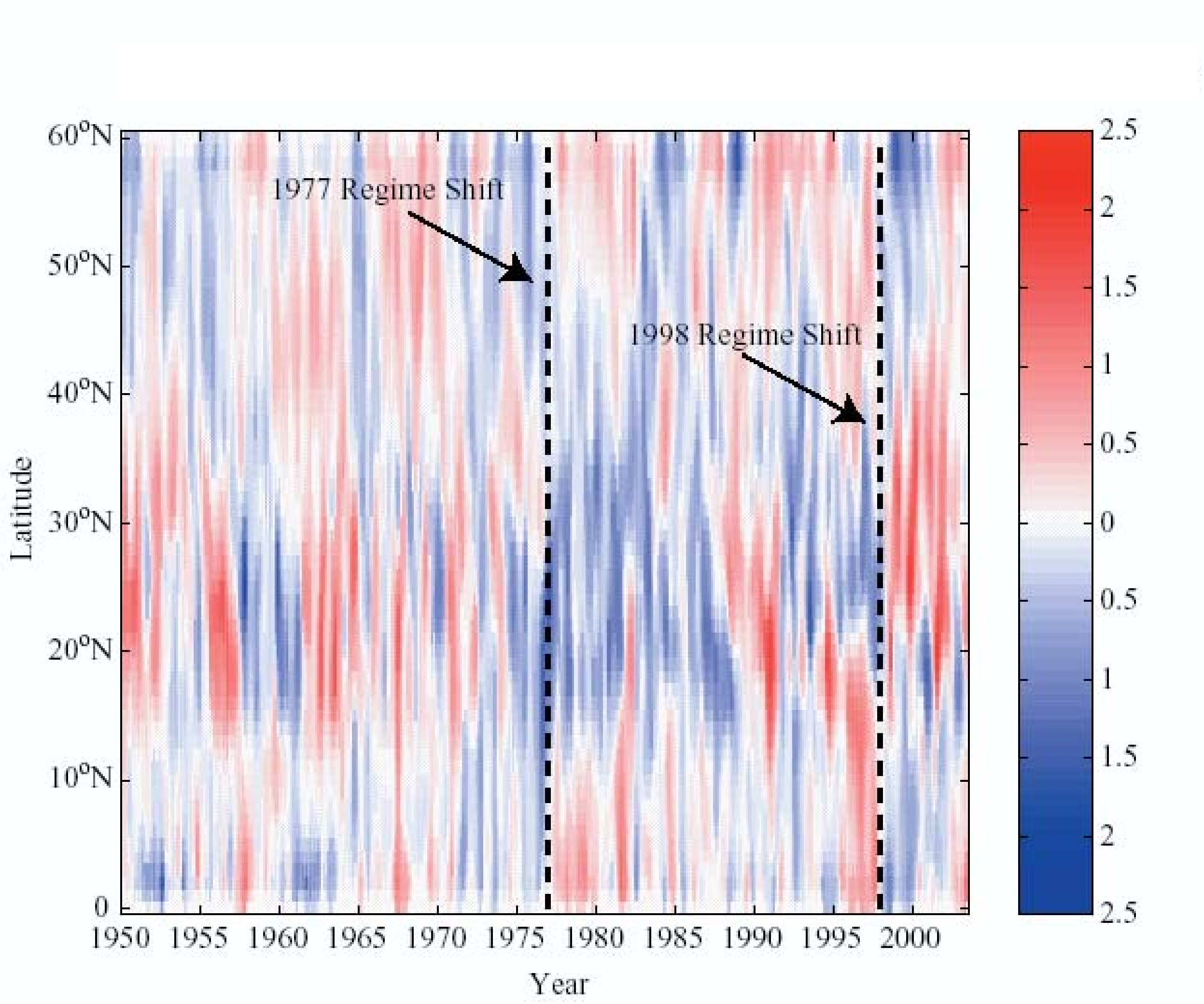


Figure 9. -- Meridional slice of Reynolds sea surface temperature (SST) (reconstructed from 1950-81, optimal interpolation from 1982 to 2003) in the central North Pacific (178°E-176°W) by latitude. The regime shifts of 1977 and 1998 are indicated by dashed lines.

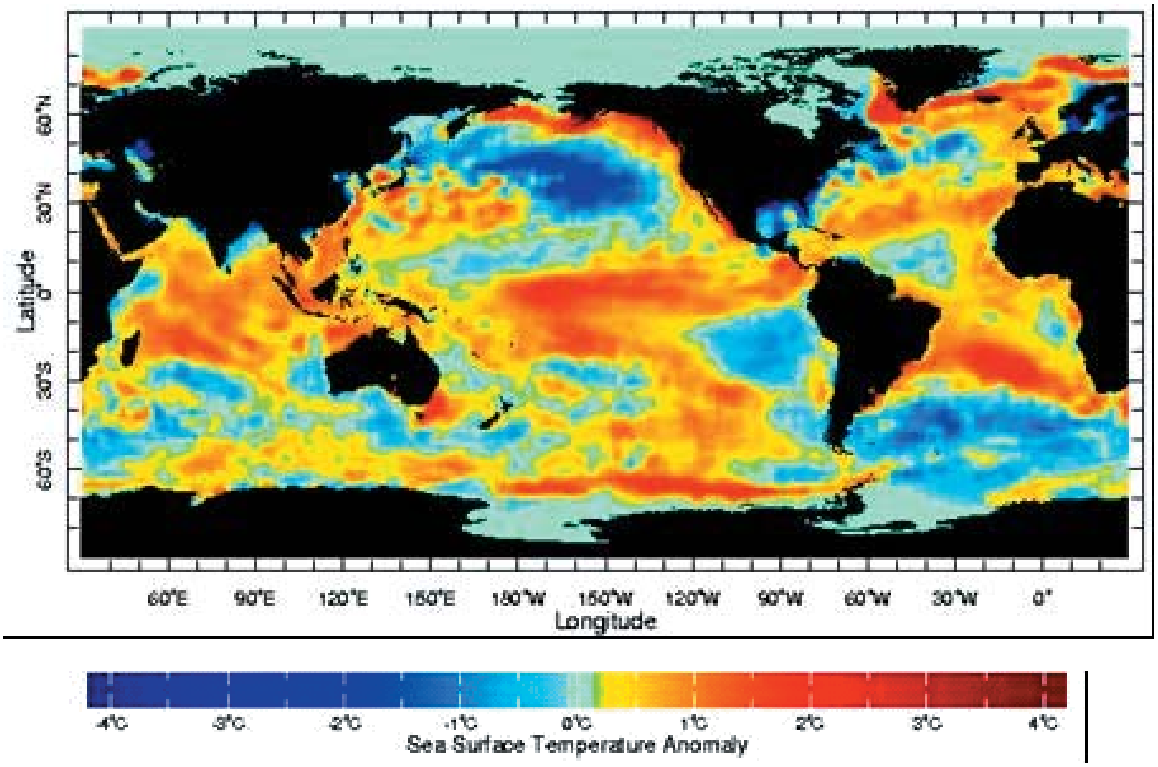


Figure 10. -- January 2003 sea surface temperature anomalies from Rodionov et al. 2003.

IV. INFLUENCE OF CLIMATE FORCING ON ANNUAL PRODUCTION

Incorporating decadal shifts in climate forcing into stock assessments requires the following steps:

a) Developing an unambiguous method for detecting a link between climate and fish production.
b) Testing proposed mechanisms underlying shifts in landings by predicting future production.
c) Determining whether the shift influenced carrying capacity (mean recruitment) or the shape of the spawner recruitment relationship (steepness).
d) Determining whether the shift is likely to remain bottom-up or whether the system will evolve such that top-down control (competition or predation) are important.

Comparison of the temporal signature of climate forcing to fish production can be accomplished in a variety of ways. Hare and Mantua (2000) aggregated all fish production time series and performed a principal components analysis on the time series. This approach was successful in detecting a discontinuity in production on or around 1976-77 and 1988-89. Alternatively scientists may compare time series of recruitment anomalies. Anderson and Piatt (1999) modified this technique by smoothing time series using a 3-year running average of biomass for several species in the Gulf of Alaska (GOA). Each method has inherent strengths and weaknesses.

Meeting participants provided time series of annual production (recruitment) for stocks throughout the study region (Figs. 11-16). Anomaly plots of recruit per spawner were developed for each region. The pattern of production differed between species and regions. Some stocks (e.g., flatfish, and yelloweye rockfish) exhibit highly autocorrelated recruitment patterns. Others exhibit episodic recruitment events that sustain the stock for several years (e.g., Pacific hake, walleye pollock, and Pacific cod).

The standard for detecting change in fish production may differ between different species. For stocks that exhibit autocorrelated time series of recruitment, the primary challenge lies in differentiating climate forcing from density-dependent processes within a species or from stocks with similar life histories. For episodic species, several factors may be influencing annual production, and strong year classes only occur when the processes align. Bailey (2000) and Hunt et al. (2002) hypothesized that the processes controlling recruitment may shift as the system adjusted to a new production regime. In the early part of the regime forcing may be bottom-up while in a mature system the forcing may stem from bottom-up and top-down processes.

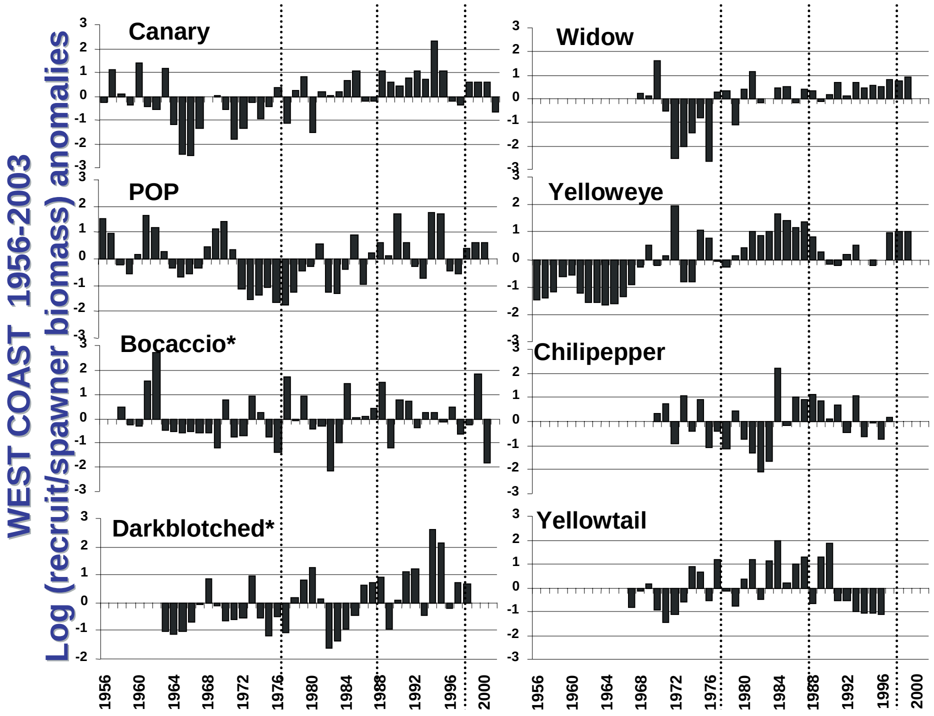


Figure 11. -- Recruit per spawner anomalies for West Coast groundfish species assessed with age- or size-structured models. Anomalies are normalized (estimate minus the average of all years) values of the log ratios of recruit abundance per unit mass of spawning biomass. The vertical dotted lines represent identified "regime changes" (Hare and Francis 1995, Hare and Mantua 2000, Mantua and Hare 2001).

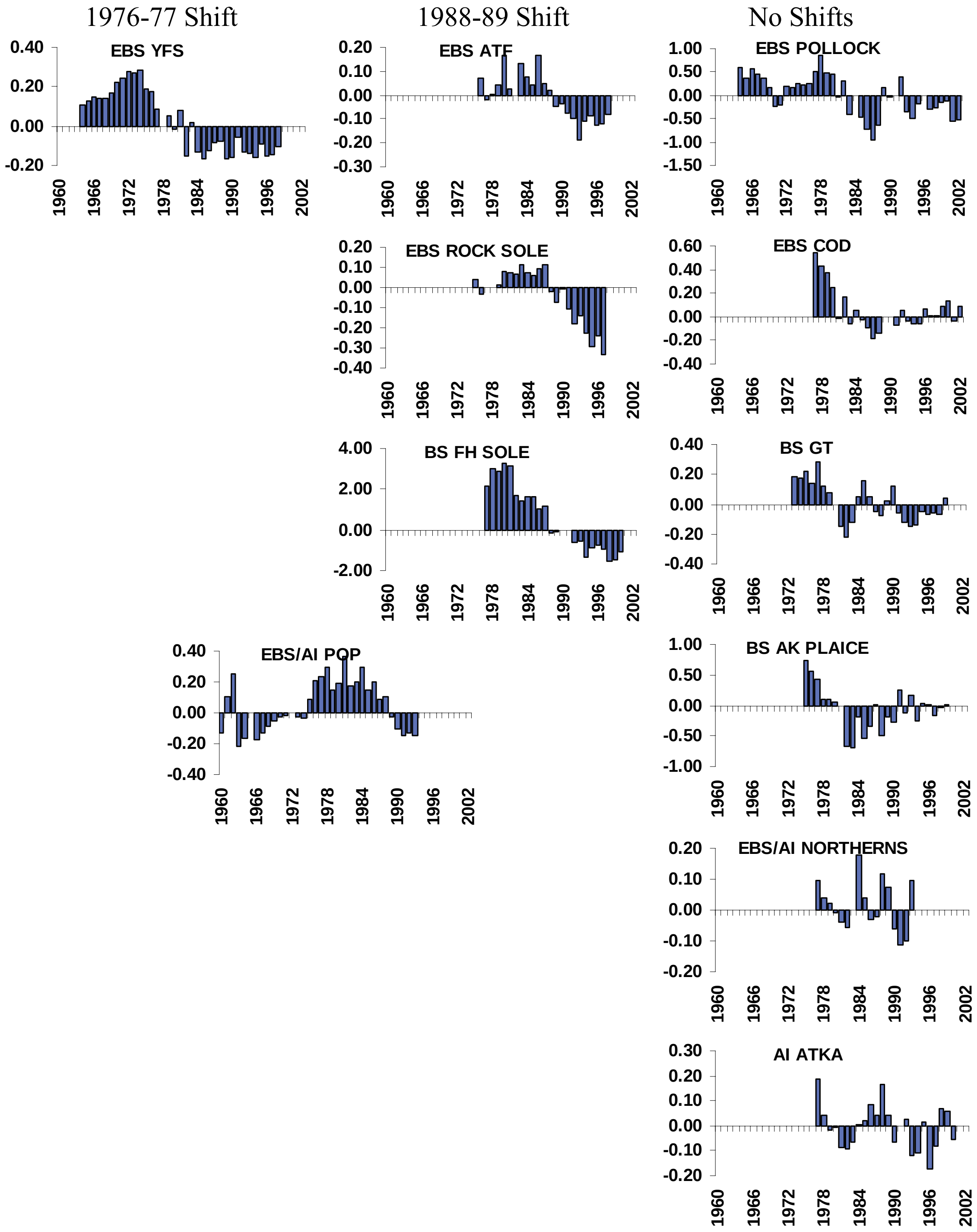


Figure 12. -- Recruit per spawner residuals for groundfish of the Bering Sea. The ratios of recruits per spawner were log-transformed and the median over all years was calculated for each species. The median was subtracted from the log ratios in each year and expressed as a proportion of the median. YFS = yellowfin sole, ATF = arrowtooth flounder, FH sole = flathead sole, POP = Pacific ocean perch, GT = Greenland turbot.

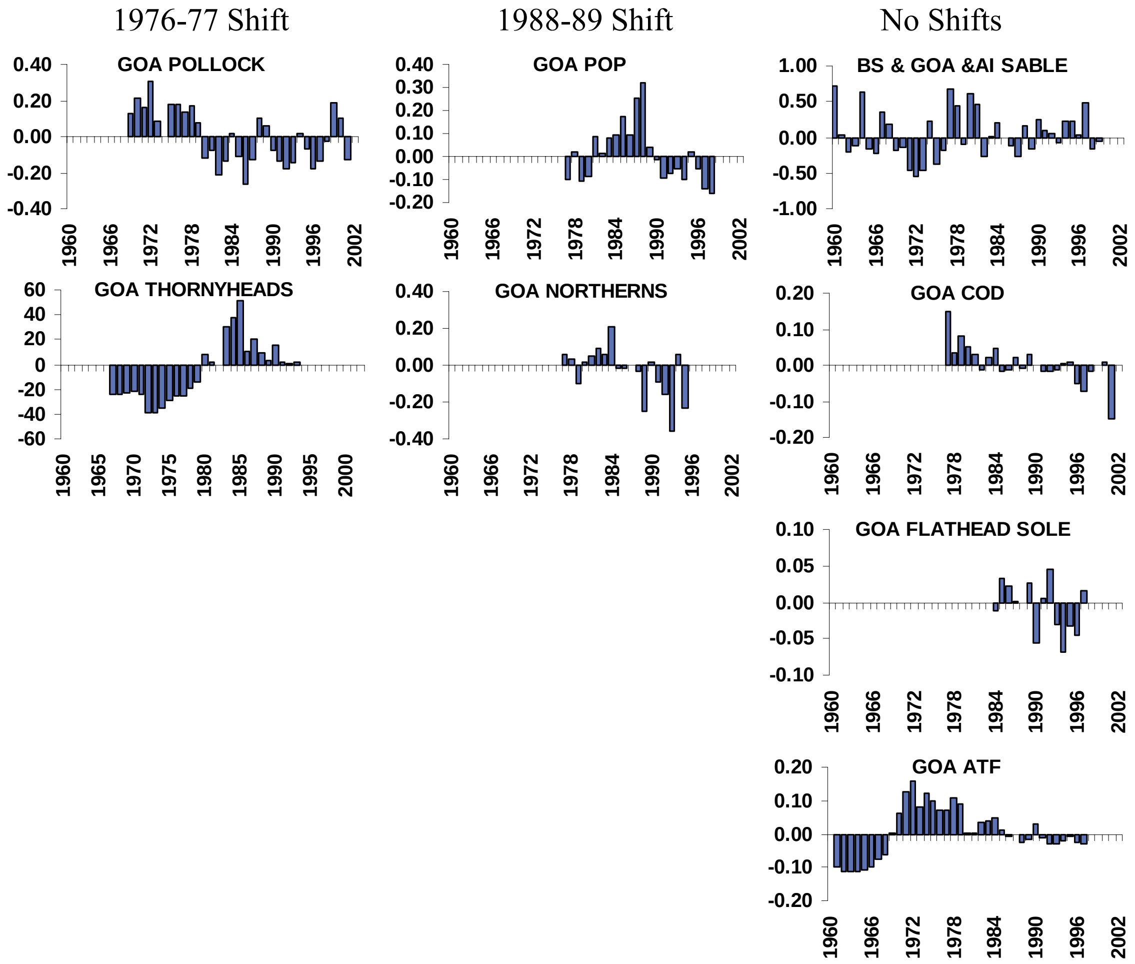


Figure 13. -- Recruit per spawner residuals for groundfish of the Gulf of Alaska. The ratios of recruits per spawner were log-transformed and the median over all years was calculated for each species. The median was subtracted from the log ratios in each year and expressed as a proportion of the median. YFS = yellowfin sole, ATF = arrowtooth flounder, FH sole = flathead sole, POP = Pacific ocean perch, GT = Greenland turbot.

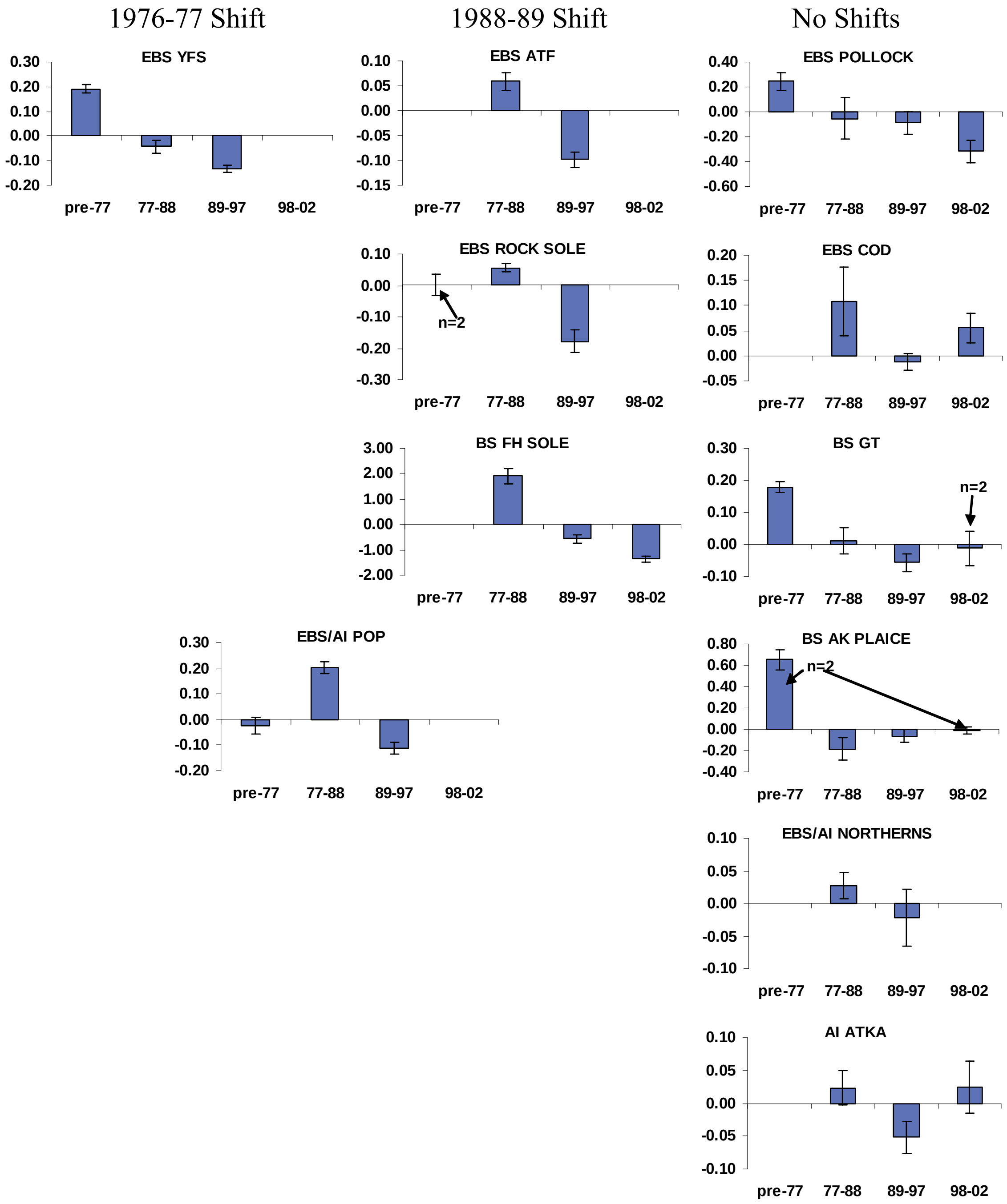


Figure 14. -- Average residuals of the log of recruit per spawner ratios of Bering Sea groundfish in each of four time periods expressed as a proportion of the overall median. Standard errors bars are shown. YFS = yellowfin sole, ATF = arrowtooth flounder, FH sole = flathead sole, POP = Pacific ocean perch, GT = Greenland turbot.

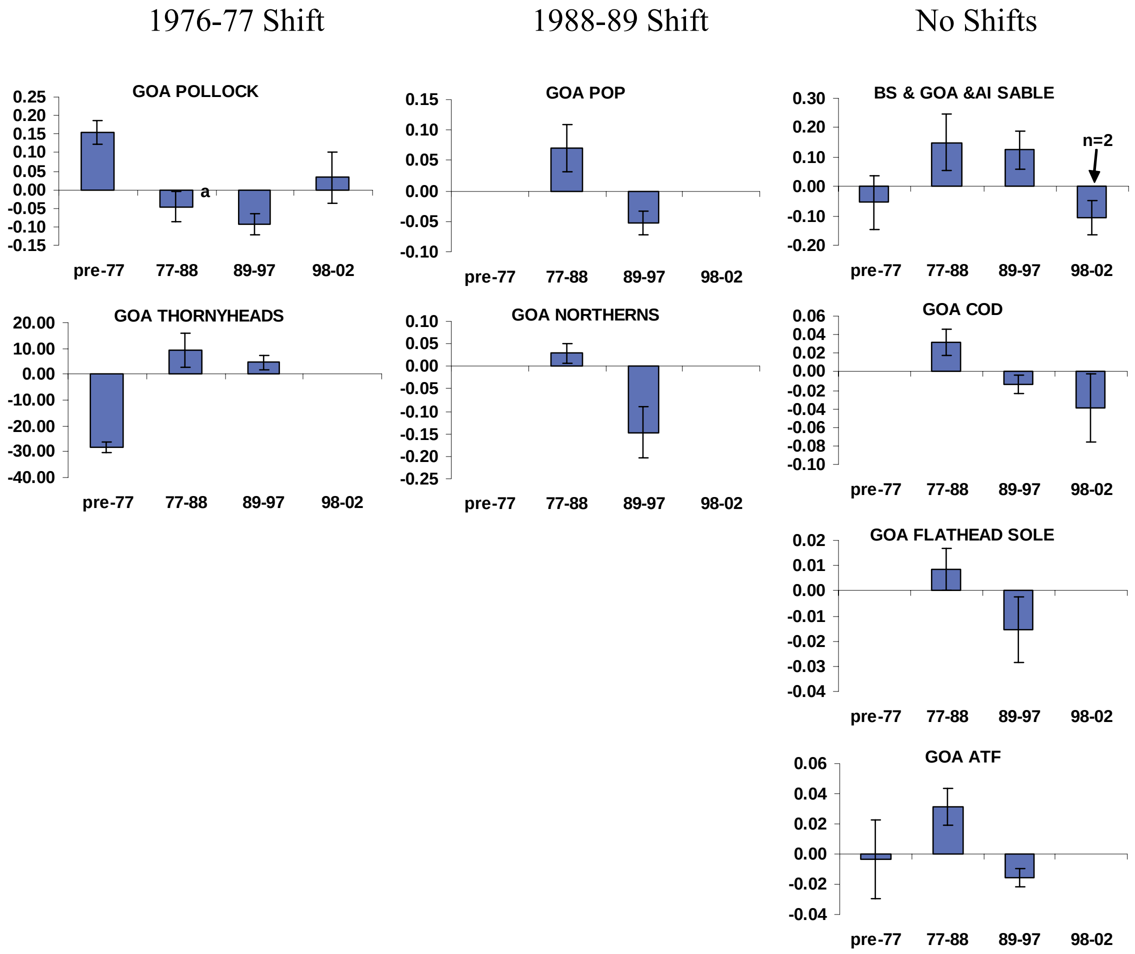


Figure 15. -- Average residuals of the log of recruit per spawner ratios of Gulf of Alaska groundfish in each of four time periods expressed as a proportion of the overall median. Standard errors bars are shown. YFS = yellowfin sole, ATF = arrowtooth flounder, FH sole = flathead sole, POP = Pacific ocean perch, GT = Greenland turbot.

IVA. Bering Sea (J. Boldt and E. Conners)

Several studies have shown a shift in fish production and abundance associated with identified decadal-scale climate changes: the 1976-77 shift in the Pacific Decadal Oscillation (PDO) index (Hare and Francis 1995, Hare et al. 1999, Hare and Mantua 2000), and the 1988-89 shift in the Arctic Oscillation (AO) index (Wilderbuer et al. 2002). The mechanisms by which these climate changes induce change in fish production are the focus of current studies. Hunt et al. (2002) proposed the Oscillating Control Hypothesis, which predicts that temperature is the controlling factor determining whether bottom-up or top-down processes are shaping the pelagic ecosystem of the southeast Bering Sea. In cold years, it is hypothesized that the primary production bloom occurs early, along the retreating ice edge. Zooplankton production is limited by cold temperatures, thereby limiting their pelagic predators (bottom-up control). In warm years, it is hypothesized that the primary production bloom occurs later and zooplankton production is higher, which benefits pelagic organisms, leading to top-down control conditions (Hunt et al. 2002).

The 1976-77 climate shift resulted in warmer conditions in the Bering Sea and, according to the Oscillating Control Hypothesis, increased zooplankton growth benefiting larval and juvenile fish, and improved recruitment of predatory fish, such as pollock, leading to top-down control of forage fish. Summer zooplankton biomass data collected by the T/S *Oshoro Maru* from 1954 to the present, however, did not show any trend associated with longer term climate signals (Napp et al. 2002). Also, there is no evidence that euphausiid densities changed between the early 1980s and the late 1990s (Coyle and Pinchuk 2002). There is some evidence that spring-time copepod biomass on the shelf is higher in warm years compared to cold years (Smith and Vidal 1986, Stockwell et al. 2001, Napp et al. 2002, Coyle and Pinchuk 2002). The timing and biomass of *Calanus marshallae* copepodites are related to cold temperatures (Baier and Napp 2003). The abundance of copepodites is higher and their appearance in the spring is earlier in years with the most southerly extent of sea ice and cold bottom temperatures, respectively (Baier and Napp 2003). Spring zooplankton production may therefore respond to climate variability.

Jellyfish biomass may also respond to decadal-scale climate variability. NFMS bottom trawl survey data indicates there was a huge increase and subsequent decline in the biomass of gelatinous zooplankton (jellyfish) after 1989 (Brodeur et al. 2002). The catches of jellyfish, primarily the large scyphomedusa, *Chrysaora melanaster*, during the summer surveys in 2000 were the highest recorded (336,673 t) although the densities were highly variable on local spatial scales (Brodeur et al. 2002). Abundance dropped dramatically in 2001-2003 (Walters 2003).

Some Bering Sea groundfish and shellfish stocks appear to respond to climate variability (Conners et al. 2001, Rosenkranz et al. 1998). Non-parametric Kruskal-Wallis and multiple comparison tests (Dunn 1964) were utilized to determine if there were significant differences in recruit per spawner ratios between the four time periods (pre-1977, 1977-88, 1989-97, and 1998-2002). Generally, decadal-scale variability in recruit per spawner time series was detected in flatfish and rockfish, but not roundfish species (Figs. 12-15 and Tables 3-4). Roundfish (pollock, cod, and Atka mackerel) showed no shifts in survival associated with the hypothesized climate regime shifts. The 1988-89 shift in survival was apparent in all winter spawning flatfish species of the Bering Sea (Tables 3 and 4). Shifts in survival of other flatfish of the Bering Sea were not detected, except for yellowfin sole which changed with the 1976-77 shift. A shift in survival was detected in 1976-77 and in 1988-89 for eastern Bering Sea (EBS) Pacific ocean perch (POP). No shift was seen in the EBS northern rockfish survival (Tables 3 and 4). The effect of fishing during the 1960s may have influenced the EBS POP recruit per spawner biomass ratios; therefore, the analysis was performed on recruits to reduce this effect. The results of this analysis were the same as that for recruit per spawners, indicating EBS POP did experience a shift in survival in 1976-77 and 1988-89.

Recruit per spawner time series were also examined using a non-parametric change-point analysis procedure (Lanzante 1996). This procedure was used by Conners et al. (2002) to examine step changes in mean abundance of Bering Sea groundfish and by Overland et al. (1999) to examine step changes in climate data. Change-point analysis was used to determine whether a discontinuity or a linear trend model best fit the data. If a discontinuity model fit the data, then the years of step-changes were determined. If a linear trend model fit the data, then the data were de-trended and re-examined for step-changes. This was an iterative procedure requiring a minimum of 20 data points; therefore, a complete analysis could not be performed on two species: Bering Sea/Aleutian Islands (BSAI) rock sole and BSAI northern rockfish.

Results of the change-point analysis indicate that a linear trend was the best fit model for most roundfish species, whereas, a discontinuity model provided the best fit for most flatfish and rockfish species (Table 5). Primary step changes in recruit per spawner time series were found for 7 of the 11 BSAI groundfish species, 4 of which were significant ($P < 0.05$). There were two general time periods in which step changes were detected: 1974-79 and 1987-89.

A negative linear trend was the best fit model for all roundfish (pollock, cod, and Atka mackerel) except EBS cod, where a non-significant step change was detected in 1982. Two of the BSAI winter spawning flatfish (arrowtooth flounder and rock sole) showed negative step changes in 1988 ($P = 0.114$) and 1987 ($P < 0.001$), respectively (Table 5). The change-point analysis indicated a negative linear trend is the best fit model for flathead sole, the other winter spawning flatfish ($P < 0.001$). This is due to the high initial recruit per spawner values at the beginning of the time series (13.45) and the low value at the end of the time series (0.92). If the model is forced to choose a step change in the time series of EBS flathead sole, it detects an insignificant negative change in 1987 ($P = 0.772$). No significant step changes were detected for other species of flatfish in the BSAI; however, a significantly negative linear trend was the best fit model for yellowfin sole ($P < 0.001$). Step-changes detected for all rockfish species typically occurred in the 1980s.

The survival of roundfish does not appear to be related to decadal-scale climate variability as defined by the hypothesized 1976-77, 1988-89, or 1998 regime shifts. BSAI and GOA cod, pollock, and Atka mackerel show similar survival trends, indicating they may be responding to similar large-scale environmental forcing (Figure 16). Flatfish survival does show decadal-scale variability in survival. In particular, the BSAI winter spawning flatfish (rock sole, flathead sole and arrowtooth flounder) show a negative shift in survival in the late 1980s. Examination of the recruitment of winter-spawning flatfish in the Bering Sea in relation to decadal atmospheric forcing indicates favorable recruitment may be linked to wind direction during spring (Wilderbuer et al. 2002). Years of consecutive strong recruitment for these species in the 1980s corresponds to years when wind-driven advection of larvae to favorable inshore nursery grounds in Bristol Bay prevailed. The pattern of springtime wind changed to an off-shore direction during the 1990s which coincided with below-average recruitment. Rockfish survival also appears to be related to decadal-scale variability; however, the mechanism is unknown.

ENSO events are less frequently observed in the Bering Sea than in the Gulf of Alaska (GOA) (Hollowed et al. 2001); therefore, there are fewer observed effects of El Niño Southern Oscillation (ENSO) on fish stocks there. Summer zooplankton biomass data collected by the T/S *Oshoro Maru* from 1954 to the present did not show any trend associated with El Niño signals (Napp et al. 2002). Hollowed et al. (2001) did not detect a Niño North influence on EBS groundfish.

Table 3. -- Average residuals of the logged recruit per spawner ratios in each of four time periods expressed as a proportion of the overall median. Standard errors are in parentheses. The P-values from Kruskal-Wallis tests performed on non-transformed recruit per spawner ratios are shown. Results of the non-parametric multiple comparison tests are shown for species where the Kruskal-Wallis tests were significant. Bold font indicates a significant result (P < 0.05).

	Regime					
	1	**2**	**3**	**4**		
Area/Species	pre-1977	1977-88	1989-97	1998-2002	Kruskal-Wallis P-value	Non-parametric multiple comparisons of regimes
EBS POLLOCK	0.244 (0.07)	-0.054 (0.167)	-0.088 (0.092)	-0.318 (0.094)	**0.0316**	1≠4
EBS COD		0.108 (0.069)	-0.012 (0.016)	0.055 (0.03)	0.3960	na
EBS ATF		0.059 (0.018)	-0.098 (0.015)		**0.0001**	2≠3
EBS ROCK SOLE	0.003 (0.035)	0.055 (0.013)	-0.178 (0.035)		**0.0004**	2≠3
BS FH SOLE		1.906 (0.297)	-0.571 (0.157)	-1.357 (0.127)	**0.0002**	2≠3
EBS YFS	0.192 (0.017)	-0.042 (0.026)	-0.133 (0.013)		**0.0000**	1≠2
BS AK PLAICE	0.653 (0.093)	-0.186 (0.104)	-0.062 (0.062)	-0.011 (0.029)	0.1175	na
BS GT	0.179 (0.017)	0.011 (0.041)	-0.057 (0.028)	-0.012 (0.054)	**0.0273**	1≠3
EBS/AI POP	-0.024 (0.031)	0.203 (0.023)	-0.111 (0.022)		**0.0001**	1≠2, 2≠3
EBS/AI NORTHERNS		0.027 (0.02)	-0.022 (0.044)		0.2059	na
AI ATKA		0.023 (0.026)	-0.052 (0.025)	0.024 (0.039)	**0.0135**	no differences detected
BS & GOA &AI SABLE	-0.055 (0.09)	0.149 (0.096)	0.125 (0.064)	-0.106 (0.057)	0.1699	na
GOA POLLOCK	0.155 (0.032)	-0.046 (0.041)	-0.094 (0.028)	0.033 (0.069)	**0.0033**	1≠2
GOA COD		0.032 (0.014)	-0.014 (0.01)	-0.039 (0.037)	**0.0373**	no differences detected
GOA FLATHEAD SOLE		0.008 (0.008)	-0.015 (0.013)		0.3173	na
GOA ATF	-0.003 (0.026)	0.031 (0.012)	-0.016 (0.006)		0.1105	na
GOA POP		0.07 (0.039)	-0.052 (0.019)		**0.0393**	2≠3
GOA NORTHERNS		0.029 (0.022)	-0.147 (0.057)		0.2059	na
GOA THORNYHEADS	-28.404 (2.099)	9.192 (6.598)	4.677 (2.73)		**0.0003**	1≠2

Table 4. -- Summary of statistical tests performed on recruit per spawner ratios of groundfish in the Bering Sea and Gulf of Alaska. A "Y" indicates there was a significant difference between two adjacent time periods defined by one of the hypothesized regime shifts (1976-77, 1988-89, or 1997-98); an "N" indicates there was no significant difference between adjacent time periods; a "-" indicates there was not enough data available to test for a significant difference.

Fish Type	Area	Species	1976-77 Shift	1988-89 Shift	1997-98 Shift
Roundfish					
	Bering Sea/Aleutian Islands	Pollock	N	N	N
		Cod	-	N	N
		Atka mackerel	-	N	N
	Gulf of Alaska	Sablefish	N	N	N
		Pollock	Y	N	N
		Cod	-	N	N
Flatfish					
Winter spawning	Bering Sea/Aleutian Islands	Arrowtooth flounder	-	Y	-
		Rock sole	N	Y	-
		Flathead sole	-	Y	N
Other	Bering Sea/Aleutian Islands	Yellowfin sole	Y	N	-
		Greenland turbot	N	N	N
		Alaska plaice	N	N	N
Winter spawning	Gulf of Alaska	Flathead sole	-	N	-
		Arrowtooth flounder	N	N	-
Rockfish					
	Bering Sea/Aleutian Islands	Pacific ocean perch	Y	Y	-
		Northern rockfish	-	N	-
	Gulf of Alaska	Pacific ocean perch	-	Y	-
		Northern rockfish	-	Y	-
		Thornyhead rockfish	Y	N	-

Table 5. -- Years of step changes or linear trends detected in recruit per spawner time series of groundfish in the Bering Sea/Aleutian Islands and the Gulf of Alaska with non-parametric change-point analyses (Lanzante 1996). All models, both linear and discontinuity, are shown with the associated Rtn (for linear models) and Rdn (for discontinuity models) and P-values. In cases where a linear trend model fit the data, R^2 and P-values are shown. In some cases, more than one model or step-change was found. Bold font indicates significant results ($P < 0.05$).

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

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

**Rtn is the ratio of the linear trend model to the noise, Rdn is the ratio of the discontinuity model to the noise; the larger value indicates the better fitting model.

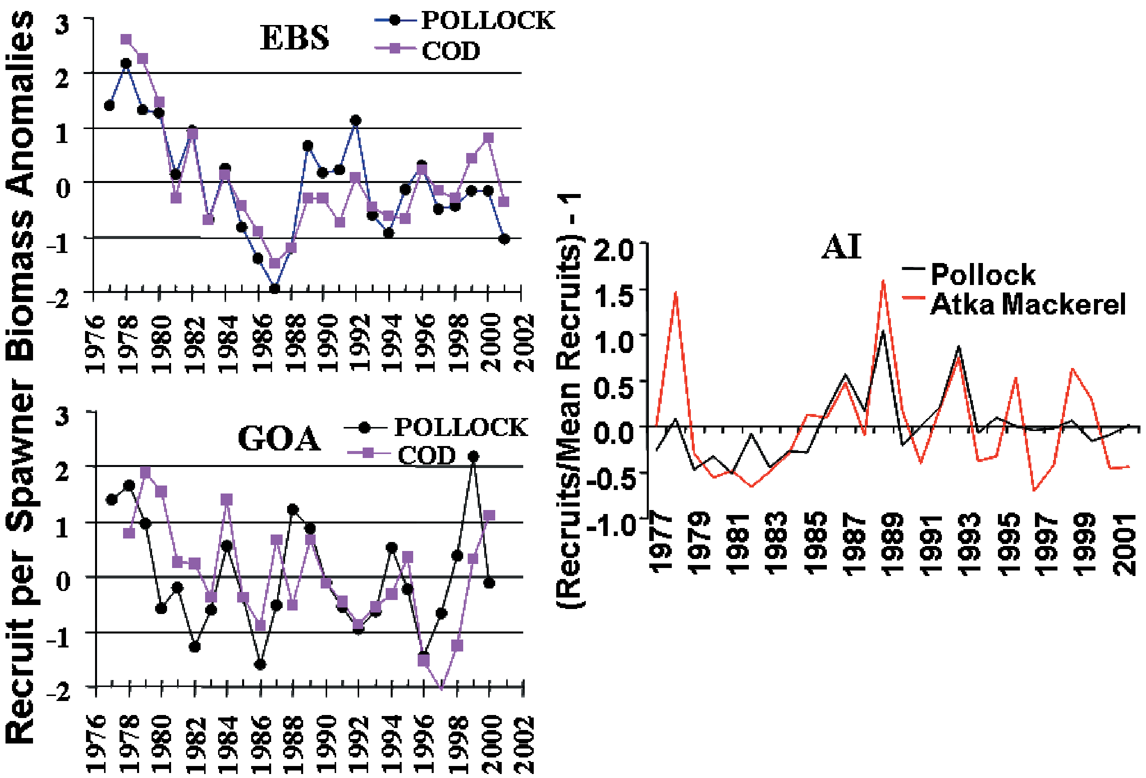


Figure 16. -- Recruit per spawner anomalies of eastern Bering Sea (EBS) and Gulf of Alaska (GOA) pollock and cod and Aleutian Islands (AI) pollock and Atka mackerel (lagged back one year) recruits expressed as a proportion of mean recruits. Atka mackerel spawn in the summer and pollock spawn in the winter; therefore, the Atka mackerel were lagged by one year to match the year classes that experienced similar conditions (modified from Barbeaux et al. 2003)

IVB. Gulf of Alaska (J. Boldt and E. Conners)

Decadal scale climate variability, as seen with the 1976-77 regime shift, has affected zooplankton populations in the GOA. After the shift in the late 1970s, the Aleutian Low intensified which increased water column stability in the GOA (Francis and Hare 1994). Water column stability in the GOA is often the limiting factor for primary production; therefore, the 1976-77 shift resulted in increased primary production in north Pacific waters, benefiting the zooplankton populations there. Zooplankton samples taken in 1956-62 and 1980-89 in the GOA confirm that zooplankton abundances increased between the two time periods (Brodeur and Ware 1992).

Some fish stocks in the GOA appear to be influenced by shifts in climate forcing. Evidence of the 1998-99 shift in climate forcing is found in the relative abundance of selected marine fish in the GOA. Pandalid shrimp, osmerids and Pacific sandfish all increased and while the relative abundance of gadids decreased in areas around Kodiak Island and the Alaska Peninsula (Anderson 2003). Salmon catch, especially sockeye and pink salmon, in Alaska increased after the 1976-77 regime shift which appears to be explained by the increased water column stability, and primary and secondary production (Francis and Hare 1994, McGowan et al. 1998). In recent years, salmon production and survival in the GOA continue to be high (Eggers 2003).

Some commercially important groundfish in the GOA also exhibited changes associated with decadal-scale variability. Non-parametric Kruskal-Wallis and multiple comparison tests (Dunn 1964) were utilized to determine if there were significant differences in recruit per spawner ratios between the four time periods (pre-1977, 1977-88, 1989-97, and 1998-2002). Generally, decadal-scale variability in recruit per spawner time series was detected in flatfish and rockfish, but not roundfish species (Figs. 12-15 and Tables 3-4). Roundfish (pollock, cod, and sablefish) showed no shifts in survival associated with the hypothesized climate regime shifts, except GOA pollock which changed with the 1976-77 shift. A 1988-89 shift in survival was not apparent in the winter spawning flatfish species of the GOA (Tables 3 and 4). Two rockfish species exhibited a negative shift in survival in 1988-89 (GOA POP, and GOA northern rockfish) and a positive shift in 1976-77 was detected in GOA thornyhead rockfish. Year-class strengths for Pacific halibut in the North GOA (IPHC Area 3A) showed higher recruitment in the 1980s and declining recruitment after 1987.

A non-parametric change-point analysis procedure was also performed on recruit per spawner time series using similar methods as for BSAI stocks (see previous section). The results of this procedure indicate that a linear trend was the best fit model for most roundfish species, whereas, a discontinuity model provided the best fit for most flatfish and rockfish species in the GOA (Table 5). Primary step changes in recruit per spawner time series were found for four of the eight groundfish species, three of which were significant ($P < 0.05$). There were two general time periods in which step changes were detected: 1974-79 and 1989-92.

A negative linear trend was the best fit model for all roundfish (pollock, cod, and sablefish). Step-changes were found for GOA winter spawning flatfish: 1992 for flathead sole, and 1968, 1979, and 1989 for arrowtooth flounder (Table 5). Step-changes detected for all rockfish species typically occurred in the 1980s, except GOA thornyheads, for which a slight increasing linear trend was detected ($P < 0.001$).

The survival of roundfish does not appear to be related to decadal-scale climate variability as defined by the hypothesized 1976-77, 1988-89, or 1998-99 years of regime shifts. Examination of the average recruit per spawner anomalies, however, indicates that roundfish experience similar time trends in survival within ecosystems. For example, pollock and cod show similar recruit per spawner trends within the GOA (Fig. 15). This may be an indication that roundfish respond in similar ways to large-scale climate changes that are not defined by the years of hypothesized regime shifts. Rockfish survival also appears to be related to decadal-scale variability; however, the mechanism is unknown.

Effects of El Niño Southern Oscillation (ENSO) on zooplankton in the GOA are mixed. For example, no changes in zooplankton were seen in the GOA in 1983, a strong El Niño event on the West Coast (Bailey et al. 1995). Similarly, zooplankton abundance was low in Prince William Sound (PWS) during the 1992-93 ENSO, but high in 1992 and low in 1993 in the central GOA (Bailey et al. 1995). Zooplankton abundance monitored at Ocean Station PAPA showed a random pattern of interannual variation (Mackas et al. 2001). Rather than responding consistently to ENSO events, summer biomass of zooplankton in the northeast Pacific shows interannual variation that is related to the intensity of the winter winds in the GOA (Brodeur and Ware 1992). Interannual variations in zooplankton that occur in the GOA are therefore not always related to ENSO events.

Niño North-related periods of warm ocean conditions appear to have a positive effect on the recruitment of northern Pacific fish stocks, but inconsistent effects on the year-class strength of different species (Bailey et al. 1995). Interannual variations in northward flow, associated with Aleutian Low variability, may be responsible for changes seen in northern Pacific fish species. For example, unusually strong northward transport could carry Pacific cod larvae out of their feeding area in Hecate Strait and account for the decreased recruitment during these conditions (Tyler and Westerheim 1986). Northward advection into the GOA is strengthened during years of Niño North conditions (Ingraham et al. 1998) and could, therefore, affect recruitment of fish, such as cod. ENSO years may also disrupt community structure, creating a release from predation or competition for herring and some groundfish, resulting in strong year classes (Bailey et al. 1995). Herring in Southeast Alaska (SEAK) have had strong year classes in ENSO years, possibly because higher sea levels and onshore convergence (due to intensification of the Aleutian Low) retain larvae inshore (Pearcy 1983). Arrowtooth flounder, halibut, and sablefish often have strong year classes that coincide with ENSO events, however this is not a consistent occurrence (Bailey et al. 1995). Gadids experience a higher frequency of strong year classes in Niño North conditions in the GOA (Hollowed et al. 2001). Overall, there appears to be evidence that fish stocks of the GOA are influenced by ENSO conditions.

IVC. Northern California Current (R. C. Hooff, W. T. Peterson, J. Colbert, and M. Schirripa)

Decadal scale climate variations and El Niños appear to affect the California Current ecosystem. The most dramatic evidence of post-1998 ecosystem changes in the California Current is revealed via distribution and abundance patterns of key zooplankton and fish species. Since 1999, adult chinook (*Oncorhynchus tshawytscha*) salmon returns to the Columbia River have rebounded to historical high levels. Ocean survival of coho (*O. kisutch*) salmon off the Oregon coast increased dramatically, returning to levels observed during the 1960-76 time period (Logerwell et al. 2003). During much of the 1990s, increased abundances of warm water fish species such as Pacific hake (*Merluccius productus*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*) and Pacific sardine (*Sardinops sagax*) were observed in trawl surveys off the Oregon and Washington coast, while cold water species, such as northern anchovy (*Engraulis mordax*) and smelt (Osmeridae) declined during the same period (Brodeur et al. 2000, Emmett and Brodeur 2000). Recent surveys, however, have found that anchovies and smelt have increased by an order of magnitude while warm water species have simultaneously declined (Brodeur et al. 2003, Emmett 2003).

The year-class strength of sablefish in British Columbia and Washington waters also appears to be influenced by climate variations. King et al. (2000) found that, after the 1976-77 regime shift, the frequency of above-average sablefish year-class strength increased. A hypothesized mechanism for this change in year-class strength is an increase in copepod production associated with the intensified Aleutian Low, the southwesterly winds, and the warmer coastal sea surface temperature (SST) off Vancouver Island during that time period (McFarlane and Beamish 1992, King et al. 2000). Schirripa and Colbert (unpublished) found that negative northward Ekman transport anomalies in February, negative eastward Ekman transport anomalies in June, and sea level in July, in addition to spawning stock biomass, explained 69% of sablefish recruitment variation from 1974 to 2000.

Recent changes in plankton dynamics, particularly secondary production, have been prominent throughout the California Current System (CCS). In central California, phytoplankton and zooplankton biomass have doubled since 1998 (Chavez et al. 2003). Results from California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys off southern California indicate that macrozooplankton biomass is 20-30% greater than during the 1991-97 time period, though it is important to note that compared to the 1984-90 time period, current levels are substantially less (Schwing et al. 2002). A variety of other zooplankton taxa have shown a similar response to post-1998 conditions; specifically, euphausiid populations have increased dramatically in waters off of both Vancouver Island (Mackas et al. 2001) and the central Oregon coast (Feinberg and Peterson 2003).

Furthermore, species-specific analyses provide additional evidence of significant inter-annual and perhaps decadal changes in zooplankton community structure beginning in the late 1990s. For example, a particular genus of salp (*Cyclosalpa* sp.) that was abundant during 1951-76 CalCOFI sampling, and extremely rare over the past 25 years, was observed in fairly substantial numbers beginning in 2001 (Lavaniegos and Ohman 2003, Schwing et al. 2002). In Oregon, where total copepod biomass revealed a two-fold increase between 1998 and 2000, inter-annual fluctuations of boreal coastal copepods provides a particularly strong signal of changing ocean conditions (Fig. 17, Peterson and Schwing 2003). This "northern copepod index" (based on seasonal biomass anomalies of taxa common to coastal subarctic waters) is positively correlated with periods of high secondary production throughout coastal waters of the northern California Current (Peterson and Keister 2003, Mackas et al. in press) and is inversely related to the Pacific Decadal Oscillation (PDO) index. Moreover, this index is positively correlated with ocean survival rates of Oregon coho salmon (Peterson and Schwing 2003, Logerwell et al. 2003), thereby suggesting a link between salmon, zooplankton, and climate variability.

While the 1999-2001 time period reveals many physical and biological characteristics reminiscent of pre-1977 sampling, not all indicators provide conclusive evidence to support the late 1990s regime shift hypothesis. For example, Feinberg and Peterson (2003) show that while coastal shelf euphausiid egg production off of Oregon has increased since 1999, chlorophyll concentrations have remained relatively stable. These data may suggest that higher trophic levels may be more sensitive to ecosystem change than some conventional oceanographic indicators, or alternatively, that bi-weekly sampling is insufficient for capturing inter-annual trends primary production dynamics. Other anomalous conditions, such as the intrusion of sub-arctic waters on to the coastal shelf during July 2002 (Huyer 2003, Kosro 2003), highlight increased variability observed in the system. These events, along with basin-wide analyses by Bond et al. (2003) raise the possibility that the California Current System may not be adequately characterized by a simple two-state paradigm.

Although a variety of observations between 1999 and 2002 suggest that the CCS has undergone a shift from warm, low production conditions, to cooler, high production conditions, researchers are still challenged by a fairly limited time series with respect to inter-decadal timescales. Negative PDO values (and associated cool phase conditions) persisted for 4 years following the hypothesized shift in late 1998. A negative PDO of more than 1-year duration had not been observed since the early 1970s (Schwing et al. 2002). Beginning in August 2002, however, the influence of moderate El Niño-like conditions took hold in the California Current, resulting in positive PDO values that have persisted for fourteen consecutive months up until the publication of this document. Future surveys (particularly those following the 2002-2003 El Niño) will be required prior to further speculation about the magnitude and duration of climate regime shifts in the Northeast Pacific.

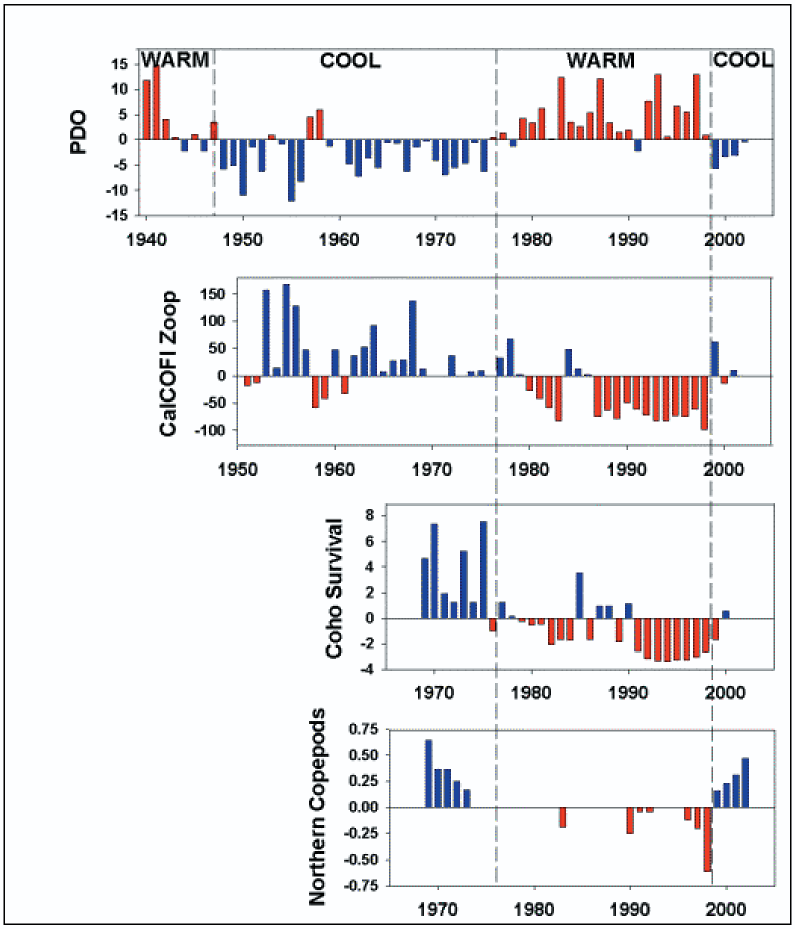


Figure 17. -- Time series of (a) the Pacific Decadal Oscillation (PDO) index summed annually over May-September, (b) annual anomalies of California Cooperative Oceanic Fisheries Investigations (CalCOFI) zooplankton volumes, (c) coho salmon survival, and (d) biomass anomalies of cold-water copepod species (from Peterson and Schwing 2003).

IVD. Southern California Current (C. Reiss)

Pacific Sardine

Pacific sardine (*Sardinops sagax*) is one of the few commercially valuable marine species in the California Current that is managed explicitly by incorporating an environmental index to adjust harvest rates. A long-standing relationship between the environment and the population of sardines has been documented and formalized in the Coastal Pelagics Fishery Management Plan (CPS FMP). Sardine populations tend to increase during warm “regimes” like the decade prior to 1948 and the period since 1977, than during cooler periods such as the period between 1948 and 1976 (Fig. 18a). The continued production of Pacific sardine in recent years despite a short-term change in the sign of the PDO, and the perception of a change to a cool period in 1999, is the result of continued warmer conditions in the Southern California Bight (Fig. 18a).

Reproductive success, measured as the number of recruits produced by a given spawning biomass, varies positively with temperature (Fig. 18b). Increasing the mean 3 year sea surface temperature from 17 ° to 17.5 °C is correlated with a doubling of reproductive success per unit biomass. Based on this relationship, derived from data collected during the decline and the initial recovery of the sardine population, Jacobson and MacCall (1995) used the 3-year average sea surface temperature measured at Scripps Pier to model the effect of temperature on the life time reproductive success of sardine.

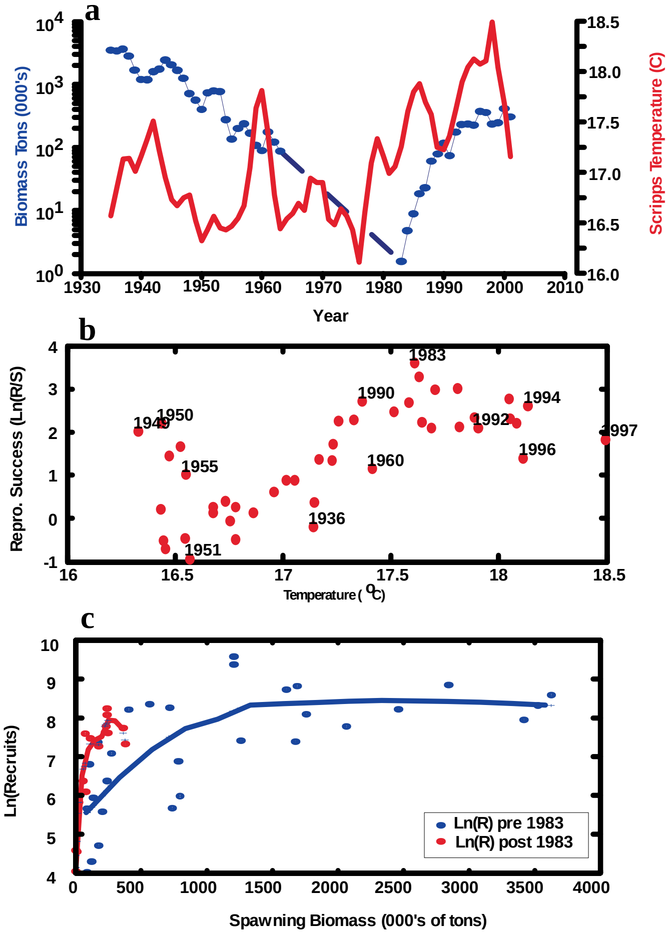


Figure 18. -- Sardine biomass and Scripp’s temperature (a – top panel), sardine reproductive success as a function of temperature (b – middle panel), sardine stock-recruit relationship (c – bottom panel).

As part of the Ecological Indicators program, we have been re-examining the stock recruit relationship of Pacific sardine. Using both the historical data during declining years of the sardine population and the last 15 years of data from the current recovery, we found that the productivity of the stock (the average recruitment given a biomass) seems to be higher (Fig.18c). While the high biomass of the past has not been achieved, the rate of increase may be attributed to the consistently high average temperatures of the last decade (Fig. 18b).

Thus, our re-analysis indicates that the temperature-productivity relationship formalized by Jacobson and McCall (1995) is still valid. Our research continues by focusing on the mechanisms in the environment that may differ between warm and cool periods or regimes. Of particular interest is the recent findings by Logerwell and Smith (2001), that offshore areas associated with mesoscale activity produce higher numbers of survivors (larvae > 8.75 mm) than inshore areas, usually considered favorable juvenile habitat. Mesoscale activity, in the form of eddies and squirts can be quantified by calculating the "eddy variance" that is related to broad-scale changes in net surface heat flux forcing acting in phase across the eastern Pacific Basin (Di Lorenzo et al. 2003). This eddy variance statistic may provide an index of retention and essential juvenile habitat within the offshore areas of the California Current potentially resulting in an increase the in the number of recruits per spawning biomass. Successful tests of these mechanisms should provide the ability to forecast spin-up and spin-down times of the sardine populations under different climatic change scenarios.

Market Squid

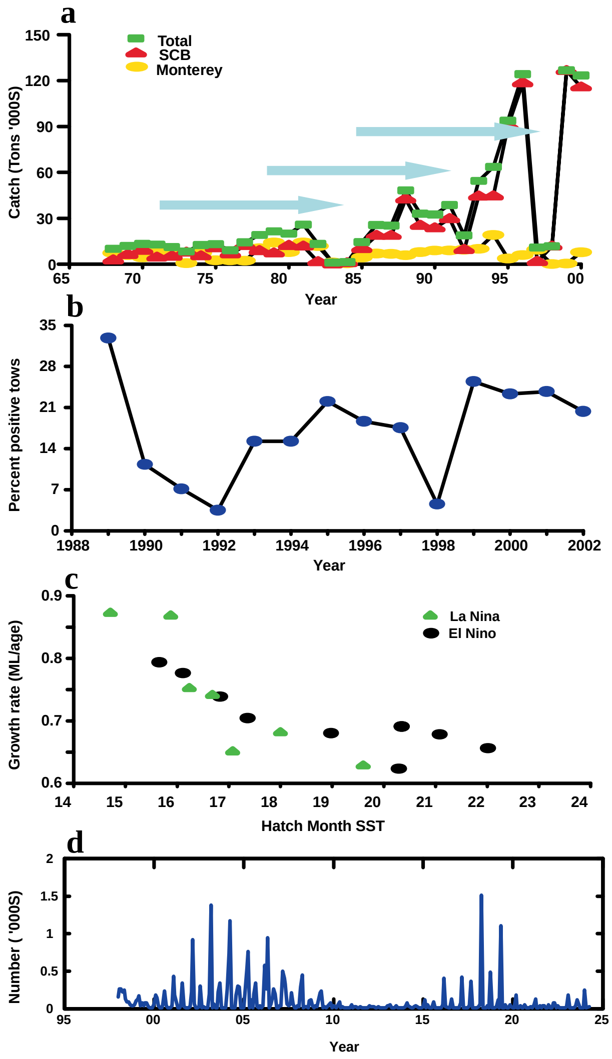


Figure 19. -- Market squid catch, where arrows indicate El Niño years (a), percent positive tows where squid were caught in the CalCOFI para-larval surveys (b), squid growth rates as a function of sea surface temperature during La Niña or El Niño years (c), and predicted squid abundance (d).

Market squid (*Loligo opalescens*) are both ecologically and economically important within the California Current. Ecologically, they are a principal food for some marine mammals and sharks and form a major link in the ecosystem. Economically, market squid is a $41 million fishery, and the catch rates in the Southern California Bight have increased exponentially since the early 1980s (Fig. 19a).

While the exponential increase is remarkable, almost unbelievable is the near collapse of the fishery during El Niño events, and its subsequent rebound only a year later. Given the short life span (~6 months), low fecundity (~3,000 eggs), semelparous nature, and its response to El Niños, there is a strong likelihood that squid will respond to the environment. Clearly, development of an indicator that can predict El Niños will help the fishery, but an understanding of how the environment impacts the population persistence is critical and more important to the long-term management of this species.

The disappearance of squid during El Niños is not the result of movement from the principle fishing grounds. Evidence from NMFS trawl surveys shows that squid disappear from the shelf and slope from Pt. Conception to Vancouver, B.C. and para-larval surveys conducted as part of CalCOFI show that during El Niños, there is little if any production in the Southern California Bight (SCB, Fig. 19b).

We have been able to develop indices of the probability of fishery collapse during El Niños using sea surface temperature (SST) and coastal sea level (CSL) several months prior to the fishery (Fig. 19c), yet this type of index will provide little advice in managing this species over the long-term. In order to develop an environmental index that may be useful for management, we have been exploring the relationship between growth rate variability and SST.

There is a clear negative relationship between hatch month SST in the Southern California Bight and the mean growth rate of squid (Fig. 19c). Yet, there is no difference between the growth rates of squid in El Niño (1998) and La Niña (1999) years when growth is examined in relation to hatch month temperature. This consistency is useful in that we can develop a population model that has, at its center, a temperature relationship that can be derived from local and regional temperature index sites.

To investigate the effects of temperature on the population dynamics, we have begun to develop the first age-based temperature-dependent population model of any squid (Reiss et al. submitted *CalCOFI Reports*). The model uses climatic seasonal temperature forcing in the Southern California Bight and the empirical relationship between hatch month temperature and growth rate to project recruitment and fecundity at a fixed size. Mortality rates are fixed and based on simple assumptions regarding the mean maximum age at maturity. Preliminary results show that even under conditions of similar environmental forcing, but with just a small amount of stochasticity added, long periods of high seasonal abundance are followed by years of very low abundance, all driven by variability in the cumulative mortality directly attributed to temperature-dependent growth variability (Fig. 19d). Also interesting is the fact that in some years the rate of increase approaches the levels of increase that have been observed in the fishery immediately following the El Niño periods.

V. CLIMATE INFLUENCE ON BIOTIC DISTRIBUTIONS

Numerous papers document the effect of environmental factors on fish distribution (MacCall 1990, Horne and Smith 1997). These events can influence survey results if processes move fish out of or into the survey region. Movement can occur horizontally as well as vertically. In either case, methods exist to account for these events in stock assessment models. Accounting for ocean forcing on the availability of fish to surveys would help to reduce uncertainty in stock assessment advice. Improving our understanding of oceanographic forcing on fish distribution will also improve ecosystem models that currently use limited data to deduce the amount of spatial overlap between predator and prey.

A vision of many west coast academic and federal scientists, as part of the Integrated Ocean Observing Systems (IOOS) efforts, includes a comprehensive monitoring program to collect oceanographic samples along coastal regions of the North Pacific. This program would directly benefit fisheries stock assessment by providing much needed information on factors influencing fish distribution. At current funding levels, most survey information is collected during summer months.

VA. Spatial Distributions of Pollock (J. Ianelli)

Pollock spatial distribution by age

Pollock in the eastern Bering Sea (EBS) are generally known to be smaller in the northwest region and somewhat larger in the southeast part of the shelf break (Fig. 20). This pattern is hypothesized to be part of their movement throughout their life cycle where spawning occurs in the southeast region (and in the southern basin and slope areas) and the pelagic eggs and larvae are advected into the northwest region with northerly currents. Pollock generally show a large degree of variability in spatial concentrations (e.g., due to interannual variability in temperature structure). This variability is perhaps greatest for younger pollock due in part to the availability of young pollock to bottom-trawl survey gear (they are typically more common in pelagic layers than older pollock), the area and time in which they were spawned, the magnitude of advective currents during egg and larval stages, and pre-recruit predation levels. Nonetheless, Buckley et al. (2001) demonstrated distinct patterns with age and contrast these for warm and cold years (Fig. 21). The youngest fish observed in summer bottom trawl surveys appear to be farther inshore in shallower regions of the shelf at age 1. The central point of age 2 is the farthest northwest compared to the other ages (which subsequently are farther southeast with age). For the coldest years, the distribution tends to be shifted uniformly to the west and slightly south presumably due to temperature preference and pollock avoidance of the "cold pool" formation in the middle shelf region.

Pollock distribution with respect to bottom temperature

While mean EBS temperatures provide some indication of the overall change in average age-specific pollock density, closer examination of pollock density relative to temperature patterns confirms distributional shifts (Fig. 22). From these figures, it is apparent that the middle shelf region can have a broad area encapsulated by the zero-degree isotherm (as in 1999). In such cold years the densities of pollock observed in the bottom trawl survey gear are low in these regions. In warm years (e.g., 2003 where the zero-degree isotherm is largely absent), the pollock densities extend much further onto the shelf and are much more broadly ranging.

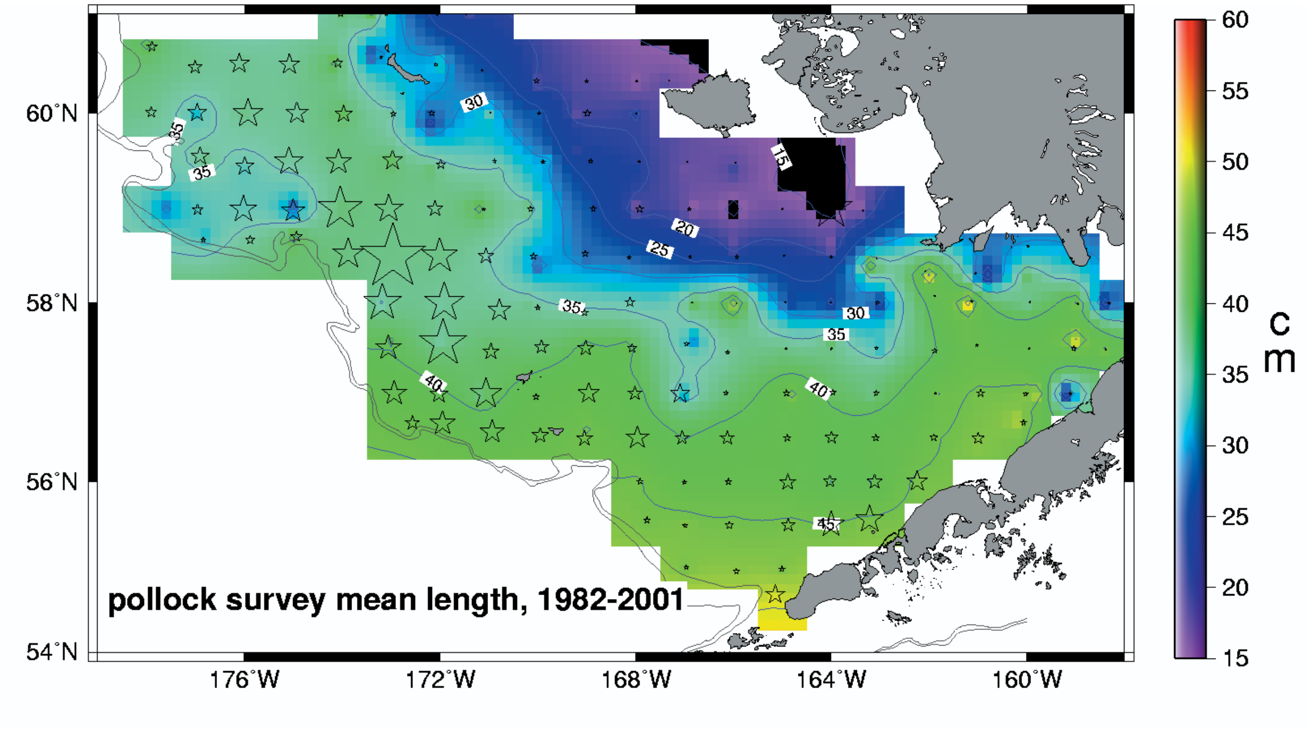


Figure 20. -- Eastern Bering Sea pollock mean-length distribution (shades = mean length in cm) based on average summer bottom trawl survey data (1982-2001). The stars represent the survey station locations and their size is proportional to pollock density (in number).

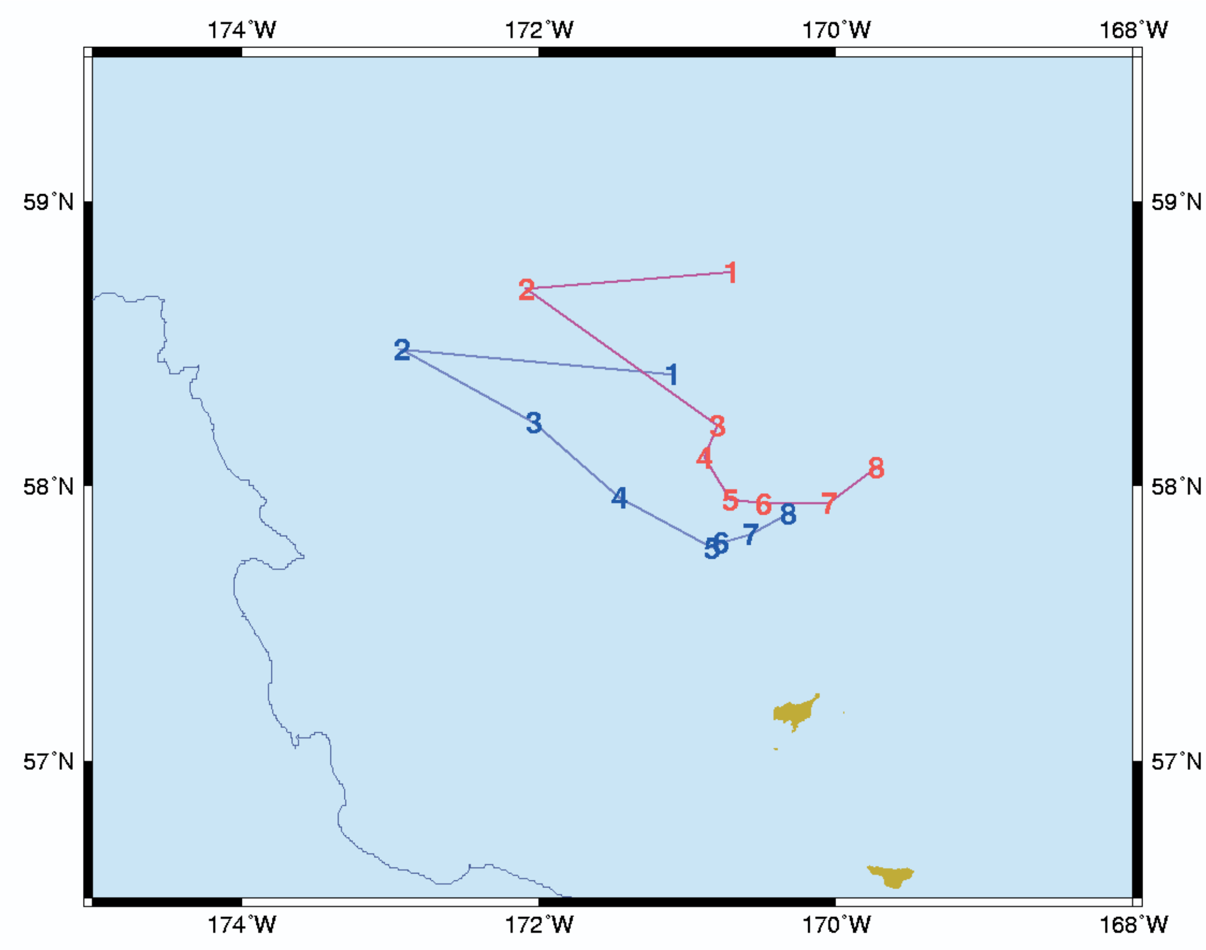


Figure 21. -- Eastern Bering Sea pollock age-specific centroids (density-weighted mean location) based on summer bottom-trawl survey data. The “cold years” are represented in blue (leftmost line) and the “warm years” are shown in red (rightmost line). The period of data analyzed is from 1982-2001 and the numbers represent the age classes (adapted from Buckley et al. 2001).

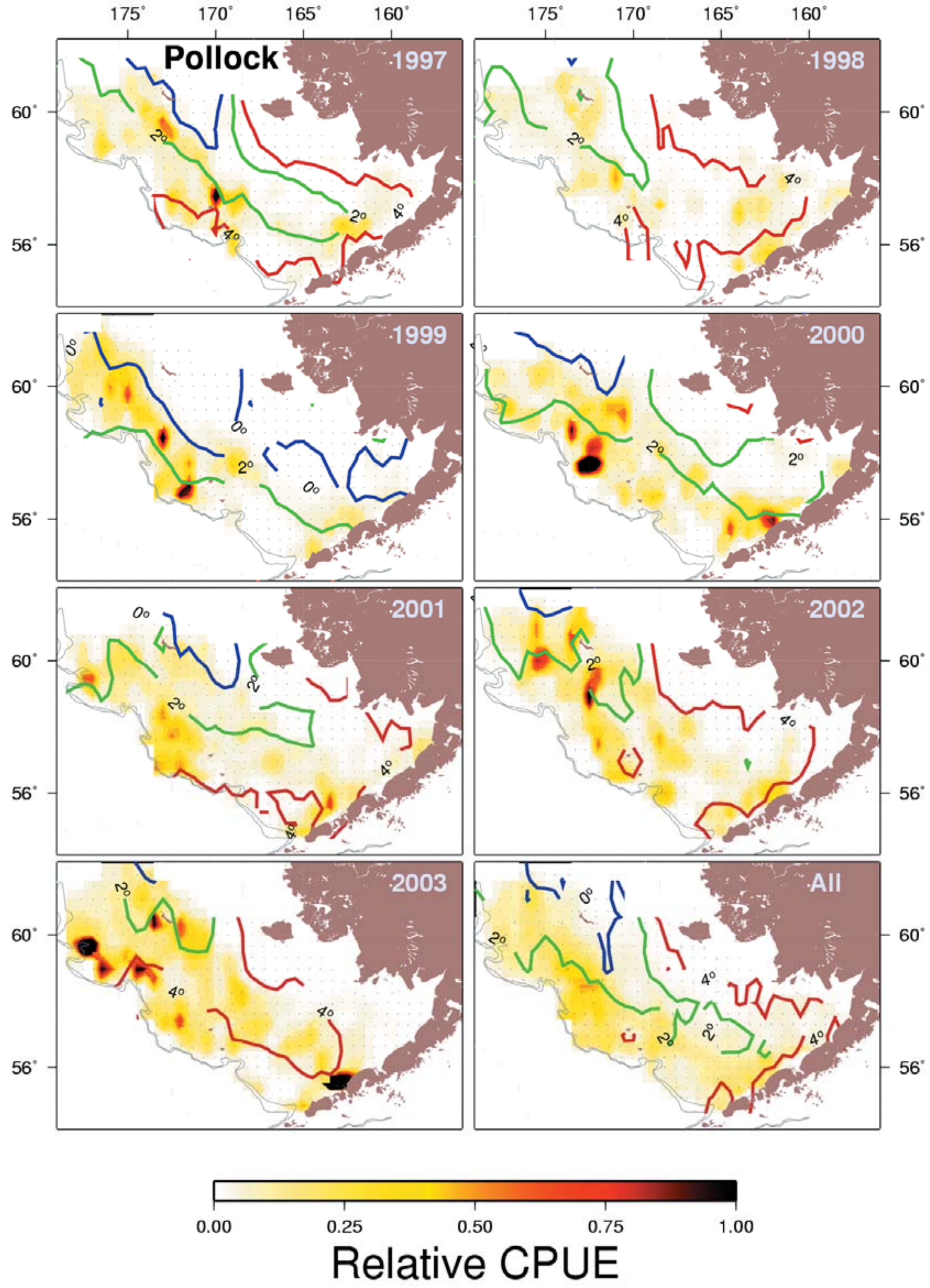


Figure 22. -- Eastern Bering Sea pollock CPUE (shades = relative kg/hectare) and bottom temperature isotherms of 0º, 2º, and 4º C for 1997-2003. The average temperature and pollock density from 1982 to 2003 is shown in the lowest right panel.

VB. Spatial Distribution of GOA Pollock and Capelin (A. Hollowed)

Ocean temperature can influence the spatial distribution of predators and prey. The Alaska Fisheries Science Center conducted acoustic midwater trawl surveys on the eastside of Kodiak Island in 2000 and 2001. Results of this study demonstrate that topographic features influence the flow patterns around troughs. The complex topography and flow patterns through the troughs result in marked thermal features within the troughs (Fig. 23). These flow patterns appear to influence the spatial distribution of walleye pollock and capelin (Figs. 24 and 25). Spatial distributions of capelin appear to be associated with subsurface intrusions of cool slope water in Barnabas Trough (Fig. 25). Spatial partitioning between predators (adult pollock) and prey (capelin) may modulate the strength of interactions between these two species. Knowledge of the factors influencing prey distribution can be used to develop reliable simulations of the energy expended by a foraging Steller sea lion to obtain sustainable amounts of prey. These studies will also allow investigators to predict the threshold number of prey schools or the threshold prey density required for successful foraging of Steller sea lions.

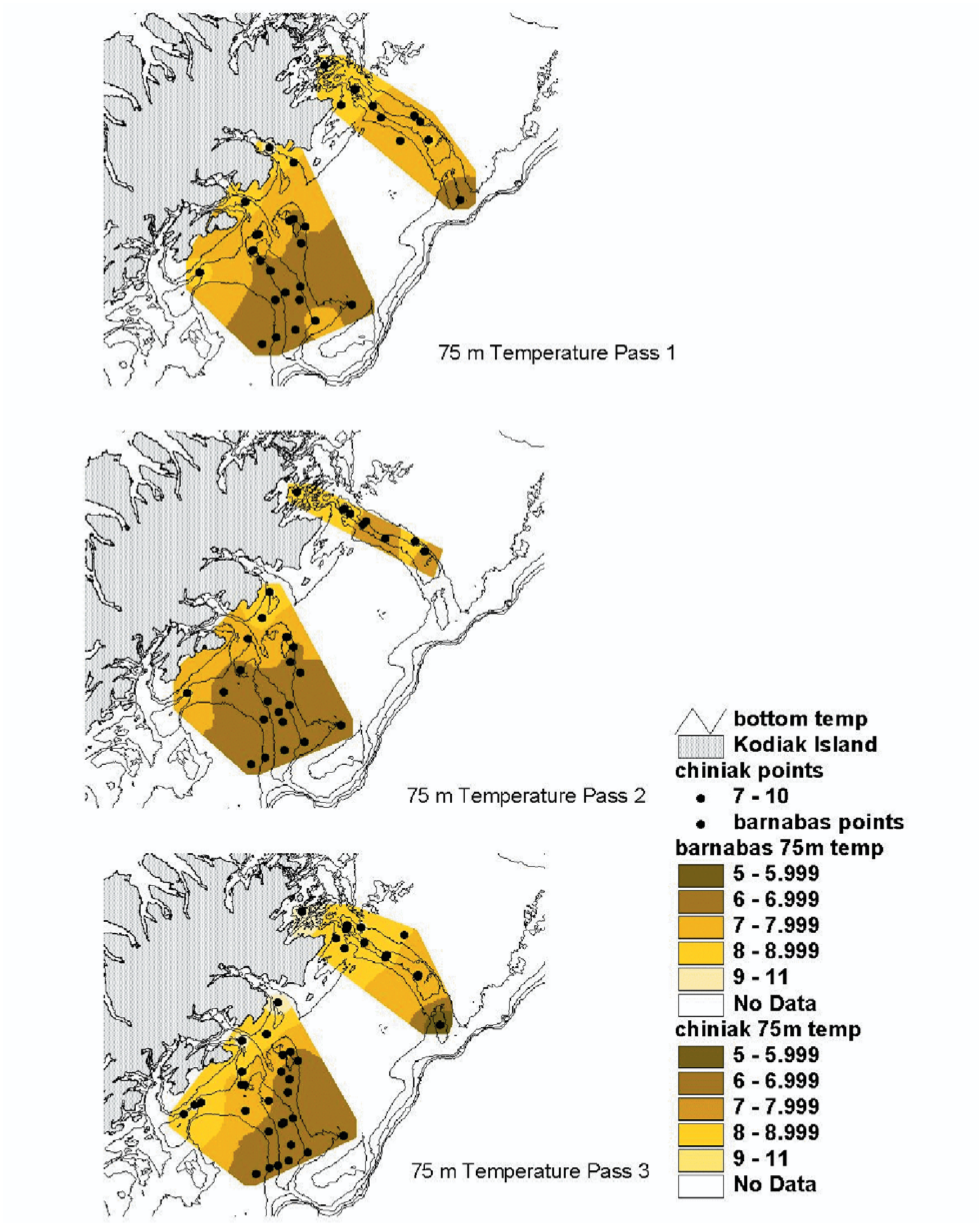


Figure 23. -- Cross-trough profiles of temperature, based on conductivity, temperature, depth (CTD) profiles taken in Chiniak and Barnabas Troughs, during three passes in August 2001.

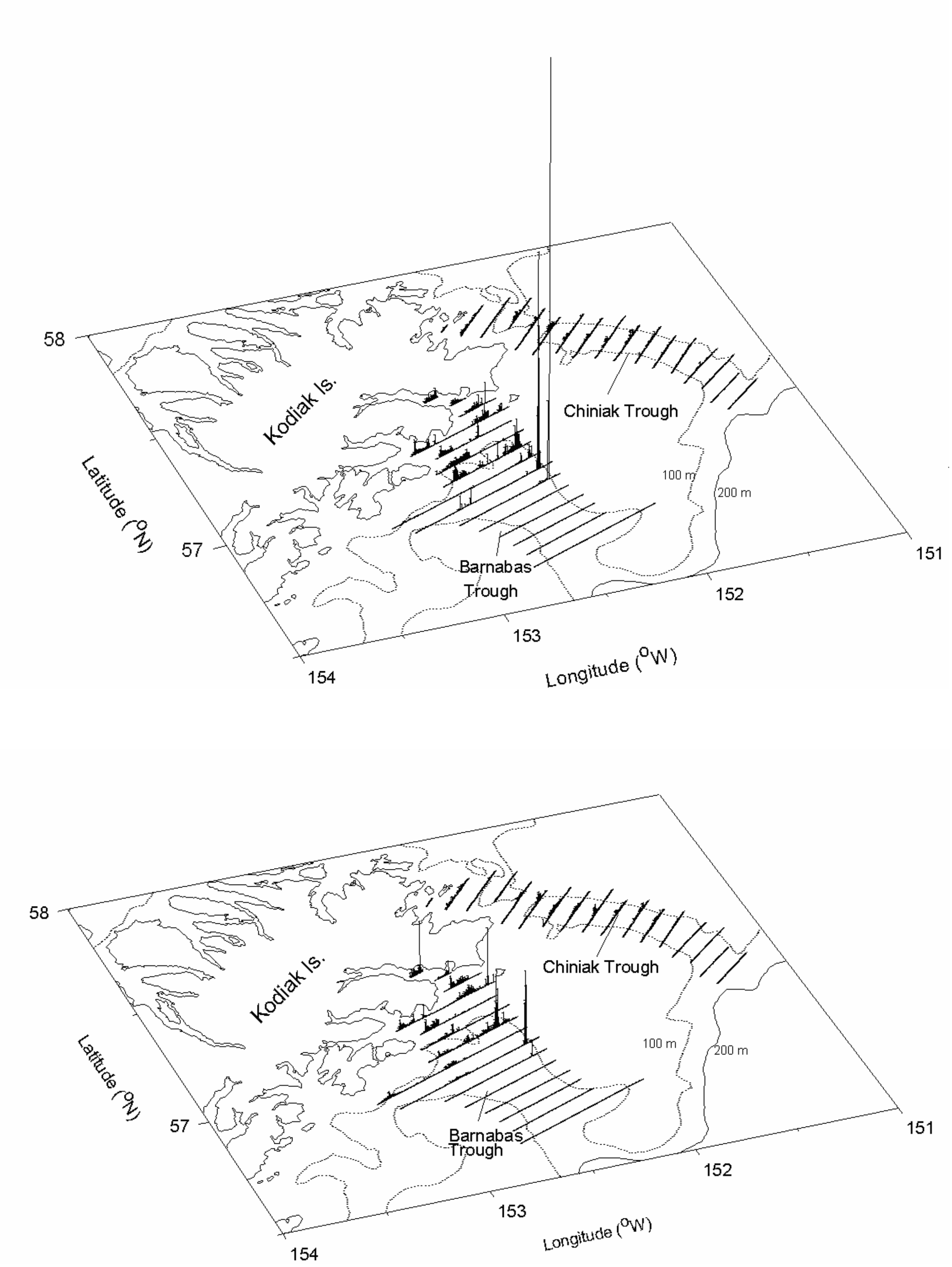
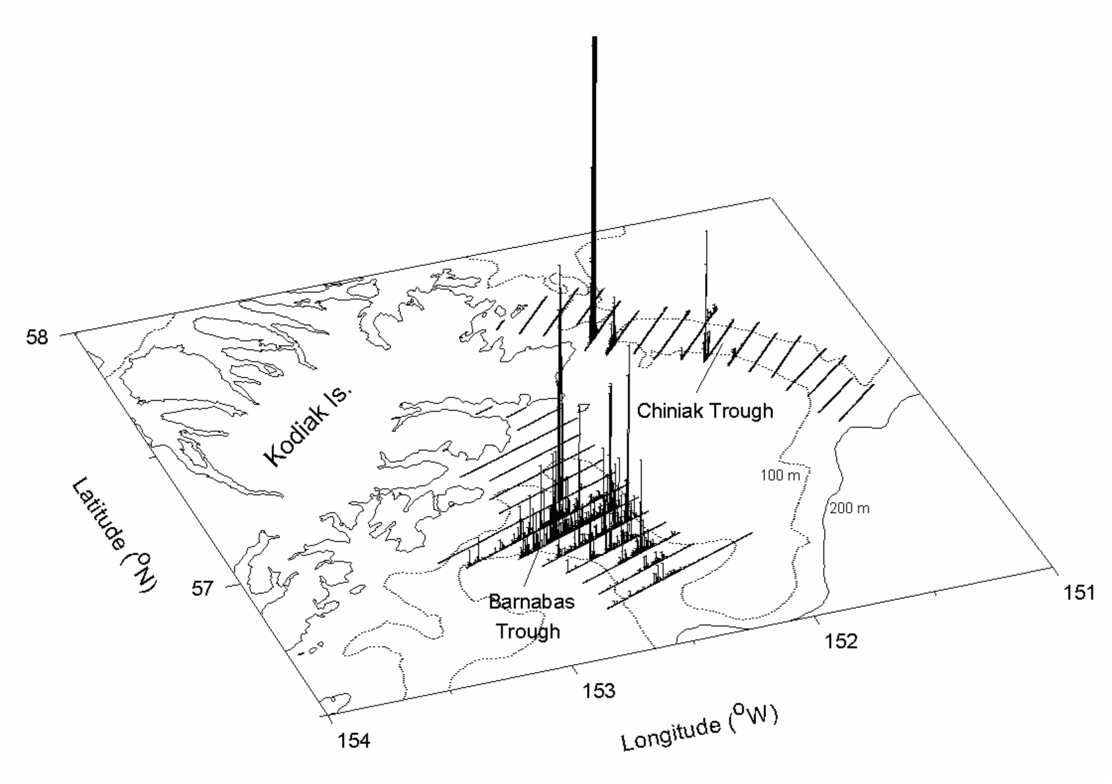


Figure 24. -- Acoustic backscatter attributed to adult pollock along transects during two passes of the study area in August 2001.



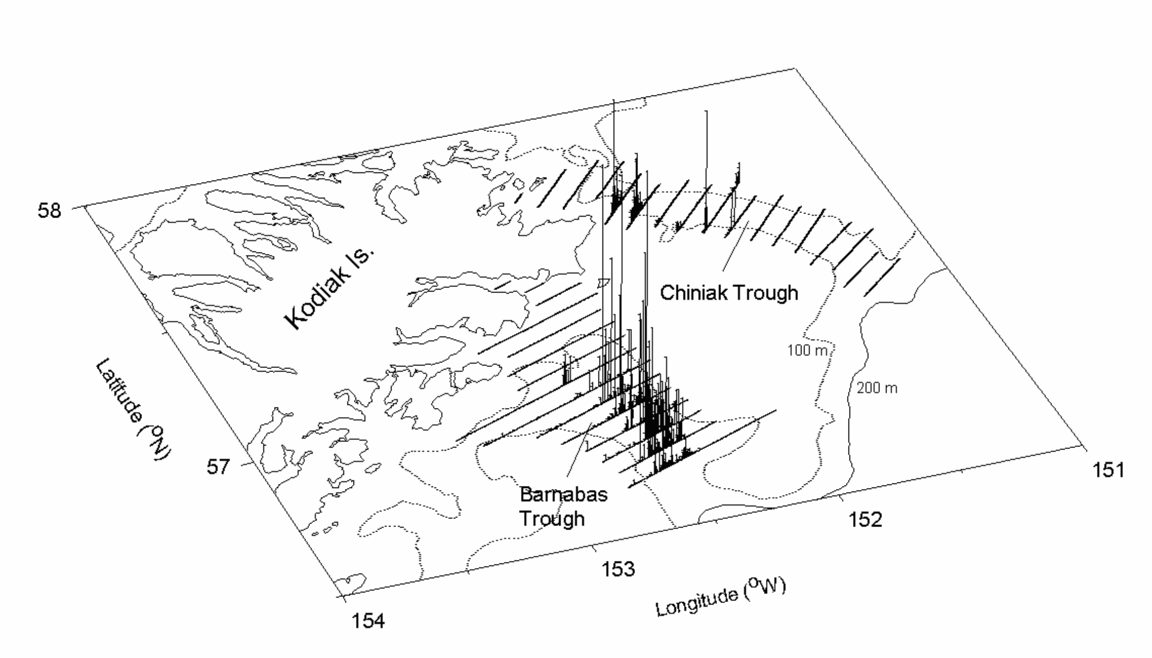


Figure 25. -- Acoustic backscatter mainly attributed to capelin along transects along two passes of the study areas in August 2001.

VC. El Niño Influences on Alaskan Fish Distribution (J. Boldt)

Effects of El Niño Southern Oscillation (ENSO) can include changes in fish distribution, such as salmon distribution and migration patterns. The occurrence of the Sitka Eddy is related to the northward flow in the Gulf of Alaska (GOA). Increased strength of the Aleutian Low seen in some ENSO years causes increased northward flow in the GOA and a well developed Sitka eddy. When the eddy is well developed, salmon returning to their parent rivers in central British Columbia (B.C.) avoid it and are diverted southward rather than migrating along the coasts of Southeast Alaska (SEAK) and B.C., therefore, affecting the SEAK salmon fishery (Hamilton and Mysak 1986). Bristol Bay sockeye salmon may also respond to ENSO events as they return to their natal streams earlier in warmer years than in colder years (Mysak 1986). Pink salmon fry emigration from Prince William Sound (PWS) streams is shorter in duration and occurs during the peak zooplankton bloom in warm years in contrast to cold years (Cooney et al. 1995). Therefore, if an ENSO event, decreased cloud cover, or some other warming event results in increased sea surface temperature (SST), pink fry growth and survival may improve because the timing of their emigration and food supply better coincide (Cooney et al. 1995).

VD. Spatial Distribution of California Current Fish (J.C. Field and S.R. Ralston)

The effect of climate on the distribution of commercially and ecologically important species in the California Current System (CCS) has been recognized for some time. Hubbs (1948) felt so strongly about the correlation between water temperature and fish distributions that he felt "justified in drawing inferences, from the known data on fish distribution, regarding ocean temperatures of the past." In particular, Hubbs cited a warm era in the mid-19th century in which apparently established populations of several tropical species were found in Southern California, several of which were not seen in the region again until the warm events of the 1980s and 1990s (MacCall 1996, Lea and Rosenblatt 2000). Hubbs also drew a distinction between eras that seemed to be associated with the establishment of warm-water populations and the occasional warm years, now known to be associated with stronger El Niño events that brought irregular tropical or subtropical fish much farther north along the coast. These observations set the stage for understanding how the distribution and abundance of species in the California Current responds to both interannual (e.g., El Niño) and interdecadal (e.g., Pacific Decadal Oscillation-scale) variability.

The California Current essentially begins where the west wind drift (or the North Pacific Current) reaches the North American Continent, generally offshore of the northern tip of Vancouver Island. There this large, broad current, which essentially spans the region between the southern limb of the Alaskan Gyre and the northern limb of the North Pacific Gyre, splits into two broad coastal currents: the California Current to the south and the Alaska Current to the north. Chelton and Davis (1982) were among the earliest to recognize that these two currents seem to fluctuate out of phase, such that "when the poleward transport of the eastern limb of the subpolar (Alaskan) gyre increases, the equatorward transport of the eastern limb of the subtropical (North Pacific) gyre decreases." These two general modes of circulation enable the California Current to bridge two oceanic domains during the summer upwelling season, the cool subarctic domain and the warm temperate domain. The degree to which the subarctic water extends south in any given year seems to depend on atmospheric conditions (Mantua et al. 1997, Parrish et al. 2000). Although the mechanisms are poorly understood, atmospheric conditions seem to have favored the southward transport of coastal subarctic waters during pre-1977 and post-1998 years (Peterson and Schwing 2003). In these years, the zooplankton community is dominated by the large, boreal species of copepods that, in turn, seem to indicate good foraging opportunities for juvenile salmon and other predators. In warmer years (as well as during the winter downwelling season of most years) the zooplankton communities tend to be comprised of southern (subtropical) species (Peterson and Keister 2003).

These patterns of alternating warming and cooling have repeated themselves sequentially over the last century, with consequent impacts to the distribution and abundance of species. During the collapse of the California sardine (*Sardinops sagax*) fishery following the return to cool conditions in the late 1940s and 50s, it was clear that the sardines' range was contracting north to south, as evidenced by the sequential collapse of fisheries from British Columbia to San Pedro in the Southern California Bight (Murphy 1966). Similarly, as the sardines have recovered over the last two decades, they have done so from south to north (Emmett and Brodeur 2000, Conser et al. 2001), reaching even far into the Gulf of Alaska during the anomalously strong El Niño event of 1997-98 (Wing et al. 2000). This is consistent with the notion that sardines tend to expand northward in both abundance and range during warm regimes (McFarlane et al. 2002), a characteristic shared with Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*) and Pacific hake (*Merluccius productus*).[1] For example, Dorn (1995) observed that a much greater proportion of the hake biomass is found north of the United States (U.S.)/Canada border during warm years versus cooler years; a distributional shift that has long complicated management between the United States and Canada of this shared resource. An extreme exaggeration of this distributional shift is exemplified by the differences in abundance of hake in 1998 (a warm year) and in 2001 (a cool year) as estimated by the NMFS Alaska Fisheries Science Center (AFSC) triennial hydroacoustic survey (Fig. 26). These shifts may have major impacts on regional ecosystem processes, by altering the distribution and biomass of hake, mackerel and other migrant predators of euphausiids and forage fish that may compete with resident salmon and rockfish.

Distributional shifts are also manifest at higher trophic levels throughout the California Current. Off California, warm years (and regimes) have been known for over a century to bring gamefish such as tunas and billfish farther north and inshore for easy access by recreational fishers (MacCall 1996, Lea and Rosenblatt 2000). Similarly, major warm events off Oregon and Washington have brought albacore (*Thunnus alalunga*) and other large pelagics into nearshore waters, including yellowtail (*Seriola lalandi*), yellowfin tuna (*Thunnus albacares*), large numbers of jumbo squid (*Dosidiscus gigas*) and even striped marlin (*Tetrapturus audax*) during the 1997-98 El Niño events (Pearcy 2002). Jumbo squid were also described off the Oregon coast during the 2003 El Niño event (W. Peterson, pers. comm., Northwest Fisheries Science

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[1] MacCall (1990) developed a basin model for such populations, in which the optimality of habitat increases towards the bottom of the topographically irregular basin, and the shape of the basin itself may change over time in accordance with fluctuating environmental conditions. Although the model was developed to capture the population dynamics of the central subpopulation of northern anchovy (*Engraulis mordax*), it is also appropriate for consideration of how the distribution and abundance of other coastal pelagics may be dictated over time by long term variability in ocean habitat. MacCall (2002) has suggested a transport-related mechanism for these patterns of variability related basin-scale circulation patterns.

Center, Newport, OR). Data over the past several decades show that seabird communities have responded to warming and cooling trends as well; migratory sooty shearwaters (*Puffinus griseus*) declined by as much as 90% during the latest warm regime (Veit et al. 1996), although it remains unclear whether this represents a shift in distribution or an actual decline in population. A great many other seabird species have been described as having either warm or cool water affinities, and vary their distribution, abundance, productivity and even diet accordingly (Ainley et al. 1995, Sydeman et al. 2001, Schwing et al. 2002). The response of marine mammals is less clear, although Forney (2000) reviews evidence for similar shifts in the distribution of toothed cetaceans during warm and cool events.

The most important predators in the California Current System, humans, have long been known to change their distribution and feeding habits in response to variability. McEvoy (1996) illustrates how over a century of climate shifts in California fisheries have been associated with large-scale movements of labor, capital and technology that subsequently spurred the development of newer, and in many cases significantly larger, fisheries. More recently, Dalton (2001) tracked the connection between the environment, the distribution of commercially important species, the impacts of such distributional shifts on ex-vessel prices and markets, and the resulting response of fishing fleets with regard to changes in effort and gear between different fisheries in Monterey Bay. His work also demonstrates that climate affects fisheries beyond the obvious mechanism of local abundance, through the consequent effects on prices, effort and forward-looking behavior.

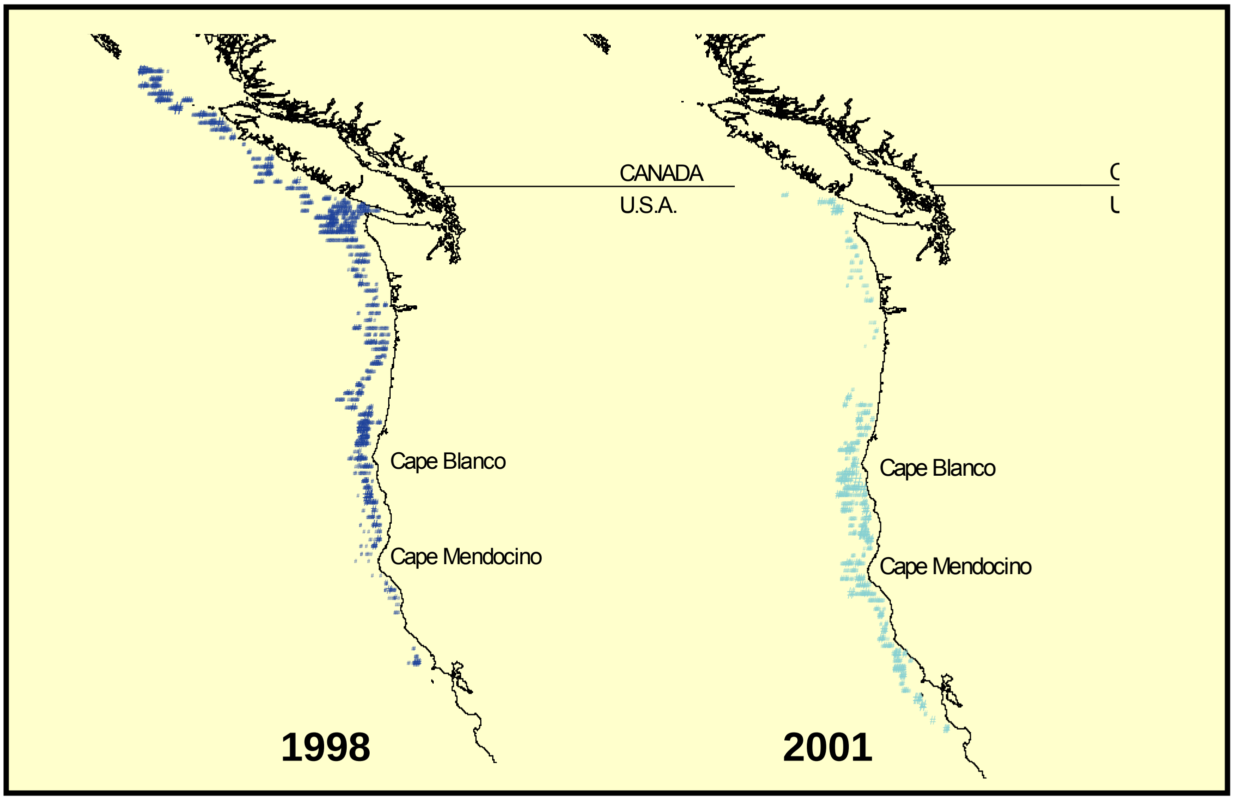


Figure 26. -- Summer distribution of Pacific hake in 1998 (warm) and in 2001 (cool) as estimated by the NMFS triennial hydroacoustic survey. Figure from Agostini et al. (2004).

VI. EVIDENCE FOR SYNCHRONOUS STRONG YEAR CLASSES

Patterns of variation in recruitment and survival of marine and anadromous fishes show synchronicity among stocks ranging from regional to broad geographical scales. Synchronous strong year classes occur in numerous groundfish populations from California to the Bering Sea (Hollowed and Wooster 1992) with fewer strong year classes in the Gulf of Alaska (GOA) and Bering Sea (BS) than off the U.S. West Coast (Hollowed and Wooster 1995). Strong year classes tend to occur more frequently and recruitment tends to be greater during the positive phase of the Pacific Decadal Oscillation (PDO) when the Aleutian Low is more intense and sea surface temperatures are above average along the coast (Hollowed and Wooster 1995, Hare and Mantua 2000). Recruitment is moderately to strongly correlated among herring populations within the GOA, while herring in the BS are distinct from other Northeast Pacific populations (Williams and Quinn II 2000a). Similar to groundfish, recruitment of most herring populations in the GOA and BS, with the exception of British Columbia herring, is enhanced during periods with warm coastal air and sea surface temperatures (Williams and Quinn II 2000b). Catches of all salmon species in Alaska tend to show synchronous long-term variations and have generally been high during the recent warm phase of the PDO (Hare and Francis 1995). In contrast, catches along the U.S. West Coast have been low during the same period (Hare et al. 1999). Survival rates among different salmon stocks in the GOA and BS display synchrony at regional spatial scales on the order of hundreds of kilometers, but are largely independent at larger spatial scales (Peterman et al. 1998, Pyper et al. 2001, Pyper et al. 2002). Survival rates of salmon stocks in Alaska are enhanced when coastal sea surface temperatures are warm, while survival rates of British Columbia and Washington stocks tend to be reduced during warm periods (Mueter et al. 2002).

VIA. Synchrony in Alaskan Fish (J. Boldt)

The survival of roundfish does not appear to be related to decadal-scale climate variability as defined by the hypothesized 1976-77, 1988-89, or 1998 years of regime shifts. Examination of the average recruit per spawner anomalies, however, indicates roundfish experience similar trends in survival within ecosystems. For example, pollock and cod have similar recruit per spawner trends within both the BSAI and GOA (Fig. 16). Aleutian Island pollock and Atka mackerel (not included in this analysis) also show similar patterns in recruitment (Fig. 16, Barbeaux et al. 2003). This may be an indication that roundfish respond in similar ways to large-scale climate changes that are not defined by the years of hypothesized regime shifts.

VIB. Synchrony in Alaskan Fish (F. Mueter)

A more detailed analysis was completed to update and combine previous analyses of covariation by examining patterns in recruitment and, where available, survival estimates of demersal and pelagic species within and between the GOA and the BS. Specific objectives were to 1) determine the extent to which the productivity of groundfish species (gadids, flatfishes, rockfish, sablefish, Atka mackerel) and pelagic species (salmon and herring) covaries, and 2) determine the extent to which the productivity of species in the BS and GOA covaries, and 3) to identify groups of covarying species.

Methods

A time series of recruitment was compiled for 28 stocks of groundfish (16 stocks), salmon (10 stock groups), and herring (2 stock groups) from the BS and GOA (Table 6). Corresponding time series of spawning biomass (most groundfish), total adult biomass (Pacific halibut), or the number of spawners (salmon) were compiled to examine trends in survival rates. No biomass estimates were available for herring populations. Survival rate indices were calculated for each stock by computing residuals from a Ricker spawner-recruit relationship with autocorrelated errors.

To examine patterns of covariation among time series of log-transformed recruitment and survival (stock-recruit residuals) within and between the GOA and BS Spearman rank correlations, randomization tests, and multivariate analyses were used. Individual correlations between multiple pairs of time series are difficult to test for significance because of strong autocorrelation within the recruitment and survival series and because multiple tests are required that are not independent. Therefore the overall distributions of correlation coefficients across all pairwise comparisons graphically (histograms) and statistically (randomization tests) were examined. Appropriate randomization tests that accounted for autocorrelation within series were developed to assess whether 1) the observed pairwise correlations are on average centered on zero, and 2) the observed correlations are no more "spread out" (over-dispersed) than would be expected under independence (i.e., if recruitment and/or survival fluctuate independently). These tests can be considered global tests for the presence of significant patterns of covariation. Cluster analyses and ordination of recruitment and survival rate series were used to explore these patterns in mode detail, specifically to examine whether groups of stocks with similar patterns of recruitment and / or survival could be identified.

Results

Correlation analyses and randomization tests - Average Spearman rank correlations among log-transformed recruitment series of demersal stocks within the BS were significantly larger than zero (Fig. 27a, $\rho = 0.11$, $P = 0.020$), indicative of overall positive covariation in recruitment among stocks. In contrast, survival rates among these stocks tended to be uncorrelated on average ($\rho = -0.015$, $P = 0.60$, not shown). However, correlation coefficients for both recruitment (Fig. 27a, $P = 0.005$) and survival ($P = 0.002$, not shown) were significantly over-dispersed, suggesting that the magnitude of correlations in the BS, both positive and negative, was higher than expected. This implies that certain groups of species were positively correlated, while others were negatively correlated. In the GOA we found significant positive covariation among both recruitment (Fig. 27b, ρ = 0.12, P = 0.014) and survival rates (r = 0.17, P = 0.004) of 9 demersal stocks, but no evidence that correlation coefficients were over-dispersed.

Average correlations among neither recruitment nor survival rate series of two salmon stocks and one herring stock in the BS were significantly different from zero (P > 0.4, not shown), and there was no evidence of over-dispersion. In contrast, there was relatively strong positive covariation among both recruitment (average correlation: ρ = 0.24, P < 0.001, Fig. 27e) and survival rates (ρ = 0.20, P < 0.001) of 9 salmon and herring stocks in the GOA. Correlations were stronger among different stocks within species than among different species. However, there were some strong positive correlations among stocks of different salmon species, particularly between pink and chum salmon stocks.

Correlations between groundfish recruitment in the BS and groundfish recruitment in the GOA were of the same average magnitude as correlations within regions (Fig. 27c, r = 0.12, P = 0.007), which was partly a result of positive correlations between stocks of the same species in the two systems. The observed rank correlations between stocks of the same species in the GOA and BS were ρ = –0.003 for walleye pollock, ρ = 0.31 for Pacific cod, ρ = 0.48 for arrowtooth flounder, and ρ = 0.17 for flathead sole. Correlations between survival rates of demersal stocks in the two systems were small and not significant at the 95% confidence level (ρ = 0.055, P = 0.066). Recruitment of pelagic stocks in the BS was positively correlated with recruitment of pelagic stocks in the GOA (Fig. 27d, average correlation: ρ = 0.19, P = 0.010), as were their survival rates (ρ = 0.19, P = 0.017).

Finally, we found moderate positive covariation between the recruitment of pelagic stocks and the recruitment of demersal stocks in the GOA (ρ = 0.11, P = 0.032), but not in the BS (ρ = 0.026, P = 0.36). The corresponding survival rates showed no evidence for positive covariation in the GOA (ρ = 0.074, P = 0.121) or in the BS (ρ = –0.065, P = 0.928), and no evidence for over-dispersion.

Cluster analysis and ordination **-** Based on time series of recruitment with different periods of overlap, Bering Sea stocks clustered into four well-separated groups (Fig. 28a). Walleye pollock and Pacific cod shared a similar pattern of recruitment and had the highest observed correlation among all pairwise correlations (Spearman's rank correlation: ρ = 0.77). Flathead sole, arrowtooth flounder, and rock sole formed a second group with strong positive covariation (average pairwise rank correlation: ρ = 0.66). A third group consisted of Greenland turbot, yellowfin sole, and Alaska plaice, whose recruitment had a rank correlation of 0.41 on average. Finally, the pelagic stocks (sockeye salmon, Pacific herring, and chum salmon) comprised a fourth, less cohesive group with an average rank correlation of 0.02. Recruitment was typically uncorrelated or negatively correlated among stocks in the different groups.

A cluster analysis of survival rate series resulted in three less well-defined groups (Fig. 28b) that differed from those based on recruitment (Fig. 28a). Walleye pollock and Pacific cod formed a relatively cohesive group with Greenland turbot, due to a strong correlation between cod and pollock survival (ρ = 0.61), as well as a positive correlation between the survival of turbot and cod (ρ = 0.37). A second group consisted of arrowtooth flounder, yellowfin sole, and rock sole, whose survival rates had an average correlation of 0.37, while flathead sole, Alaska plaice and sockeye salmon comprised a third, moderately correlated group (ρ = 0.32). Survival rates of species in the first group were negatively correlated with those in the second group; in particular there was a strong negative correlation between yellowfin sole survival on the one hand and survival rates of pollock and cod on the other hand ($\rho = -0.64$ and $\rho = -0.61$, respectively).

In contrast to the BS, recruitment patterns of fish stocks in the GOA did not cluster into very cohesive groups (Fig. 29a) and were characterized by a more continuous distribution in ordination space (not shown). However, recruitment of Pacific ocean perch, thornyhead, and sockeye salmon was well correlated (average correlation: $\rho = 0.61$), while recruitment of halibut, chum salmon, herring and pollock was moderately correlated ($\rho = 0.23$). Clustering of survival rate series for GOA stocks resulted in at least two cohesive groups of species (Fig. 29b). The first group included three slope species (Pacific ocean perch, northern rockfish, and shortspine thornyhead), whose survival was relatively strongly correlated ($\rho = 0.51$). Another relatively cohesive group was comprised of the two gadids (Pacific cod and pollock), two flatfish species (Pacific halibut and arrowthooth flounder), and two salmon species (pink and chum salmon). The average correlation among survival rates of these species was 0.38, and their survival rates were uncorrelated or negatively correlated with those of the first group. In particular, arrowtooth flounder survival was negatively correlated with survival of all three species in the first group.

Summary and conclusions

There is evidence of strong positive covariation among certain groups of stocks within the BS and the GOA. Most notably, survival rates of pollock and cod were strongly correlated within the BS and GOA, but were only weakly correlated between the two ecosystems. If survival rates (residuals from stock-recruitment models) are indicative of environmental influences, strong covariation in survival is likely to reflect common environmental forcing. Hence a common forcing mechanism appears to drive the survival of cod and pollock within each of the two ecosystems, while different factors may drive survival in the BS than in the GOA. Recruitment and survival rates for a number of species in the GOA were positively correlated with gadid recruitment and survival, suggesting common environmental forcing across these species. In contrast to widespread positive covariation, there were few cases where recruitment or survival rates showed strong negative correlations. A notable exception is the strong negative correlation between survival of yellowfin sole and survival of Pacific cod and walleye pollock, which may suggest that environmental forcing in the Bering Sea has opposite effects on the survival of yellowfin sole and gadids.

Table 6. -- Stocks and stock groups used in analysis by species and region (Bering Sea = BS, Gulf of Alaska = GOA), range of year classes and number of years (NR) for which recruitment data was available and number of years (NSR) with both spawner (or spawning biomass) and recruitment data.

Scientific name	Common name	Region	Year classes	NR	NSR
Atheresthes stomias	arrowtooth flounder (ATF)	BS	1973-1999	27	24
		GOA	1958-1996	39	36
Hippoglossoides elassodon	flathead sole (FHS)	BS	1975-1999	25	23
		GOA	1981-1996	16	13
Reinhardtius hippoglossoides	Greenland turbot (GT)	BS	1970-1999	30	30
Hippoglossus stenolepis	Pacific halibut	GOA	1950-1995	46	46
Limanda aspera	yellowfin sole (YFS)	BS	1959-1997	39	34
Lepidopsetta sp.	rock sole (RS)	BS	1971-1998	28	24
Pleuronectes quadrituberculatus	Alaska plaice	BS	1970-1998	29	28
Theragra chalcogramma	walleye pollock	BS	1962-2000	39	37
		GOA	1967-2000	34	32
Gadus macrocephalus	Pacific cod	BS	1975-1999	25	22
		GOA	1975-1999	25	22
Sebastes alutus	Pacific ocean perch (POP)	GOA	1959-1998	40	38
Sebastes polyspinis	northern rockfish (NRF)	GOA	1975-1994	20	18
Sebastolobus sp.	thornyheads	GOA	1962-1996	35	30
Oncorhynchus nerka	sockeye salmon	BS	1958-1995	38	38
		western GOA	1952-1995	44	44
		central GOA	1972-1993	22	22
Oncorhynchus gorbuscha	pink salmon	western GOA	1963-1996	34	34
		Kodiak	1963-1997	35	35
		central GOA	1972-1997	26	26
Oncorhynchus keta	chum salmon	BS	1979-1993	15	15
		western GOA	1963-1993	31	31
		central GOA	1973-1993	21	21
		PWS	1967-1994	28	28
Clupea pallasi	Pacific herring	BS	1972-1992	21	0
		GOA	1972-1993	22	0

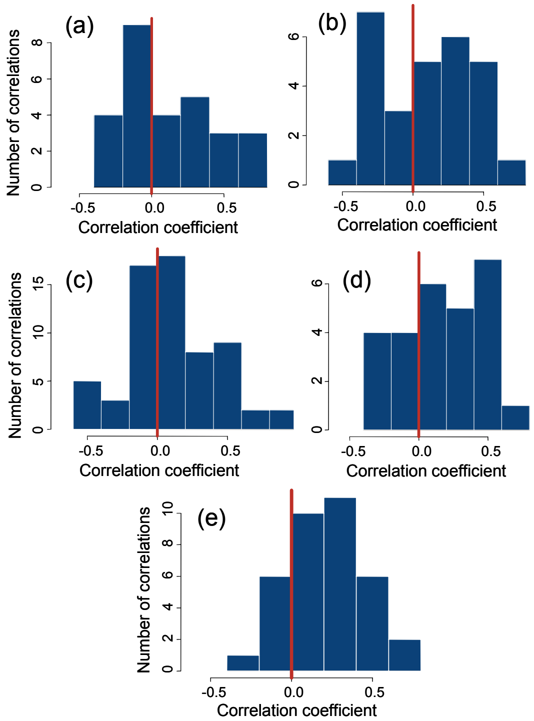
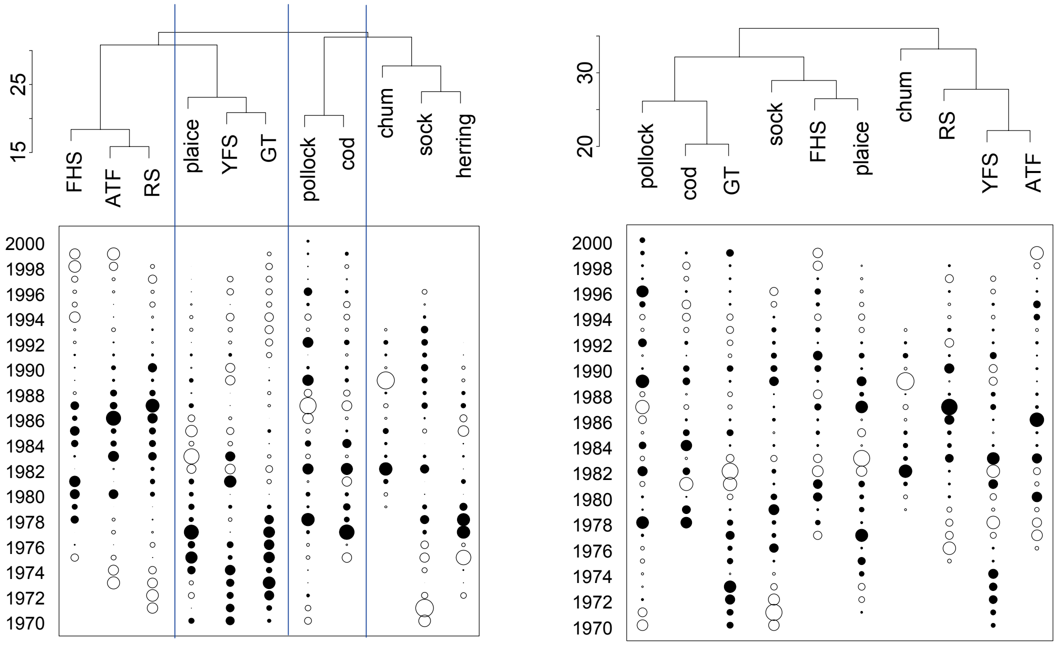


Figure 27. -- Histograms depicting the distribution of all pairwise correlation coefficients (Spearman's rank correlations) among log-transformed recruitment series of 8 demersal stocks in the Bering Sea (a), among 9 demersal stocks in the Gulf of Alaska (GOA) (b), among all 17 demersal stocks (c), among all 12 pelagic stocks (d), and among 9 pelagic stocks in the GOA (e). All stocks are listed in
Table 3.



a

b

Figure 28. -- Dendogram of Bering Sea stocks based on hierarchical cluster analysis (average linkage clustering) of pairwise Manhatten distances among standardized a.) recruitment and b.) survival series, and standardized series of positive (filled circles) and negative (open circle) a. a.) recruitment and b.) survival anomalies for each species, 1970-2000. For species codes see Table 3.

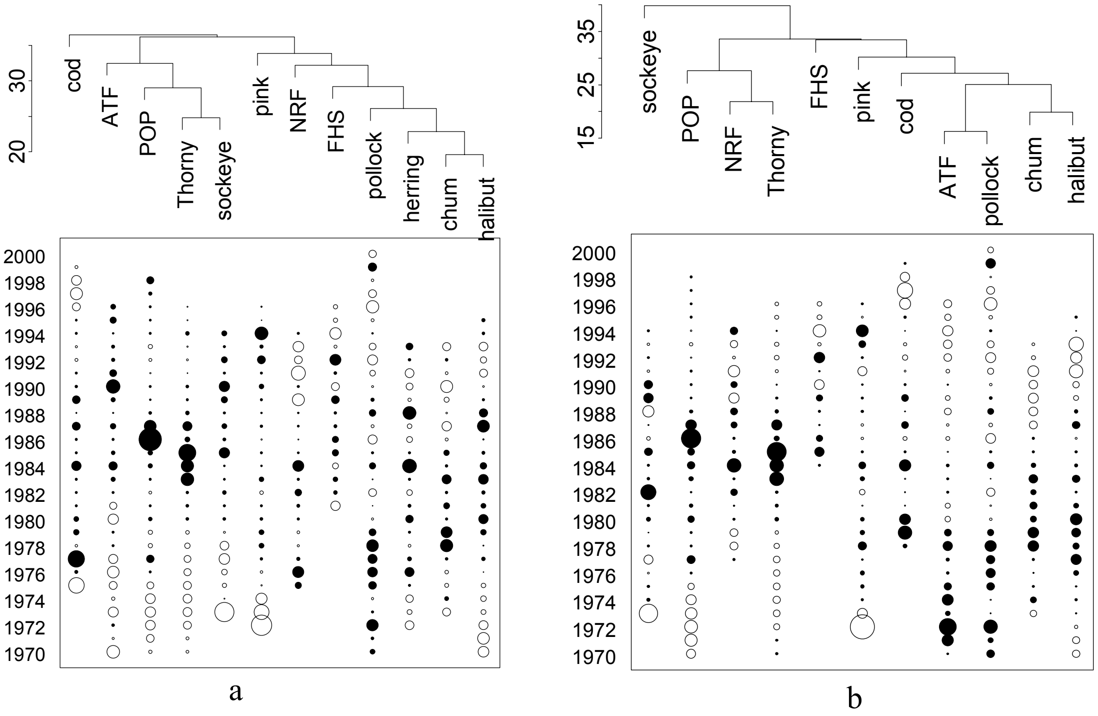


Figure 29. -- Dendogram of Gulf of Alaska stocks based on hierarchical cluster analysis (average linkage clustering) of pairwise Manhatten distances among standardized a.) recruitment and b.) survival series, and standardized series of positive (filled circles) and negative (open circle) a.) recruitment and b.) survival anomalies for each species, 1970-2000. For species codes see Table 3.

VIC. Synchrony in California Fish (J. Field and R. Ralston)

Most commercially important stocks in the California Current system experience tremendous variability in year-to-year recruitment success, and many show clear signs of shifts in recruitment on decadal scales as well. This variability is characterized by a lack of central tendency for most species; meaning that most recruitment events are either extremely high or extremely low, such that what might be considered “average” recruitment is actually quite uncommon (Smith 2000). Coastal pelagics in particular experience tremendous variability in recruitment success, but interestingly short-lived species may actually experience less variability. Stock assessment results reviewed by Smith (2000) suggest that anchovy recruitments vary 30-fold, sardines 60-fold and hake 100-fold; all of these populations have subsequently been shown to vary tremendously over decadal time scales (Baumgartner et al. 1992, MacCall 1996). A single year class, or a series of strong year classes, can have enormous impacts on both the abundance and on fisheries for given stocks. For example, the two largest observed recruitments for Pacific hake, the 1980 and 1984 year classes, caused a near tripling of the total stock biomass, and contributed over 2 million metric tons of hake, or over 60% of all hake landed between 1983 and 1997 (Fig. 30, data from Helser 2002). Similarly, Pacific mackerel experienced a series of strong recruitments between the mid-1970s and mid-1980s, and Pacific sardine experienced strong recruitments from the mid-1980s through the 1990s, that caused both populations to increase by almost two orders of magnitude over little more than a decade.

Recruitment events for many West Coast groundfish also vary considerably, although many populations utilize extreme longevity as a mechanism to cope with environmental uncertainty, and populations thus tend to have a greater diversity of age structure. Still, strong year classes may dominate both biomass and landings over decadal time scales; the bocaccio, *Sebastes paucispinus*, population more than doubled in the mid-1960s following an extremely strong recruitment event (MacCall 2003), and the 1984 age class of chilipepper, *S. goodei*, rockfish dominated the biomass of that stock well into the 1990s. Over 20 years of midwater trawl surveys for pelagic juveniles suggests recruitment events for many commercially important rockfish (*Sebastes* spp.) stocks are both highly variable and largely synchronous, with large recruitments occurring in 1984, 1987-88, 1991, and most years since 1999 (Fig. 31). Stock assessment outputs generally confirm these results (e.g., Williams et al. 2000), and a comparison of assessment results suggest that at least 40% of the variability in recruitment (as inferred by stock assessments) is shared amongst six of the major west coast rockfish stocks (bocaccio, chilipepper, widow (*S. entomelas*), canary (*S. pinniger*), yellowtail (*S. flavidus*), and Pacific ocean perch (*S. alutus*)[2]). The year 1984 also stands out as one of significant importance for chinook salmon, as coded wire tag data indicate that ocean survival for the 1984 year class seems to have been particularly high (B. Wells, Southwest Fisheries Science Center, personal communication). Furthermore, most rockfish and many other groundfish, as well as most West Coast salmon populations, experienced extremely poor recruitment throughout most of the 1990s, a factor that has contributed to ongoing groundfish and salmon crises on the West Coast. An important question with regard to spatial synchrony in strong (as well as weak) recruitment

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[2] Based on principle components analysis of stock assessment results. Perhaps unexpectedly, Pacific hake share the majority of their recruitment variability with these species as well, while pelagics such as Pacific sardine and Pacific mackerel seem to have higher recruitments during the warmer, lower transport years.

years is the extent to which such events reflect coastwide (within the California Current System) or regional (mesoscale) recruitment events. To address this question for rockfish, we have used regional landings and catch-at-age data to generate regional age-structured stock assessment models for chilipepper, widow and yellowtail rockfish (*Sebastes entomelas*, *S. flavidus* and *S. goodie*). Figure 32 shows the results, as standardized log recruitment deviations, note that spatial scales are different for each species. We then evaluated the relationship between resulting recruitment time series using principle components analysis, a commonly used means of finding variables to explain the maximum amount of variance in the data that is increasingly used in fisheries and oceanography (Hare and Mantua 2000, Botsford and Lawrence 2002). Results suggest a high degree of spatial synchrony between regions; the first principle component (of logged recruitment time series) explained approximately 72%, 57% and 51% of the variability in recruitment for chilipepper, widow, and yellowtail rockfish, respectively. Interestingly, the second principle component for each species (explaining roughly 13%, 17% and 15% of the variability, respectively) seems to account for the major differences between northern and southern areas, with the greatest differences between loadings occurring between ports separated by Cape Mendocino and Cape Blanco. These results suggest that large-scale processes are important factors in determining year-class strength (at least, for winter spawners with extended juvenile stages), despite notable spatial differences north and south of major geographic features.

Continuing work on the juvenile rockfish survey data strongly suggests that years of high southward transport tend to be associated with strong year classes for rockfish stocks (S. Ralston, unpublished data). Thus, large spatial and temporal scale phenomena have a major influence on rockfish reproductive success, and conditions affecting transport and retention in the California Current are the key to understanding rockfish recruitment dynamics. These years also seem to be associated with increased abundance of forage fish (Brodeur et al. 2003, Peterson and Schwing 2003), as well as high recruitment of sablefish (M. Schirippa unpublished data), and pink shrimp (Hannah 1999). As these events seem to have occurred more frequently both prior to the 1977 regime shift, and following the 1999 shift, it is increasingly apparent that good recruitment years are associated with conditions promoting high-transport of subarctic waters. Consequently, the interannual and interdecadal scale climate conditions that relate either directly or indirectly to transport are critical variables in determining relative year class strengths for a wide range of commercially and ecologically importance. The ability to better monitor environmental conditions in the California Current System, as well as infer direct and indirect estimates of year-class strengths from surveys and other sources, will dramatically improve the short-term forecasts of biomass levels and allowable catches from stock assessments. This in turn will lead to better long-term understanding and prediction of both trends in production and rebuilding trajectories for overfished and depleted species.

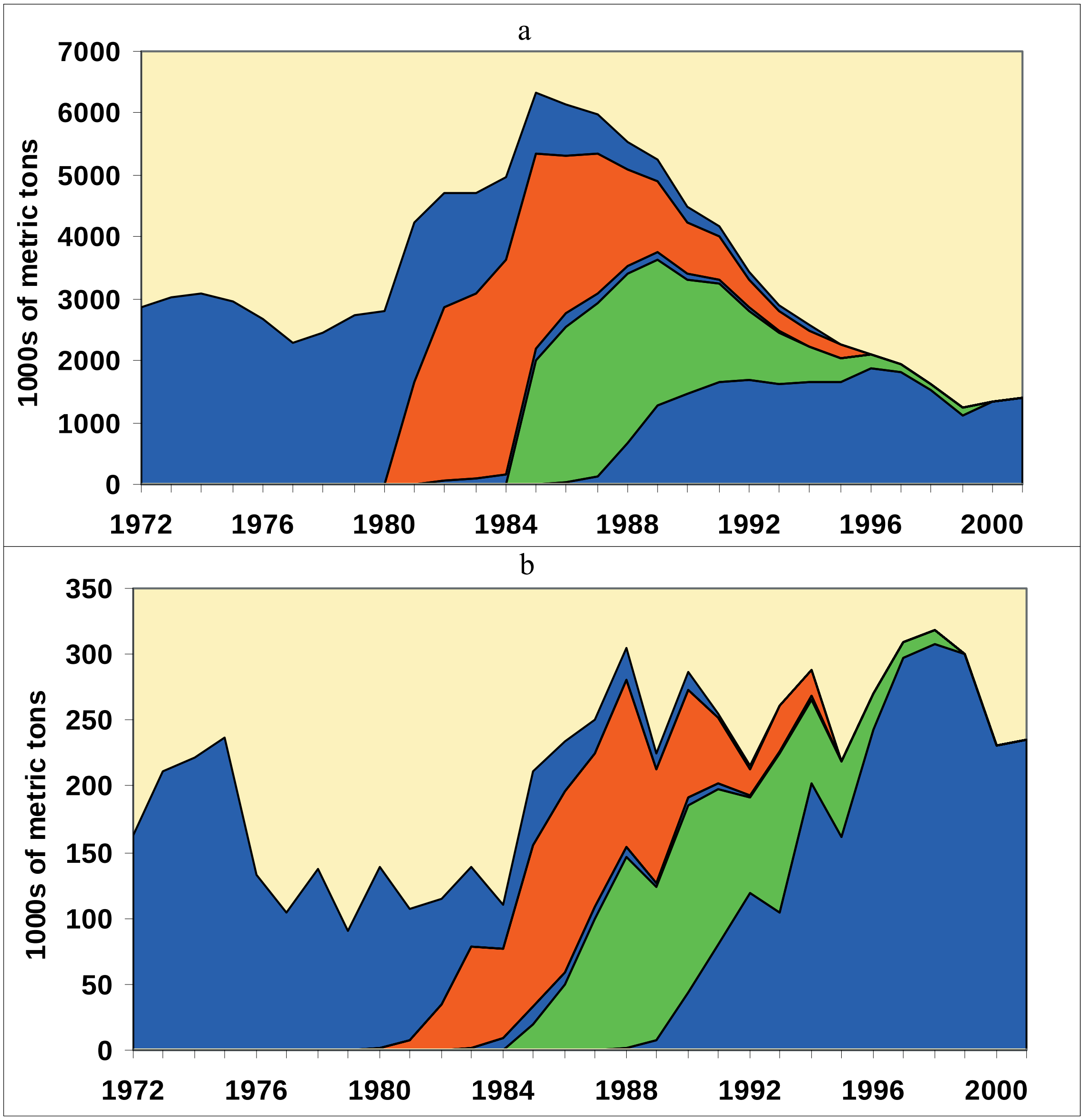

Figure 30. -- Relative importance of the 1980 (orange) and 1984 (green) year classes on the total biomass (a) and landings (b) of Pacific hake. Note that biomass levels include estimates of age 1 and age 2 hake.

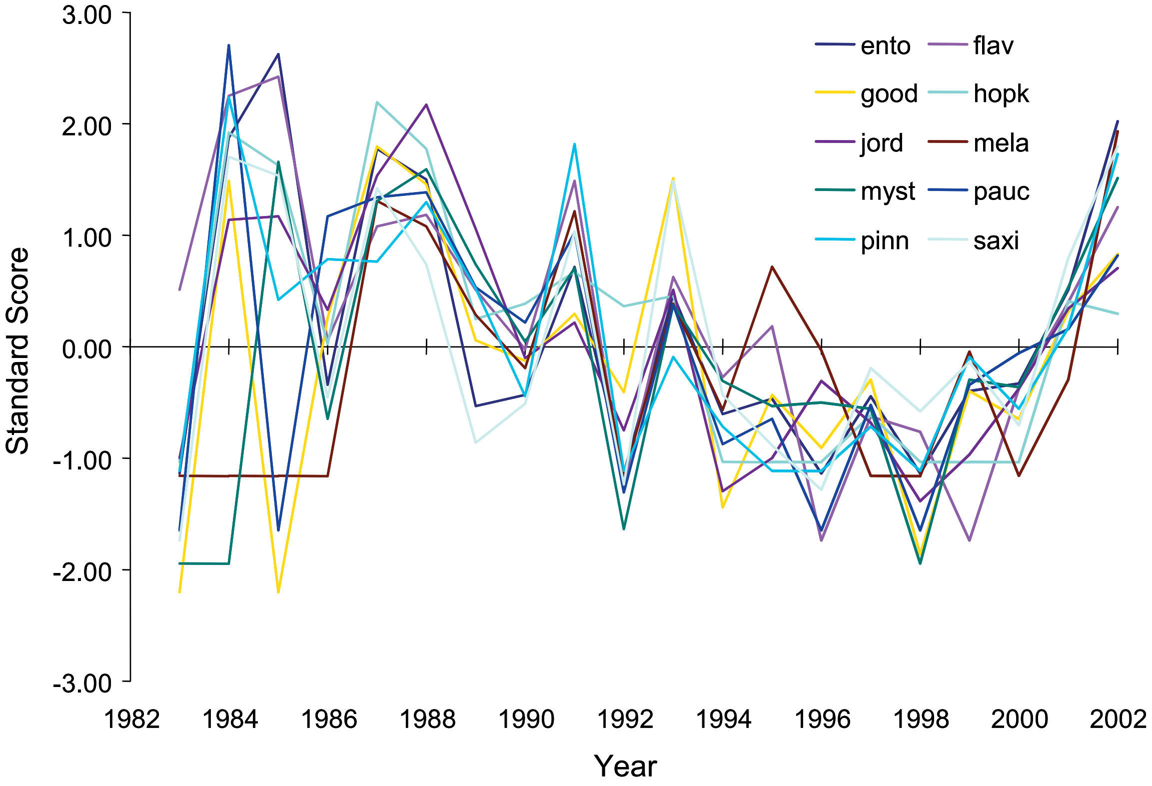

Figure 31. -- Generalized linear model (GLM) results for the relative abundance of ten species of juvenile rockfish from the NMFS midwater trawl survey, 1983-2002 (data from S. Ralston)

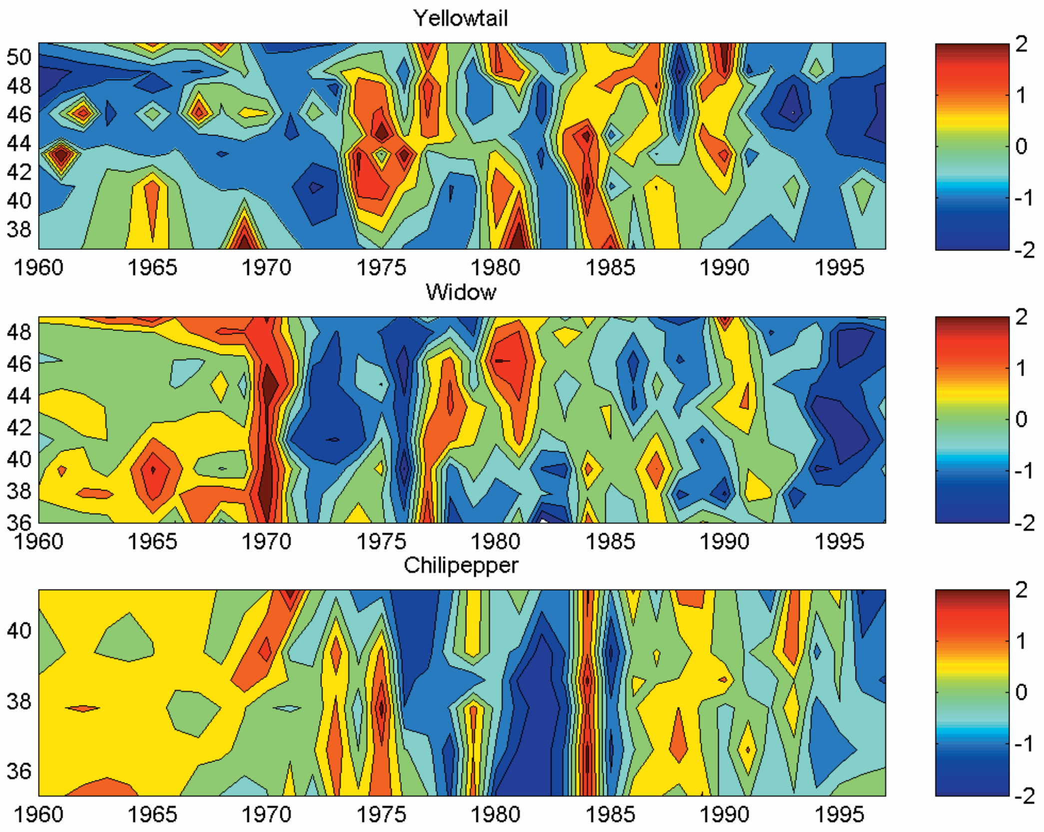

Figure 32. -- Contour plot of year-class strength deviations, based on regional catch at age data, over space and time for chilipepper, widow and yellowtail rockfish in the California Current (note difference in latitudinal scale).

VID. Synchrony Between the Average Lengths of Mature Coho and Chinook Salmon and the Environment (B. K. Wells and C. B. Grimes)

Approach

We examined the synchrony between environmental variation and return size of Pacific salmon. We used the average length of escapement collections of coded-wire-tagged coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) salmon from brood years starting as early as 1971 (Pacific Salmon Commission coded wire tag database; http://www.rmis.org/index.html). We restricted our samples to age-3 coho returns and 2 sea-winter (2SW) chinook returns (age-3 fall chinook and age-4 spring chinook). Release ages used were age 1+ for coho and spring chinook and 0+ for fall chinook. Eco-regions included Alaska (AK), British Columbia - Puget Sound (BC-Puget), Columbia River (Col), and Washington-Oregon-California (WOC) following coherency patterns of survival reported by Magnusson (2002) and also consistent with larger scale environmental forces such as oceanic circulation and terrestrial dynamics (e.g., river length, flow, and estuarine habitat).

We used cross-correlation analysis to examine synchrony between environmental and escapement size time series. We examined Multivariate El Niño - Southern Oscillation Index (MEI, Wolter and Timlin 1998), Pacific Decadal Oscillation (PDO, Mantua et al. 1997), Northern Oscillation Index (NOI, Schwing et al. 2002), and Aleutian Low Pressure Index (ALPI, Beamish and Bouillon 1993) values for the years 1974 - 2002. We also evaluated the effects of seasonal flow rates at the mouth of reference rivers within each eco-region (Table 7). To reduce auto-correlation, and remove trends related to fishing alterations, all biological and environmental time series were fitted to a linear least squares regression and the residuals were used for the analysis. We then calculated the effective degrees of freedom following Pyper and Peterman (1998). In the three cases where there was a short break in the return time series (WOC coho, BC - Puget fall chinook, and Col fall chinook) we used interpolation between raw values to fill the gap. We used an alpha of 0.05 to judge significance of cross-correlations.

The cross-correlative approach had the benefit of allowing the detection of the previous impact of environmental forces on growth before the final age of sampling. Significant events that occurred during age-2 could be observed because, in the analysis, one series was lagged over the other. If the environmental series was pushed forward one year to match the fork length series for an escapement population we could infer that the effect of that environmental forcing factor was set during the second, and not the third, year of life (for age-3 returns). To be consistent we always lagged the environmental indices over the length series.

Results and discussion

The average length of fish at release was reported for a subset of each return population of coho and chinook (coho AK - *n* = 8,103, coho BC-Puget - *n* = 66,195, coho col - *n* = 51,634, chinook fall BC-Puget - *n* = 7,578, chinook fall Col - *n* = 4,346, chinook fall WOC - *n* = 2,432, chinook spring AK - *n* = 1,364, and chinook spring Col - *n* = 19,577). Return size could not be modeled by the length at release. The amount of variation in the model accounted for by release size was extremely low. The highest correlation value was $r^2 = 0.09$ for Col coho followed by $r^2 = 0.05$ for AK coho (average $r^2 = 0.03$).

The average size of returning age-3 coho and 2SW chinook varied considerably over the years for which there was available data (Fig. 33). Table 7 summarizes the period of each average fork length time series available. The average length of returning coho populations south of Alaska were in synchrony and in phase, suggesting that growth of these synchronous groups was driven by similar mechanisms (Table 8; samples sizes: AK *n* = 23,679, BC-Puget *n* = 158,739, Col *n* = 155,792, and WOC *n* = 186,904). Specifically, growth variations of coho stocks south of Alaska were synchronous and in opposite phase with warm conditions (positive PDO) and weak North Pacific High pressure during ocean residence. From these results it is evident that the mechanisms which controlled return size of coho above and below the up- and downwelling transition zone were different. Chinook did not show any obvious patterns of synchrony between populations (samples sizes: fall BC-Puget *n* = 21,005, fall Col *n* = 18,575, fall WOC *n* = 13,883, spring AK *n* = 7,003, Col *n* = 63,390).

The length of age-3 coho and 2 SW chinook salmon over time was synchronous with variation in the environment (Table 8). Interestingly, in all cases where there was significant correlation, the peak value was distinct and typically only one lagged value was significant. When more than one lag was significant there were no more than two significant correlations. Also, except for Alaska fish (Table 8), no lags greater than 1 or less than -1 were significant. Precise matching of series at such small lags suggests that significant correlations were not by chance, but rather described synchrony of series and that each series had limited auto-correlation. In fact, there was no reduction in degrees of freedom required (Pyper and Peterman 1998).

Some general patterns may be gleaned from our analyses that can be interpreted to estimate differences in the environmental factors controlling growth in the up- and downwelling regions of the northeast Pacific coast. The WOC salmon groups were significantly correlated and in opposite phase with the MEI values following 1SW indicating that fish along the U.S. West coast were affected negatively by ENSO-like conditions. This was most apparent for fall chinook from the 1998 return year (Fig. 33). This strongly suggests that the growth trajectory of the WOC chinook salmon is set following the 1SW. Also, in contrast to WOC chinook , BC-Puget chinook average return size was positively correlated to MEI and PDO values in the final year. This result is consistent with BC-Puget chinook migration northward (Healey 1991) and improved growth as a result of shallower mixed layer and increased productivity along the subarctic coast.

An intriguing and unexpected result was that returning BC-Puget coho, Col coho, and Col chinook were related only to summer flow during parental migration and egg preparation by hatcheries. Other correlations to river discharge, across seasons, yielded negative lags or multiple, discontinuous significant correlations (they did not show any apparent pattern). Directly, these results support that parental contribution/egg quality is important in determining age and/or size at return (Hankin et al. 1993). For BC-Puget and Col coho the trajectory set at parental selection was modified in subsequent marine exposure. However, it appears, relative to the oceanographic conditions examined here, that the growth trajectory or age at maturation of Col chinook was set at parental or egg selection (Hankin et al. 1993). Further, fall Col chinook were negatively related to flow while spring chinook were positively related. Among other possibilities, this opposing correlation may relate to hatchery location, distance traveled by collected fish, or dam operations.

Chinook salmon have a significantly broader age structure than coho. Such variation in age-at-return suggests that age-specific growth rates determined from returning fish (as done here) may vary little across years as the growth rate is partially responsible for determining the probability of returning at any given age. Indeed, an informal examination of the age structure of chinook, related to the same environmental indices examined here, suggests that the diversity and average age of returning fish is a result of balancing growth and natural mortality of aging members of substantial cohorts. We noted broadening of age distribution most dramatically for Columbia spring fish. Concomitant with the broadening age distribution, these fish had the least variation in size across years of the fish examined (Fig. 33). Results presented in Figure 2 of Magnusson and Hilborn (2003) show that over the last 30 years, hatchery chinook population dynamics have been driven by relatively few large cohorts. During the same time period coho showed less punctuated survival (Magnusson and Hilborn 2003). Chinook salmon may therefore have been buffering against poor growth years by expanding their age structure.

Our next step in this examination of the effects of environment on growth will be to use catch statistics, return rates, and mortality to model the relationship of abundance to average size. Hence, we will remove statistical artifacts on average return size related to size-mediated survival and density dependence. We will refine further the results through examination of scale patterns from fish collected along their entire range. In total, however, we have shown clearly that the average size and hence size-dependent average fecundity and possibly condition are indeed synchronous with large-scale environmental factors.

Table 7. -- Data summary. Coho and chinook salmon age-3 returns were collected from along their range.

Species	Type	Domain	Age 3 returns	Release regions used	Brood years
Coho	-	Alaska	1981 - 2002	Southeast Alaska	1978 - 1999
	-	BC - Puget S.	1974 - 2002	Queen Charlotte Islands	1980 - 1997
				Western Vancouver Island	1972 - 1999
				Johnstone Strait	1974 - 1999
				Georgia Strait	1971 - 1999
				Fraser R. - Thompson R.	1980 - 1998
				Strait of Juan de Fuca	1971 - 1999
				Mid-Puget Sound	1971 - 1998
				Stillaguamish R. - Snohomish R.	1971 - 1999
				Nooksack R.	1971 - 1999
				Hood Canal	1971 - 1999
	-	Columbia R.	1975 - 2001	Central Columbia R.	1974 - 1999
				Lower Columbia R.	1972 - 1999
	-	WOC	1974 -1975 /	North Coastal Washington	1971 - 1999
			1977 -2002	Grays Harbor	1972 - 1999
				North Coastal Oregon	1975 - 1999
				South Coastal Oregon	1977 - 1999
Chinook	Fall	BC - Puget S.	1974 -1978 /	Western Vancouver Island	1971 - 1998
			1981 -2001	Johnstone Strait	1971 - 1998
				Georgia Strait	1971 - 1998
				Strait of Juan de Fuca	1971 - 1998
				Mid-Puget Sound	1971 - 1998
				South Puget Sound	1971 - 1998
				Nooksack R.	1971 - 1998
				Hood Canal	1971 - 1998
	Fall	Columbia R.	1974 - 2001	Upper Columbia R.	1971 - 1998
				Central Columbia R.	1971 - 1998
				Lower Columbia R.	1973 - 1998
	Fall	WOC	1979 - 2002	North Coastal Washington	1976 - 1999
				North Coast Oregon	1976 - 1999
				South Coastal Oregon	1976 - 1999
				Sacramento R.	1976 - 1999
				San Joaquin R.	1976 - 1999
Chinook	Spring	Alaska	1981 - 2002	Central Alaska	1978 - 1999
				Southeast Alaska	1978 - 1999
	Spring	BC - Puget S.	1983 - 2001	Coastal BC	1980 - 1998
				Fraser R. - Thompson R.	1980 - 1998
				South Puget Sound	1980 - 1998
				Nooksack R.	1980 - 1998
	Spring	Columbia R.	1974 - 2001	Snake R.	1972 - 1998
				Upper Columbia R.	1979 - 1998
				Central Columbia R.	1971 - 1998

Table 8. -- Maximum cross-correlations for the lengths of age-3 coho and chinook escapees to each other and environmental variables. In the top panels, black cells represent negative correlations and gray blocks represent positive correlations. The values in parentheses represent the amount the column variable was lagged against the row variable. The bottom panel represents correlations between environmental variables. Columns were lagged against rows.

	Coho BC-Puget	Coho Col	Coho WOC	Chinook Fall BC-Puget	Chinook Fall Col	Chinook Fall WOC	Chinook Spr AK	Chinook Spr BC-Puget	Chinook Spr Col	Chinook Spr WOC	MEI (Dec-Feb)	MEI (Mar-May)	MEI (Jun-Aug)	MEI (Sep-Nov)	PDO (Dec-Feb)	PDO (Mar-May)	PDO (Jun-Aug)	PDO (Sep-Nov)	NOI (Dec-Feb)	NOI (Mar-May)	NOI (Jun-Aug)	NOI (Sep-Nov)	ALPI
Coho AK																							44 (-2)
Coho BC-Puget		52 (0)	39 (0)			56 (-1)	54(2)									-49 (0)	-64 (0)	-50 (0)	37 (0)	47 (1)			
Coho Col			62 (0)				46 (1)					-46 (0)		-42 (0)		-40 (0)	-48 (0)	-50 (0)	39 (0)	43 (0)			
Coho WOC									46(-2)		-48 (-1)	-54 (-1)	-46 (0)	-47 (0)	-39 (-1)	-58 (-1)	-58 (0)	-46 (-1)		56 (0)			
Chinook Fall BC-Puget					-51 (-2)				60 (0)						60 (-1)	44 (-1)		44 (0)					
Chinook Fall Col									-61 (2)						-46 (1)						-37 (0)	-39 (0)	
Chinook Fall WOC							-50 (2)			64 (0)		-41 (1)	-49 (1)				-63 (1)	-47 (1)				42 (1)	
Chinook Spr AK											44 (2)	45 (2)	56 (3)	53 (3)		46 (2)			-52 (2)			-56 (3)	55 (-2)
Chinook Spr BC-Puget																		51 (0)	-51 (1)		-52 (0)	-56 (0)	46 (1)
Chinook Spr Col													40 (0)		50 (-1)								
Chinook Spr WOC											-45 (1)	-56 (1)					-48 (1)			53 (1)			

	MEI (Mar-May)	MEI (Jun-Aug)	MEI (Sep-Nov)	PDO (Dec-Feb)	PDO (Mar-May)	PDO (Jun-Aug)	PDO (Sep-Nov)	NOI (Dec-Feb)	NOI (Mar-May)	NOI (Jun-Aug)	NOI (Sep-Nov)	ALPI
MEI (Dec-Feb)	*86 (0)*	*77 (1)*	*89 (1)*	*45 (0)*	*62 (0)*	*47 (0)*	*43 (1)*	*-81 (0)*	*-75 (0)*	*-49 (1)*	*-64 (1)*	*52 (0)*
MEI (Mar-May)		*66 (0)*	*72 (1)*	*43 (-1)*	*59 (0)*	*70 (0)*	*55 (0)*	*-69 (0)*	*-81 (0)*	*-39 (0)*	*-45 (0)*	*48 (0)*
MEI (Jun-Aug)			*91 (0)*	*61 (-1)*	*61 (-1)*	*61 (0)*	*68 (0)*	*-65 (-1)*	*-53 (0)*	*-66 (0)*	*-79 (0)*	*53 (-1)*
MEI (Sep-Nov)				*48 (-1)*	*63 (-1)*	*41 (0)*	*56 (0)*	*-78 (-1)*	*-61 (-1)*	*-59 (0)*	*-73 (0)*	*55 (-1)*
PDO (Dec-Feb)					*72 (0)*	*58 (1)*	*72 (1)*				*-42 (1)*	*39 (0)*
PDO (Mar-May)						*61 (0)*	*53 (1)*	*-72 (0)*	*53 (0)*	*-42 (1)*	*-46 (1)*	*52 (0)*
PDO (Jun-Aug)							*76 (0)*	*-45 (0)*	*-66 (0)*	*-57 (0)*	*-47 (0)*	
PDO (Sep-Nov)									*-50 (0)*	*-57 (0)*	*-47 (0)*	
NOI (Dec-Feb)									*75 (0)*	*48 (1)*	*63 (1)*	*-54 (0)*
NOI (Mar-May)												
NOI (Jun-Aug)											*59 (0)*	
NOI (Sep-Nov)												*-46 (-1)*

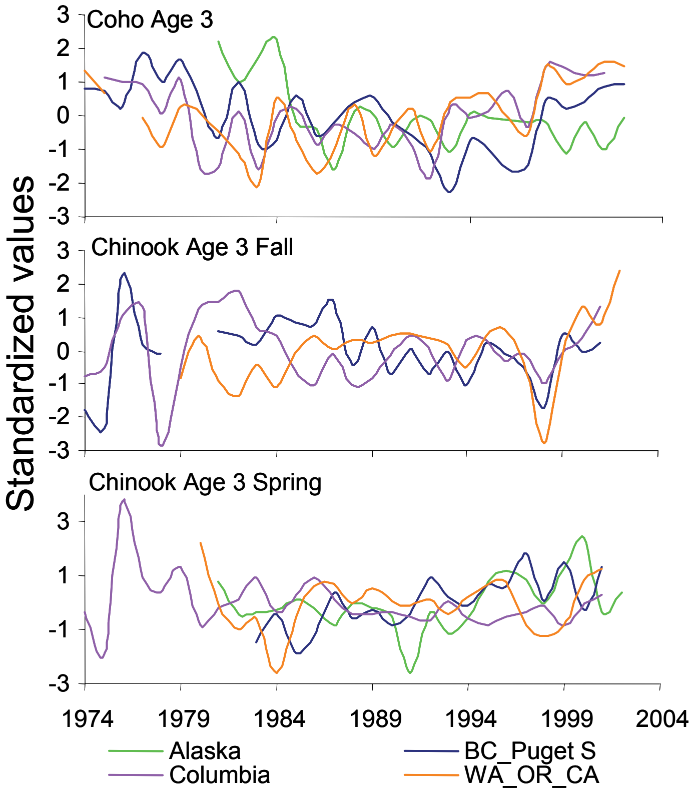

Figure 33. -- Standardized residuals [(observation - group mean)/standard deviation] of average fork lengths (mid-eye fork length for Alaska fish) for age-3 coho, and fall and spring chinook for the years in which tagged fish were recaptured.

VII. MODELING TECHNIQUES FOR INCORPORATING ECOSYSTEM INDICES IN STOCK ASSESSMENTS

VIIA. Ecosystem Modeling and Climate (J.C. Field and K. Aydin)

Ecosystem models are not intended to replace single-species models, but rather to provide a template on to which the results of single-species models are integrated with other research, to supplement single-species models with insights regarding interspecific interactions, and to provide a template for formally addressing the larger context in which stocks and species exist. As both Hollowed et al. (2000b) and Fulton et al. (2003) point out, it is questionable whether multispecies models provide better advice than single species models with regard to their primary objectives for traditional fisheries management; describing stock status and propose specific actions to direct stocks towards desirable short-term states. However ecosystem models are the only class of models with the potential to answer many environmental questions that single-species models cannot, particularly with regard to the impacts of changing rates of primary and secondary production, changes in natural (predation) mortality, the potential consequences of various selective harvest activities to (particularly important with regard to juvenile mortality), and the consistency of single-species assessments with regard to both ecosystem productivity and with each other.

Another key application of such models may be in simple hypothesis testing, as was recently demonstrated in the use of Ecopath with Ecosim (Walters et al. 2000) to evaluate plausible scenarios for the decline of Steller sea lion populations (NRC 2003). As ecosystem models have evolved, key challenges have been determining how best to incorporate climate impacts and forcing processes into model dynamics, an effort that requires numerous simplifying assumptions in order to accommodate the modeling framework. For example, climate is known to affect the California Current both from the bottom-up (through short- and long-term variability in primary and secondary productivity) as well as from the top-down (through variability in the spatial distribution of key predators such as hake, arrowtooth flounder, albacore, sardine and mackerel). Consequently, efforts to model the California Current, the Gulf of Alaska and the eastern Bering Sea have not been able to even approach fitting historical time series without such effects, and have recognized the importance of incorporating climate as a forcing mechanism for both bottom-up and top-down processes.

One characteristic of these models is that they are extremely stable; given sufficient time following the removal of a perturbation (either climate or fishery induced), modeled populations generally recover and systems eventually return to equilibrium. Alterations to the basic model assumptions shows promise for developing alternative model scenarios, in which rule changes can occur and ecosystems can alternative between multiple states (K. Aydin, Alaska Fisheries Science Center, personal communication.). This refinement uses the concept of scramble competition (Rice 2001), in which resource availability changes abruptly, independent of changes in consumer abundance, with life history adaptations and characteristics being a partial determinant of the winners or losers in competition for resources. This approach may be useful in evaluating the role that alternative life history characteristics have in shaping ecosystem structure and stability, as well as evaluating the possible interactions between climate and fishery-induced perturbations.

For the “climate-forced” model, the euphausiid biomass is driven directly with the output from a physically forced nutrient, phytoplankton, zooplankton (NPZ) model from Robinson and Ware (1999), while the impact of migratory top predators (such as hake) is mediated by adjusting the vulnerability of their prey to predation based on climate-driven patterns in distribution (Dorn 1995). The model “fit” is not wonderful, however it is clear that incorporating climate by some means is necessary to capture many of the trends in this ecosystem. This example is simply meant to illustrate importance and options for incorporating climate processes into multispecies or ecosystem modeling (J. Field, unpublished data).

VIIB. Incorporating Ecosystem Indicators in Stock Assessments (J. Ianelli)

Explicitly incorporating ecosystem indicators within stock assessments generally serves two purposes. One purpose is to provide an added explanation for process variability in the biology of the species of interest. An example of this type of factor may be the effect of environmental conditions on pre-recruit (typically egg and larval) survival. If environmental conditions during these early life stages are favorable, the numbers of survivors recruiting to the population may be greater than expected based on the initial number (or proxy thereof) of eggs spawned. Incorporating this type of information can improve forecasts of future recruitment levels. In practice, the amount that this extra information reduces the variance on recruitment forecasting is relatively small on an inter-annual basis. However, such indices can also provide insights on how medium-term conditions have changed (say on decadal scales).

Environmental indices are also useful in stock assessment contexts to the extent that the factors affect observations. This is in contrast to factors affecting biological processes presented above. A simple example of this type of application is one where ambient water temperatures affect the distribution of fish relative to the sampling gear. Most fish species have a demonstrated temperature preference. If survey sampling occurs at fixed stations within the same study area (as is done for the eastern Bering Sea) and the temperature structure is variable between years, then the fish stock may be more or less available as a function of temperature. That is, the study area may hold different levels of suitable habitat for a particular species depending on the thermal structure when the survey occurs. Currently, the estern Bering Sea (EBS) pollock assessment incorporates this factor within the stock assessment analyses. Another mechanism for how an environmental factor can violate assumptions of survey gear is in how a species responds to the sampling gear. For example, in cold conditions species may be less responsive (more dormant) or more embedded in the substrate and hence are less likely to be captured by the survey gear than in warm conditions. This mechanism and approach is currently in place for a number of flatfish assessments in the EBS.

Section VI describes temperature influences on the spatial distribution of walleye pollock in the EBS. This effect can impact on the survey availability relative to average temperature. Expressed in this manner, model results suggest that during warmer years, more of the stock can be available on the shelf region (Figs. 34 and 35). This relationship is relatively weak and indicates that the actual relationship between catchability and environmental patterns could be improved further.

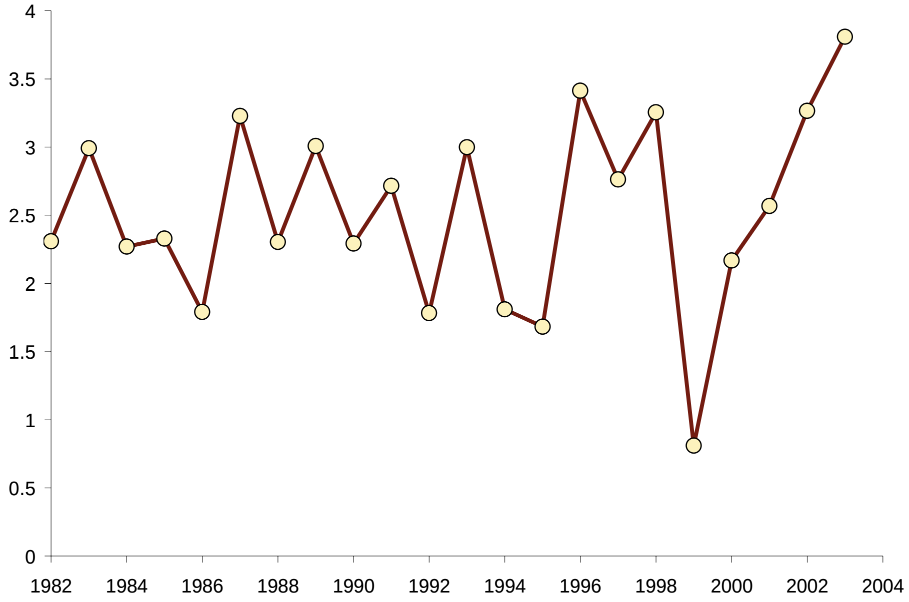

Figure 34. -- Average bottom temperature in the summer based on the bottom-trawl survey data, 1982-2003.

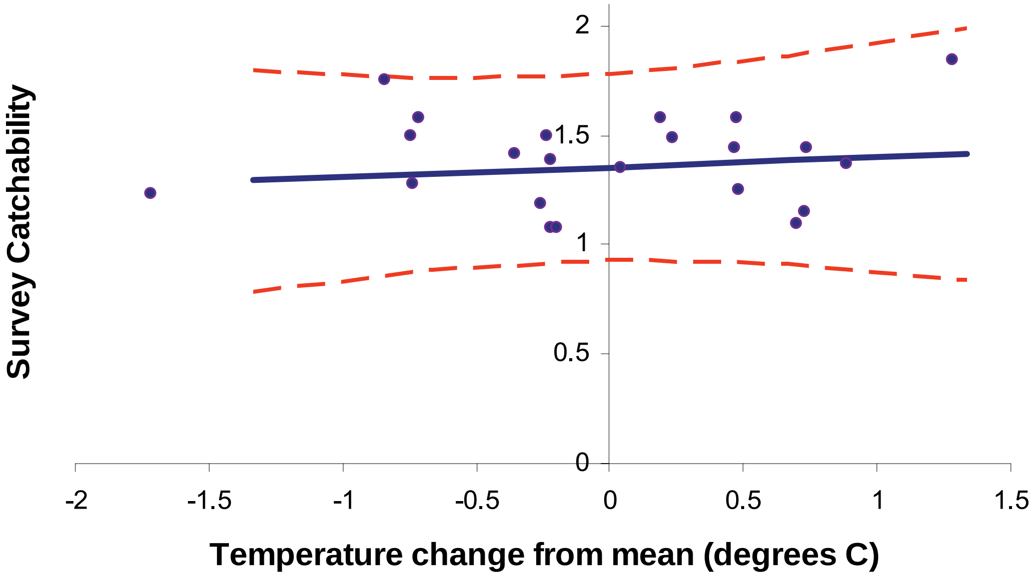

Figure 35. -- Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0) . Points represent residuals relative to survey estimates (i.e., $\hat{q}_t + \ln\left(\hat{I}_t / I_t\right)$ where $\hat{I}_t$ and I_t represent the predicted and observed survey indices, respectively, and $\hat{q}_t$ is the expected catchability given the temperature anomaly in year *t*.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Regime Shift

Decadal Variability

Based on the information presented in Section II, Ecological Investigators identified four potential temporal periods: 1971–1976, 1977–1988, 1989–1997, and 1999 to present. Regarding the late 1990s period, there are three candidate explanations for the observed late 1990s shift in climate: a) the shift was a response to a strong El Niño/La Niña event, b) the ocean system has shifted to a negative phase of the Pacific Decadal Oscillation (PDO), c) the ocean system has multiple states and the system has shifted to a state that has not been previously observed (Bond et al. 2003). Based on evidence presented in Section II of this document the following temporal patterns were detected in the climate/ocean data.

Alaska (AK): 77–88, 89–97, 98–02, 2003
West Coast (WC): 77–97, 89–97, 98–02, 2003
Central Pacific (CP): 77–88, 89–97, 98–02, 2003

The primary variables influenced by these shifts include: wind, precipitation, temperature, mixed layer depth (MLD), production, timing of spring bloom, watermass distributions in the Central Pacific (CP) and West Coast (WC). Evidence suggests that the period 1998–2002 may not mimic the 1971–76 period.

Recommendations for Fisheries Managers

Consider predicting recruitment under a new regime hypothesis. Evidence of common patterns of production responses in marine fish shows promise for developing a mechanism for early detection and verification of decadal shifts in fish production. Review of species that exhibited highly autocorrelated production responses consistent with the hypothesis of climate forcing suggests that transport to nursery grounds as opposed to zooplankton production may be the mechanism underlying shifts in recruitment.

El Niño

Conclusions

The 1990s may have been influenced by more frequent El Niño events. Timing and duration of Niño North / Niña North differ by region. This was most evident in the signature of the 2002 event was unusual with warming evidenced in the central Pacific and coastal GOA and EBS but little evidence of warming along the West Coast. One explanation for this phenomenon is that decadal variability has an impact on the intensity and regional expression Niño North / Niña North.

Recommendations

Ecological Indicators investigators could not reach consensus regarding treatment of El Niños as events or as extremes in a continuum. While climatologists recognize El Niños as discrete well-defined events, evidence of the expression of Niño North influences on marine fish is mixed.

Shifts in Biotic Distribution

Conclusions Recommendations

Several examples of spatial partitioning of marine fish coincident with patterns of ocean properties were provided. Detecting these patterns would be accelerated if the Nation would develop a network of coastal ocean monitoring. Meso-scale surveys in selected regions serve to verify mechanisms underlying observed shifts in distribution (e.g., Global Ocean Ecosystem Dynames (GLOBEC), Eastside Kodiak Island and juvenile flatfish survey). In the case of acoustic surveys, collection of oceanographic variables while the ship is underway greatly enhances detection of oceanographic influences on fish distribution.

Synchrony

Conclusions and Recommendations

Evidence of synchrony in selected rockfish and other fish was detected in all regions. Synchrony could be used to cluster species responses to ocean forcing

Modeling

Conclusions and Recommendations

Techniques for incorporating ecosystem indicators into stock assessment advice have been developed. Immediate advances can be made in the area of ocean influences on growth and availability of fish to surveys or fishing fleets. In the case of stocks with highly autocorrelated time series of recruitment, the group recommended that stock assessment scientists predict future recruitment based on observed and expected ocean conditions. These predictions will serve as a reference for verifying hypotheses.

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