Developing the California Current Integrated Ecosystem Assessment, Module I: Select Time-Series of Ecosystem State

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EXECUTIVE SUMMARY

(1) The California Current Large Marine Ecosystem (CCLME) spans approximately 3,000 km of latitude from northern Vancouver Island, British Columbia, Canada to Punta Eugenia, Baja California, Mexico.

(2) Based on latitudinal variation in physical forcing and biological communities, 3 "eco-regions" can be defined within the CCLME. We present preliminary evidence of linkage and interconnections among eco-regions ("sub-ecosystems"). In no one eco-region are all biological indicators available for ecosystem-based approaches to management.

(3) Herein, we present select biological observations as indicators of ecosystem state at multiple time scales.

(4) Based largely on NOAA's previous sentinel species program, we compiled time-series representing ecosystem "productivity". We have not attempted to integrate these indicators in this report.

(5) In recent years, the CCLME experienced unusual "ocean climate" as shown by the Pacific Decadal Oscillation index (PDO) and multivariate El Niño/Southern Oscillation index (MEI). There have also been obvious changes in the seasonal cycle of upwelling in the northern and central eco-regions.

(6) This variation in ocean climate has led to significant changes in food webs, as shown by: (i) higher copepod diversity and lower copepod and euphausiid (krill) biomass, (ii) reduced market squid (*Loligo opalescens*) abundance, and (iii) reduced and/or altered distribution and abundance of northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sajax*) and a suite of age-0 rockfish (*Sebastes* spp.).

(7) Vertebrate predators responded to these changes in the food web. Coho salmon (*Oncorhynchus kisutch*) survival has been very low and many seabirds experienced below normal breeding success, with unprecedented breeding failures of the dominant planktivorous species (Cassin's Auklet, *Ptychoramphus aleuticus*) in 2005 and 2006.

(8) Recent observations are best viewed in the context of long-term ecosystem fluctuations. Since the late 1980s/early 1990s, there have been signs of increasing system variability, diminishing ecosystem productivity, and declines in species with "sub-arctic" bio-geographic affinities. Some top predators are showing opposing changes. There has been increasing production of a dominant marine mammal (California sea lion, *Zalophus californianus*) and apparent decreasing production of large predatory fishes (e.g., Pacific hake *Merluccius productus*).

(9) The causes of these changes are not well understood, but possible mechanisms of change include (a) increased ocean stratification which may limit the efficacy of upwelling and primary productivity, (b) reduced advection and transport of cold, sub-arctic water and organisms to the ecosystem, or (c) ecosystem effects due to other human activities such as fishing.

INTRODUCTION

What is an Integrated Ecosystem Assessment?

An Integrated Ecosystem Assessment (IEA) is a dynamic, decision-support tool for management of living marine resources. Fluharty et al. (2006) include the following specific objectives for IEAs to be developed for each large marine ecosystem (LME) in the U.S.:

- To compile relevant data sets for the ecosystem (e.g., physical oceanography, atmospheric, climatological and weather observations, human use patterns and statistics, abundance and distribution of biological resources),

- To report on current conditions and trends in relevant data time series of physical, biological and human uses,

- To synthesize time series data to link important ecological outcomes to changes in relevant climate and human use drivers (i.e., forecasting),

- To evaluate data time series; provide suites of key indicators of ecosystem state (status); propose reference levels for safe and for desired states of the ecosystem,

- To forecast relationships between state indicators and pressure indicators (e.g., pollution, climate change, fishing-related removals, coastal development, etc.) to inform management, and

- To provide periodic ecosystem assessment updates to inform managers, stakeholders and the public on the state of the ecosystem.

For the California Current LME (CCLME), there are many physical and biological components that warrant observation and understanding, from a mechanistic perspective, to derive factors affecting key ecosystem form, function, and control, and the population dynamics of the top vertebrate marine predators (fish, seabirds, sea turtles, and marine mammals) of significant management concern. In this document, we present records (time-series) of key biological organisms, describe these data in the context of recent and long-term changes in the ecosystem, identify apparent gaps in knowledge, and outline possible future directions for CCLME IEA development. We emphasize that this *initial* [biological indicator] approach to development of a CCLME IEA should be complemented by other approaches (e.g., ecosystem modeling) and that the indicators shown herein are not comprehensive. Nonetheless, we suggest that the species and parameters selected are useful for understanding the population biology of species of management concern, and are therefore of great value to state and federal authorities in the CCLME.

The California Current Large Marine Ecosystem: Form, Function, and Controls

The CCLME is a large, dynamic and spatially heterogeneous marine environment in the eastern North Pacific Ocean off the west coast of North America (Duda and Sherman 2002). It spans nearly 3,000 km of latitude, from approximately the northern tip of Vancouver Island, British Columbia, Canada to Punta Eugenia, Baja California, Mexico (Figure 1). Several major physical oceanographic processes, all linked to variability in atmospheric circulation and the flow of dominant currents in the region, determine ecosystem form and function. These include *local effects* through coastal upwelling, effects of meso-scale structures (e.g., fronts and eddies) formed by jets and meanders of upwelling plumes and the California Current itself, and influences of *basin-scale* winds on sub-arctic and sub-tropical water mass intrusions. From an oceanographic perspective, the CCLME is under influence from the northern and western Pacific, as well as the tropical eastern North Pacific.

Atmospheric Considerations

The strength and juxtaposition of the North Pacific High relative to the Continental Low in summer and Aleutian Low in winter determines the phasing and amplitude of winds which force coastal upwelling and the strength of the California Current (Hickey 1979, Chelton et al. 1982). However, winds, currents, and upwelling within the CCLME are not homogenous; there is substantial latitudinal variation in physical forcing mechanisms. In the north, the CCLME is dominated by strong seasonal variability in winds and upwelling, whereas in the south there is less of a “seasonal cycle” in these parameters, meaning that winds and upwelling are more constant.

Habitat Considerations

There are numerous regions of elevated primary and secondary productivity, including seamounts, capes and coastal promontories (Figures 1 and 2). These highly productive “hotspots” offer favorable habitat for juvenile salmonids, and serve as spawning and feeding grounds for important small pelagic fish such as sardines, anchovies, and smelts. These also provide dynamic locations for trophic interactions, including foraging opportunities for a diverse, abundant suite of vertebrate predators. Many of these species are highly-migratory, visiting the CCLME from breeding grounds in Alaska (e.g., fur seals, northern fulmars), Baja California (e.g., gray whales), the Western Pacific (e.g., bluefin tuna, leatherback turtles), and as far as the southern hemisphere (e.g., several shearwaters and petrels). These living marine resources support vast societal interests, including commercial and recreational fishing and ecotourism.

Variability

Despite being diverse and productive, the CCLME is highly variable. Natural variability is exemplified by the Pacific Decadal Oscillation (PDO; Figure 3) and the El Niño/La Niña phenomena (Figure 4). These basin-scale environmental fluctuations have significant physical oceanographic (Bograd et al. 2003) and ecological effects, altering primary productivity and food webs (zooplankton: McGowan et al. 2003, Brinton and Townsend 2003; forage fish: Chavez et al. 2003). This variation in turn affects top predators (Ainley et al. 1995, Veit et al. 1997, Sydeman and Allen 1999, Sydeman et al. 2001, Hyrenbach and Veit 2003). Therefore, temporal environmental variability presents a fundamental challenge to management as population changes must be viewed from the perspective of normal ecosystem fluctuations (Botsford et al. 1997).

Human Impacts

Anthropogenic stressors, such as fishing, coastal development, pollution and global climate change affect the CCLME. These human impacts may act synergistically with natural ecosystem variability if they occur at the same time and place. For example, the west coast population of Pacific sardine (*Sardinops sagax*) was driven to low levels (and economic extinction) by extensive fishing during a period of adverse climatic conditions for this species (Chavez et al. 2003). Thus, understanding the potential interactions between natural and anthropogenic impacts is central for management of the CCLME.

Sub-ecosystem structure

The California Current is formed as the eastern leg of the North Pacific Gyre. The intensity of the transport in the California Current varies by season, year, and decade. It fluctuates, in part, relative to the position and strength of the North Pacific Current/West Wind Drift, which traverses the sub-arctic North Pacific Ocean and bifurcates between southern British Columbia and northern Oregon into the Alaska Current and California Current. While Washington and southern British Columbia may be considered a “transition zone,” we define the northern boundary of the CCLME as the northern tip of Vancouver Island, B.C., due to frequent upwelling along this section of the coastline in spring and summer (Allen et al. 2001, Whitney et al. 2005). Based on physical and biological attributes, U.S. GLOBEC (1992) subdivide the CCLME into three distinct “eco-regions” or sub-ecosystems: (1) southern British Columbia, Washington and Oregon to Cape Blanco; (2) Cape Blanco, southern Oregon, to Point Conception, California; and (3) southern California and Baja (Figure 5). Due to seasonal and longer-term climate variability, it is recognized that the boundaries of these broad eco-regions are dynamic and shift under varying oceanographic conditions.

RESULTS

Long-Term Research in the CCLME

Several long-term research projects investigating the CCLME have been conducted, with coverage spanning the entire ecosystem and 3 eco-regions (Table 1); at least three projects have over 20 year of data (Figure 2, Goericke et al. 2007). Data from several of these projects will be shown and discussed.

Recent Status of the CCLME

Basin-scale environmental indices

The PDO index (Figure 3) and Multivariate El Niño index (MEI; Figure 4) have both been in a positive (i.e., warm eastern North Pacific) state more or less continuously since late 2002. From late 1998 to early 2002, these indices were negative after nearly a decade in the 1990s of consistently positive anomalies.

Temperature and Upwelling

According to many studies, sea-surface temperature (SST) in the CCLME has increased by 0.5°C to 1.0°C over the past 50 years. Upwelling, however, has been variable, with an apparent general increase in NOAA's west coast upwelling index (Schwing and Mendelssohn 1997). Interannual variability in upwelling has been substantial, especially in recent years. In 2005, upwelling was delayed and/or interrupted and sea surface temperatures (SST) were ~2˚-6˚C warmer than normal (GRL 2006). In 2006, weak upwelling was noted in the central eco-region, while strong upwelling occurred in the north. The situation in the southern eco-region was different in both years, as average upwelling and SST was apparent (Peterson et al. 2006).

Zooplankton

Biologically, these unusual oceanographic conditions resulted in numerous changes in key ecosystem indicators. Off Oregon, copepod species richness was elevated with below-average abundance of northern-boreal species, particularly in 2005 (Figure 6). Copepod biomass in 2005 was the lowest on record, whereas it returned to near average in 2006 (Figure 7). It is hypothesized that when advection of waters from the Gulf of Alaska is strong, northern-boreal copepods are more abundant, copepod biomass is higher, and copepods species richness declines (Figure 8). These conditions apparently favor a more productive sub-arctic ecosystem off Oregon.

Off southern California, the seasonally-derived "small plankton volume" index (copepods and euphausiids) based on the California Cooperative Oceanic Fisheries Investigation (CalCOFI) program (Figure 2c) was slightly (though not significantly) below average in 2005 or 2006 (Figure 9). Average or slightly elevated zooplankton biomass was noted in the southernmost limits of the CCLME, off Baja California, in these years as well (Peterson et al. 2006).

The abundance of the euphausiid *Thysanoessa spinifera* in the diets of fish off Vancouver Island, Canada, was also below average in 2005 and 2006 (and continuing during winter 2007; Figure 10). Similarly, the abundance of euphausiids in the diet of a planktivorous seabird (Cassin's Auklet, *Ptychoramphus aleuticus)* off central California was anomalously low in 2005 (Figure 11). These euphausiids are keystone species in the coastal food webs of the CCLME.

Squid

Market squid (*Loligo opalescens*) in the southern eco-region were below-normal in 2005 and 2006 as evidenced by both landing data and California sea lion (*Zalophus californianus*) diet (Figure 12).

Forage fish indices

Northern anchovy (*Engraulis mordax*) and Pacific sardine egg counts in spring (April) 2005 and 2006 were very low, especially in comparison with 2001 – 2003 period (Figure 13). The relative increases and decreases in anchovy versus sardine eggs between years may be attributed to temperature and upwelling (Lluch-Belda et al. 1991, Jacobson and MacCall 1995).

The abundance of juvenile age-0 rockfish (*Sebastes* spp.) was exceptionally low in 2005. Essentially, complete recruitment failure in the central eco-region was observed (Figure 14). Juvenile rockfish were also conspicuously absent from the diet of a piscivorous seabird (Common Murre, *Uria aalge*) in 2005 and 2006 (Figure 15).

Vertebrate predators

Coho salmon (*Onchorhynchus kisutch*) returns to hatcheries (the Ocean Production Index [OPI]) were below average in 2005 and 2006 (Figure 16), pointing to poor ocean conditions in 2004 and 2005, the years of ocean entry. These years, though demonstrating reduced returns, were not as poor as during the mid 1990s (Peterson and Schwing 2003). Juvenile coho salmon growth off of the west coast of Vancouver Island in 2005 was the lowest on record since 1998 (DFO 2006).

Breeding success for most seabirds in the central eco-region was below average in 2005 and 2006, including complete breeding failure by the obligate planktivore (Cassin’s Auklet) in both years (Sydeman et al. 2006, Figure 17). The two most common euphausiid species, *Euphausia pacifica* and *Thysanoessa spinifera*, were found in anomalously low proportions in Cassin’s Auklet diet in 2005 (Figure 11).

The abundance of California sea lions (indexed by the anomaly in pup production from a rookery in the Channel Islands) was high and continuing an increasing trend since the mid 1980s (Figure 18), with the exception of the 1998 El Niño/Southern Oscillation (ENSO).

DISCUSSION

Up-scaling

There are regional differences within the CCLME in climate forcing and ecosystem response (Figures 5 and 19). Therefore, an assessment of the southern California Current region (eco-region 3) may vary from that for the northern California Current (eco-region 1). When considering an overall IEA for the CCLME, it may prove most useful to evaluate each eco-region/”sub-ecosystem” separately. But, in no single region are all the physical, chemical, and especially biological attributes available for comprehensive analyses. Therefore, to understand ecosystem form, function, and control, we must combine information between regions.

A simple mechanistic example for co-variation

The northern CCLME is dominated by strong seasonal variability in winds, temperature, upwelling, and plankton production. In addition to weak, delayed or otherwise ineffectual upwelling, warm-water conditions in this region could result from either onshore transport of offshore subtropical water or northward transport of subtropical coastal waters (Figure 8). Low copepod species richness and high abundance of northern-boreal copepods (Figure 6) is apparently associated with cold, sub-arctic water masses transported to the northern CCLME from the Gulf of Alaska. Therefore, copepod community composition may be used as an indicator of this physical oceanographic process.

Preliminary evidence suggests co-variation between eco-regions. When fatty, sub-arctic northern-boreal copepods are present in the northern CCLME during cool-water conditions, the productivity of the planktivorous Cassin’s Auklet, in the central sub-region, increases (Figure 19a). Conversely, when the less fatty subtropical copepods dominate the system in warm-water years (i.e., a higher southern copepod Index), Cassin’s Auklet breeding success is reduced (Figure 19b).

Area-based management?

As noted previously, there are regional differences in oceanography and biology. Moreover, within each region, there are differences in habitats that may be related to bathymetry and geology (Figure 20). Understanding the relationships between topography, oceanography, and species distributions will promote better management of CCLME resources spatially, as well as temporally. The relationships between bottom topography and ecosystem productivity are not well known, but so-called “benthic-pelagic” coupling is likely to be important for top predators. Identification and assessment of locations of high trophic interaction may be key to future management and conservation decisions in the CCLME.

Effects of global warming?

Ocean temperatures have increased, and are likely to continue to increase for the foreseeable future. Land is expected to heat faster than the ocean and these contrasts in temperatures may result in higher wind speeds (Bakun 1990, Snyder et al. 2003). Warmer waters are also increasing stratification (Roemmich and McGowan 1995, McGowan et al. 2003). The effects of stronger winds and increased stratification on upwelling, temperature and primary productivity in the CCLME are not well known (but see Schwing and Mendelssohn 1997, Mendelssohn and Schwing 2002), but clearly will have ecosystem consequences.

The timing of the seasonal cycle of productivity is changing (GRL 2006). Just as terrestrial biological systems are experiencing earlier phenology (IPCC 2007), we may observe an earlier (or later) start to the upwelling season in the CCLME, and this may vary by eco-region. If upwelling occurs earlier, we may observe an earlier seasonal cycle, from earlier phytoplankton blooms, to earlier peaks in zookplankton abundance. In contrast, as noted previously, if the efficacy of upwelling is weakened and/or delayed by increased water stratification, the seasonal cycle of different organisms may be offset, leading to mismatches between trophic levels in the abundance or availability of prey.

With these contrasting scenarios in mind, the potential for increased variability in the CCLME is probable. A more volatile climate with more extreme events will impact biological systems of the CCLME. Notably, by 2030, the minimum value of the PDO is expected to remain above the mean value for the 20th century. In addition, evidence of variability and declines in biological systems in the CCLME since ~1990 has already been shown. Such changes and others (e.g., range shifts in species' distributions) are likely to continue.

Data gaps and some future directions

We have many gaps in the long-term datasets that need to be identified and filled. For example, there has been extensive work in Monterey Bay, California on changes in phytoplankton community structure (e.g., a ratio of diatoms to dinoflagellates), and new work is commencing in Oregon (B. Peterson, personal communication). The ratio of diatoms to dinoflagellates appears to be an important index for food web development. Having this type of information available for other locations in the CCLME would be extremely valuable.

The species and parameters we have chosen are representative of different trophic levels, and known to be linked by trophic relationships, and have been considered in other ecosystem reports (Peterson et al. 2006, Goericke et al. 2007). No doubt, there will be other variables to consider, but this suite of parameters will be critical to any IEA developments for this system.

Importantly**,** we have not addressed the human dimension (fishing, development, pollution, etc.) on ecosystem dynamics. As intended, this report has focused on long-term observations (Table 1) and some key biological indicators. We have not considered socio-economic data and other human-related data, though this has been put forth as key to the IEA concept overall (Fluharty et al. 2006). Incorporating this information could advance an IEA for the CCLME.

One of the goals of IEA is to forecast future conditions for the ecosystem under consideration. This is difficult, but it is essential to consider how to best develop forecasting capabilities. Part of the solution may be to integrate, statistically, what is known and previously summarized. Integration of these indicators is therefore a primary goal of future IEA developments, which should also include modeling components. Coupling complementary field observations with spatially explicit ecosystem modeling, while beyond the scope of this document, is clearly needed to answer key ecological and management questions as well as to evaluate the efficacy of various CCLME monitoring programs.

Table 1. Summary of select long-term (10 years or longer) research projects of the CCLME.

Project name and coordinators	Region	Years covered	Description
Line P, Department of Fisheries and Oceans Canada (DFO) & others	1	1949 – present	Oceanographic sampling began on ships used for enhanced weather forecasting off British Columbia, Canada. Since then, vessels from the DFO have followed the same ~1,500 km cruise track from Vancouver Island (48.51°N, 124.81°W) to Ocean Station Papa (50.0°N, 145.0°W) 2-3 times each year (Figure 7a). Hydrography, nutrients and lower trophic level productivity is measured. Seabirds and marine mammals are also surveyed.
Rockfish Recruitment Survey, NOAA-NMFS-SWFSC & others	2	1983 – present	NOAA-NMFS and other collaborators have conducted annual surveys in the greater Gulf of the Farallones (Monterey Bay to Bodega Bay) region off central California (Figure 7b). Hydrography and estimates of recruitment for young-of-the-year (age-0) *Sebastes* are priories for this survey. Seabirds and marine mammals are also surveyed.
CalCOFI, NOAA-NMFS, California Department of Fish and Game, Scripps Institution of Oceanography & others	3	1949 – present	The California Cooperative Oceanic Fisheries Investigations (CalCOFI) has been monitoring ecosystem dynamics since 1949. In its current form, the CalCOFI survey grid consists of six parallel transects, ranging in length from 470 (northernmost) to 700 (southernmost) km (Figure 7c). This study area encompasses over 300,000 km^2 of the Pacific Ocean, ranging from 30° to 35° N, and seaward from the southern California coast to 124° W. Hydrography and icthyoplankton surveys are priorities for this program. Seabirds and marine mammals are also surveyed.
Southeast Farallon Island Seabird Ecology, U.S. Fish and Wildlife Service & PRBO	2	1971 – present	The Farallon Islands National Wildlife Refuge, managed by United States Fish and Wildlife Service (USFWS), host the largest marine bird and mammal colonies in the contiguous United States. Under contract with USFWS, PRBO Conservation Science monitors and studies the ecology of 12 seabird species and 5 pinniped species at this site. Daily measurements of SST, salinity, and weather are also made.
Channel Islands Seabird Ecology, Channel Islands National Park, California Center Environmental Studies	3	1968 - present	The California Center for Environmental Studies initiated research on Brown Pelicans (*Pelicanus occidentalis*) in the Channel Islands in the late 1960s. In 1985, the Channel Islands National Park initiated long-term studies of a variety of seabirds at Santa Barbara, Anacapa, and Prince (San Miguel) islands. This time series (not illustrated in this report) shows substantial interannual variability in seabird productivity and trends related to both the recovery of seabirds from DDT contamination of the marine environment and climate variability and change.
Vancouver Island Zooplankton, Department of Fisheries and Oceans, Canada	1	1979 - present	Since 1979, Fisheries and Oceans Canada has measured zooplankton and hydrographic conditions on the Vancouver Island continental margin. The zooplankton time series (not illustrated in this report) shows very strong interannual variability in community composition. Large copepods have shown strong shifts of the seasonal life history timing, becoming progressively earlier from the late 1970s to the present, with variation.
Newport Hydrographic Line, NOAA-NMFS-NWFSC	1	1996 – present (1969-1973)	Biweekly surveys of this line are conducted off Newport, Oregon. Priorities for this survey include hydrography and zooplankton (copepods and euphausiids). This time series augments similar data collected along the same transect in 1969-1973. Seabird observations have recently been added to this program.
Oregon and Washington	1	1998 - present	Hydrography, nutrients, chlorophyll-a, zooplankton and pelagic forage fish are sampled at six stations along each of eight

Forage Fish, NOAA-NMFS			transects ranging from Newport, Oregon to the Washington-Canadian border.
Winds to Whales – Monterey Bay, UC Santa Cruz	2	1996 - present	This interdisciplinary project organized by the Center for Integrated Marine Technologies (UCSC-CIMT) collects data on physical (winds, currents, SST), chemical (nutrients, trace metals, etc.) and biological (phytoplankton, zooplankton, marine mammals, etc.) processes in nearshore Monterey Bay.
Monterey Bay Time Series, Monterey Bay Aquarium Research Institute	2	1989 - present	Monthly shipboard surveys conducted to collect data on physical, chemical and biological properties in Monterey Bay. In1997, the surveys were conducted quarterly and became known as the Studies of Ecological and Chemical Responses to Environmental Trends (SECRET) project.
Tatoosh Island Seabird Ecology, University of Washington	1	1990 – present	Studies of the breeding success and diet of seabirds that inhabit Tatoosh Island, WA, focused on Common Murre (*Uria aalge*), began in 1990.
Triangle Island Seabird Ecology, Canadian Wildlife Service and Simon Fraser University	1	1994 - present	Studies of the breeding success and diet of the seabirds that inhabit Triangle Island. Focus on Rhinoceros Auklet (*Cerorhinca monocerata)* and Cassin's Auklet (*Ptychoramphus aleuticus*). Studies complement previous work conducted by CWS at this site in the late 1970s.
Groundfish Surveys, NOAA-NMFS-NWFSC & Fisheries and Oceans Canada	1	1977 - present	Triennial midwater/acoustic surveys of groundfish, with an emphasis on Pacific hake, are conducted from central British Columbia (Dixon Entrance) to central California (Monterey Bay). Measurements of hydrographic conditions and abundance of fish are priority measurements.

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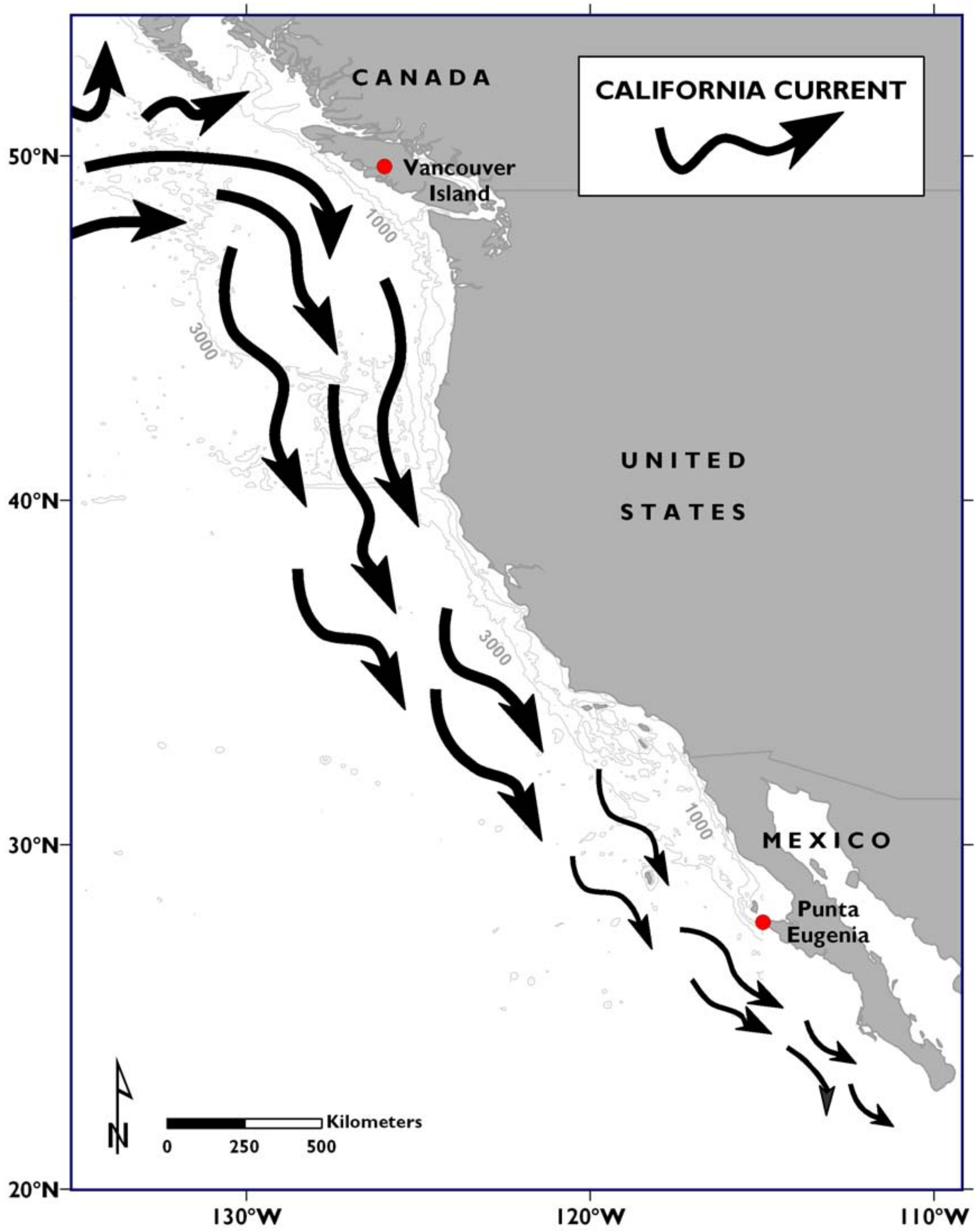


Figure 1. Conceptual map of the California Current Large Marine Ecosystem (CCLME). The geographic scope of this IEA is from Vancouver Island, Canada to Punta Eugenia, Mexico and offshore. Mangroves are found south of Punta Eugenia, but not to the north. The North Pacific Current (West Wind Drift) splits into the California Current and Alaska Current roughly at Vancouver Island.

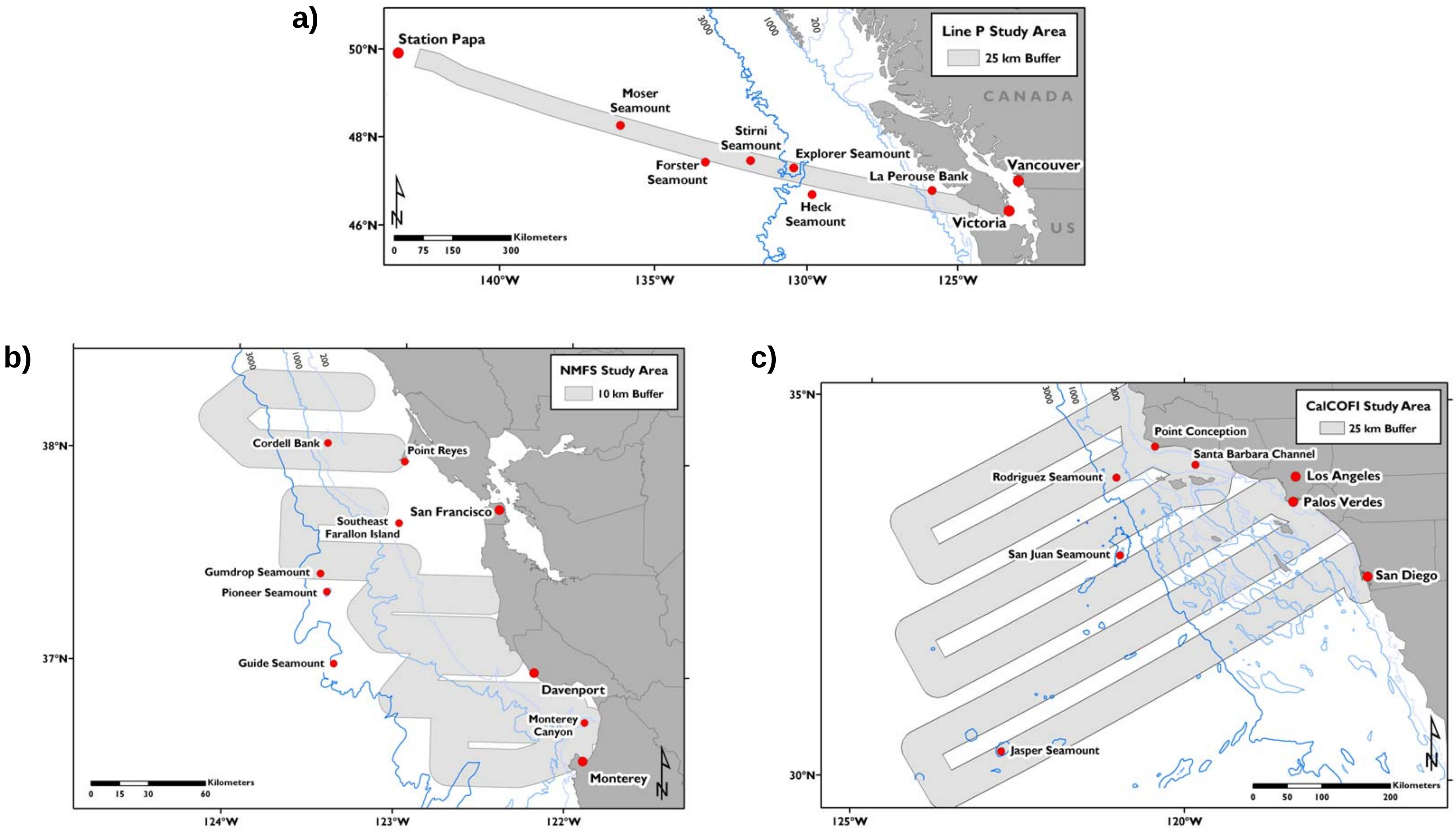


Figure 2. Examples of three (3) long-term oceanographic research programs within the CCLME. Each of these programs has been in operation for over continuous 20 years: (a) the Department of Fisheries and Oceans, Canada, “Line P” project; (b) the National Marine Fisheries Service “Rockfish Recruitment Survey”; and, (c) the “California Cooperative Oceanic Fisheries Investigation” run by a consortium of National Marine Fisheries Service, California Department of Fish and Game, and Scripps Institution of Oceanography. Some shallow-water topographies (offshore seamounts) are illustrated.

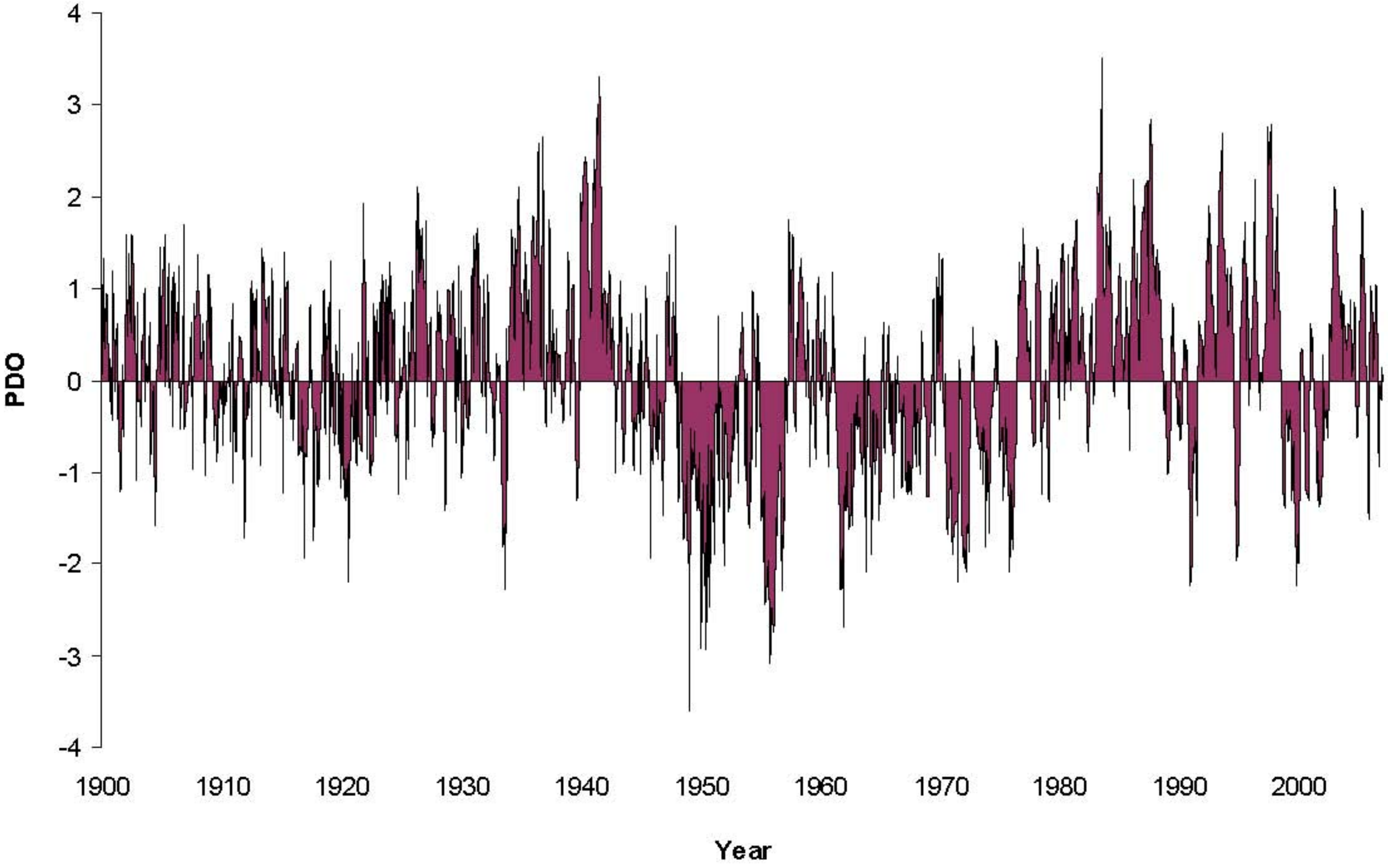


Figure 3. The Pacific Decadal Oscillation (PDO) index (1900-2006). Data courtesy Nate Mantua (Joint Institute for the Study of the Atmosphere and Ocean, UW). Positive values indicate warm eastern North Pacific SST, whereas negative values indicate cool temperatures. The long-term ocean warming signal has been removed to illustrate interannual and interdecadal SST variation. http://jisao.washington.edu/pdo/PDO.latest

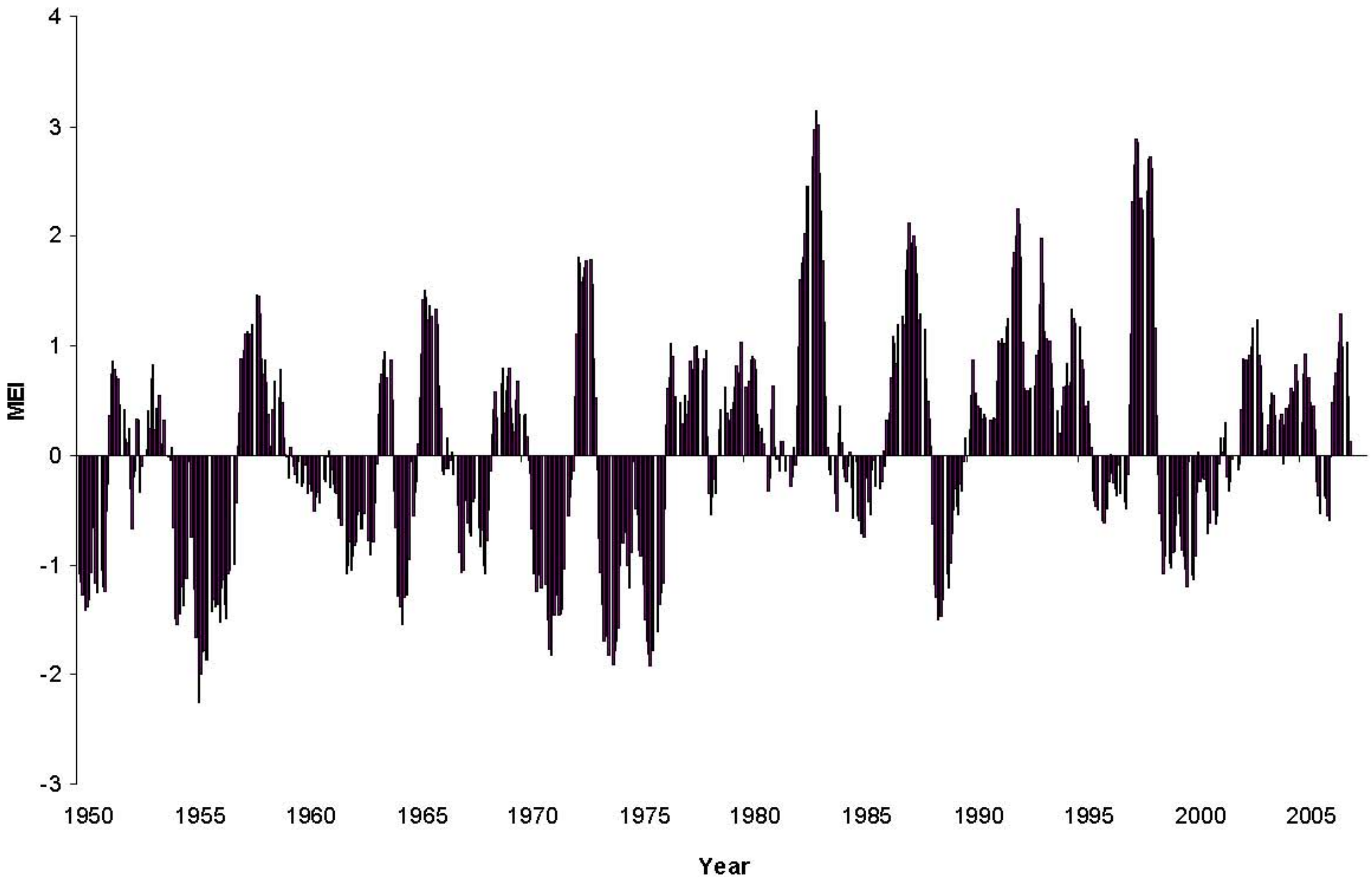


Figure 4. The Multivariate El Niño Index (MEI), 1950-2006. Data courtesy Klaus Wolter (NOAA-Earth System Research Laboratory). Positive values reflect El Niño events whereas negative values indicate La Niña. The MEI is a composite index constructed using 7 environmental variables. http://www.cdc.noaa.gov/people/klaus.wolter/MEI/table.html.

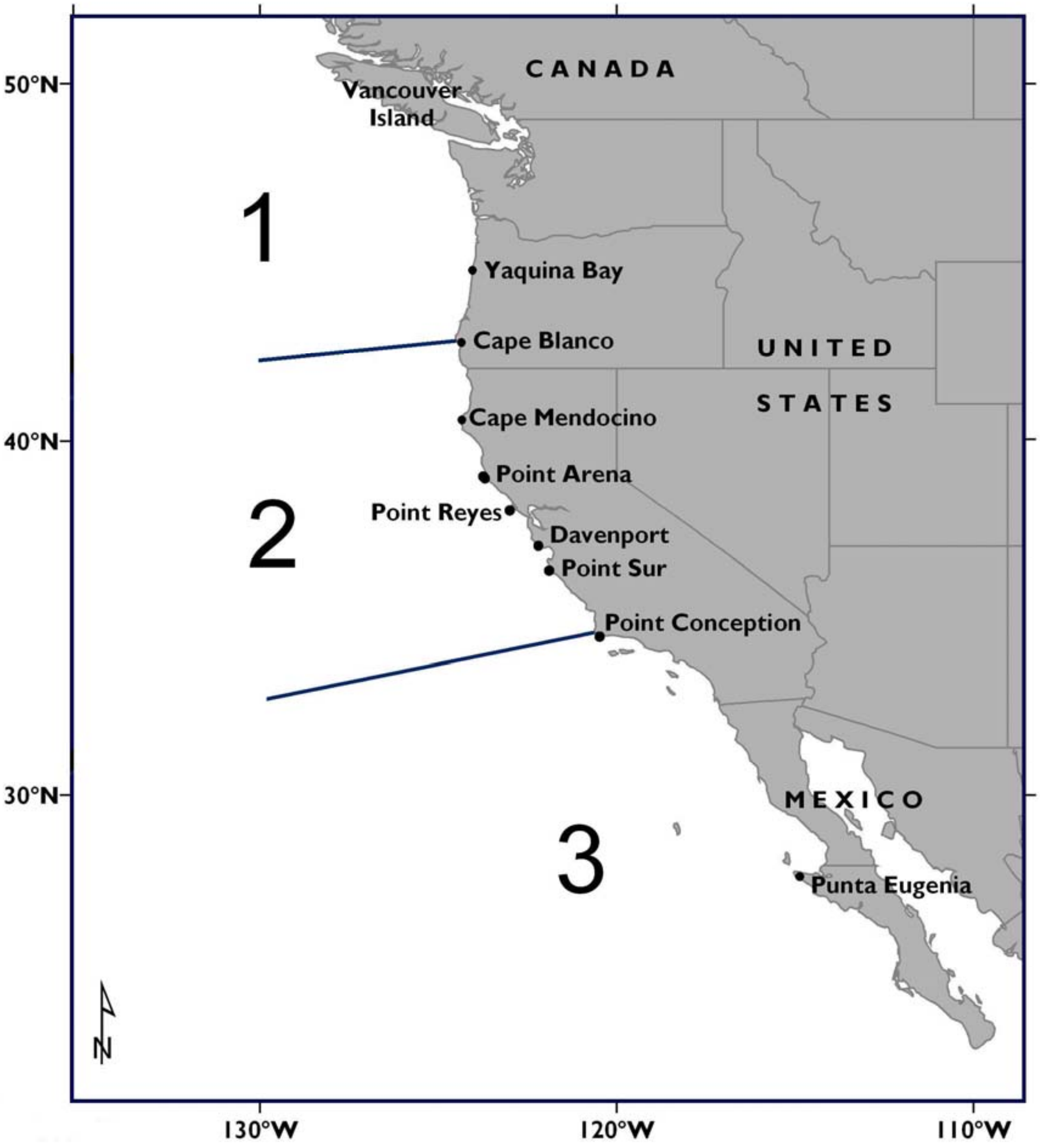


Figure 5. Eco-regions of the CCLME as defined by U.S. GLOBEC (1992). Physical oceanography and biological attributes of the ecosystem vary by region. The degree to which each "sub-ecosystem" co-varies with climate variability and change will be developed in future IEA reports.

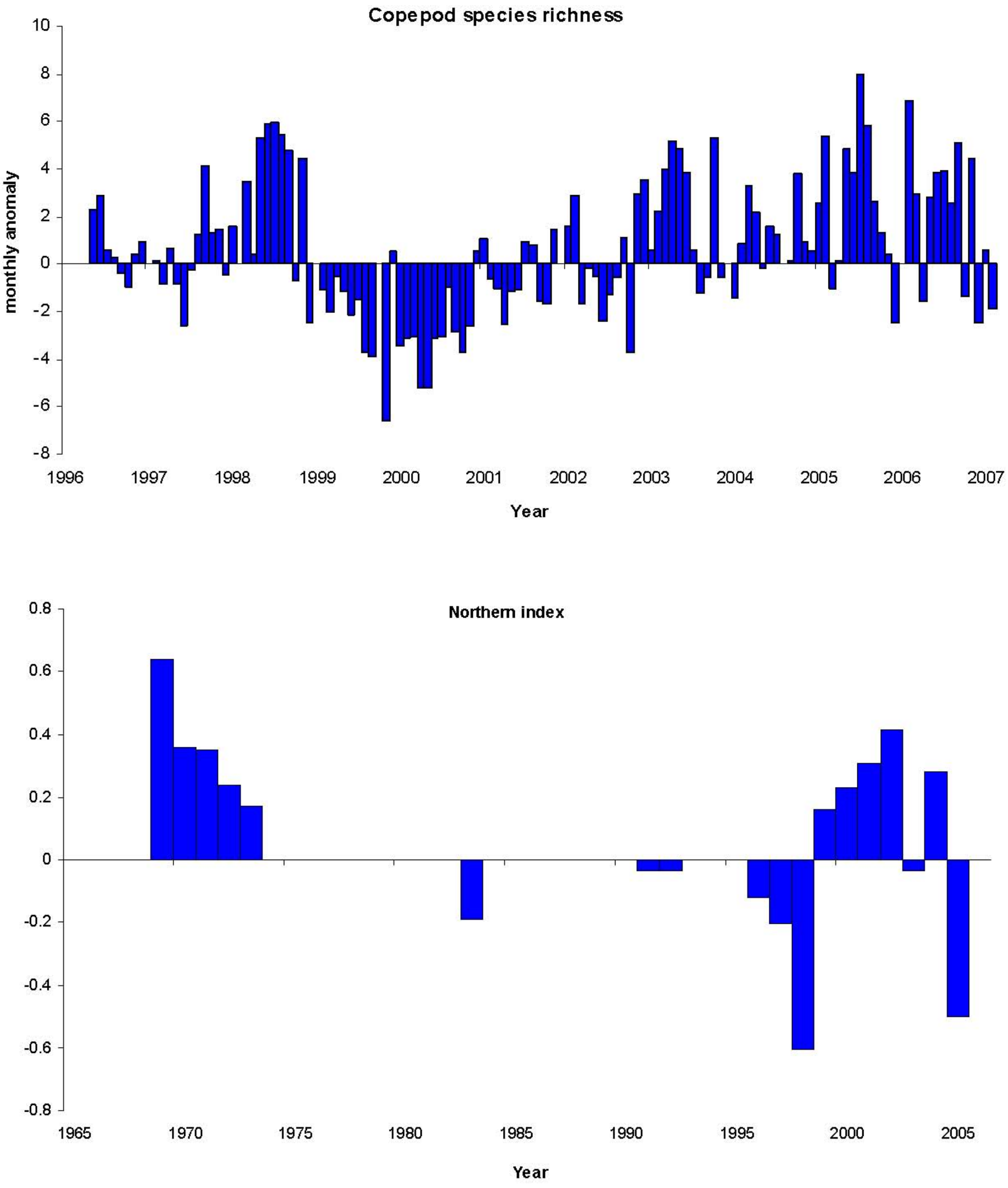


Figure 6. Copepod species richness index (1996-2006), and the "boreal" copepod index (1965-2005) from Newport, Oregon. Note that the time scales differ between the two plots. Data courtesy Bill Peterson (NOAA Fisheries, NWFSC).

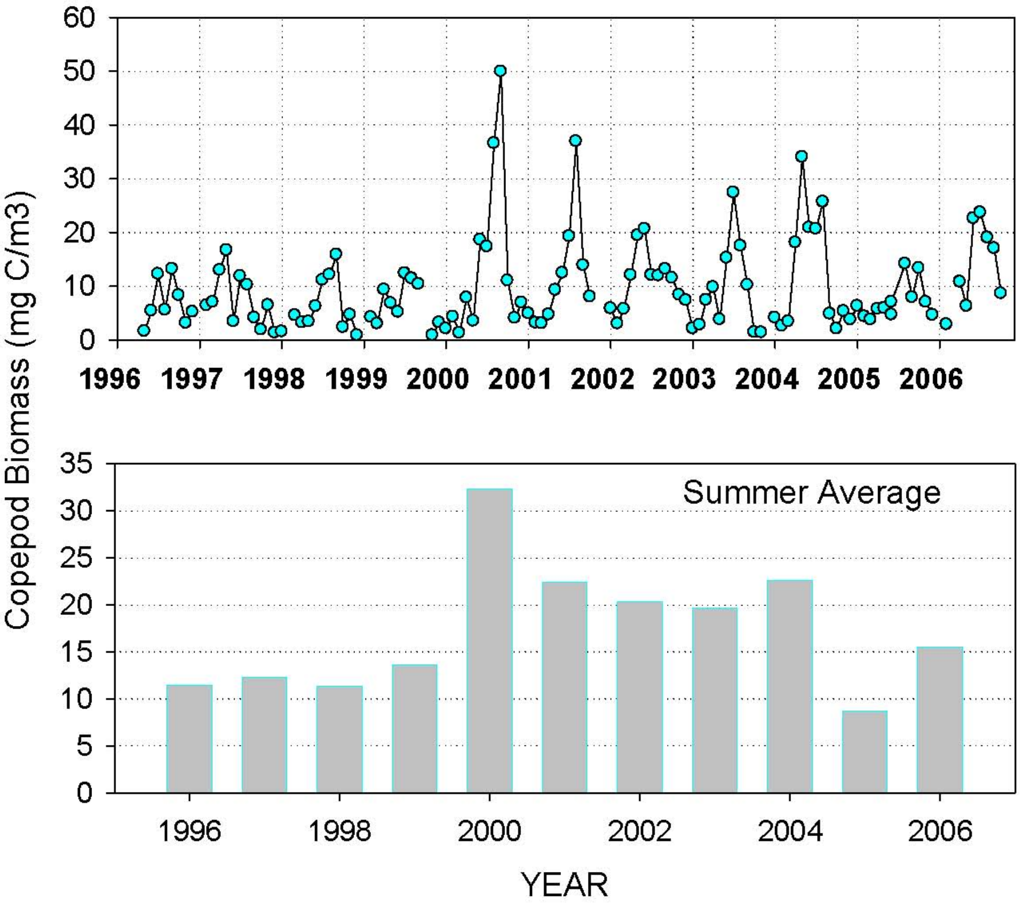
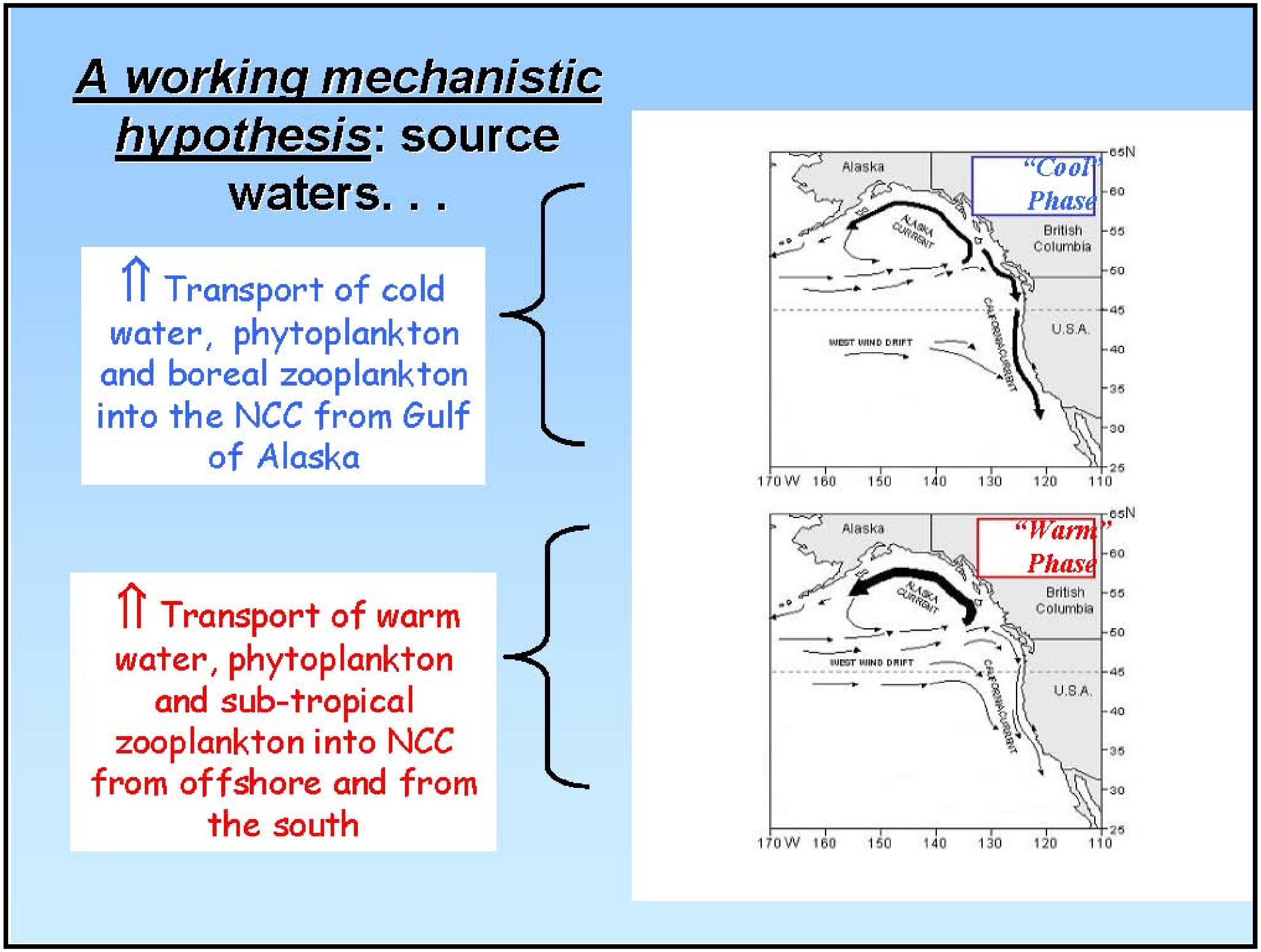


Figure 7. Copepod biomass index from Newport, Oregon (1996-2006). Monthly copepod biomass values (top panel) and average summer biomass values (bottom panel). Data courtesy Bill Peterson (NOAA Fisheries, NWFSC).



A working mechanistic hypothesis: source waters. . .

⇑ Transport of cold water, phytoplankton and boreal zooplankton into the NCC from Gulf of Alaska

⇑ Transport of warm water, phytoplankton and sub-tropical zooplankton into NCC from offshore and from the south

Figure 8. Hypothesized mechanism for variation in copepod indices off Newport, Oregon. Figure courtesy Bill Peterson (NOAA Fisheries, NWFSC). Transport of organisms from the north and south is proposed to explain these indices.

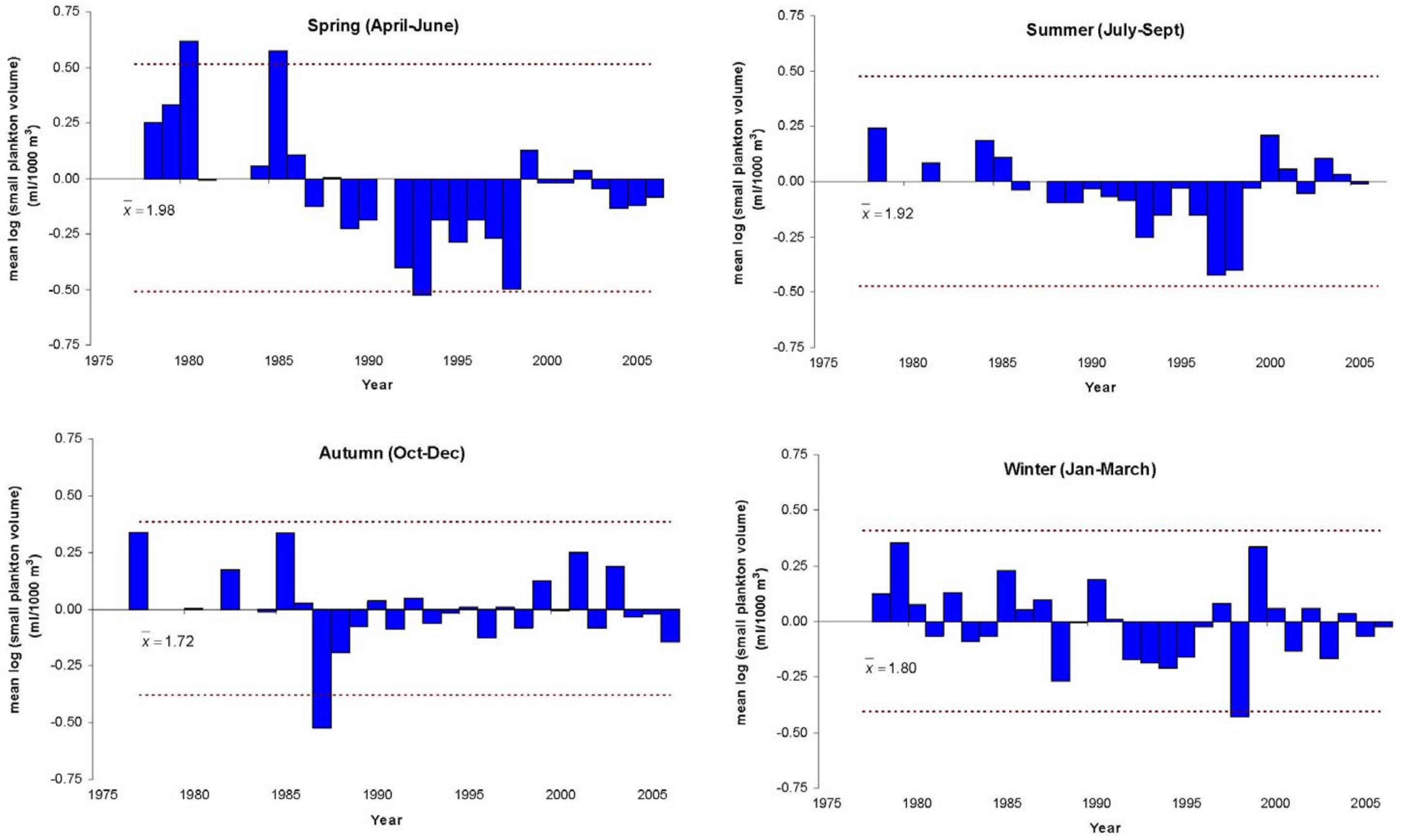


Figure 9. The southern California small plankton volume (SPV) index from CalCOFI (1977 - 2006). SPV includes all plankton with a displacement volume of < 5mL, representing copepods and euphausiids. Anomalies show the deviation of each annual seasonal value from the long-term seasonal mean. Dotted lines represent 1 standard deviation above/below the long-term seasonal mean. Data courtesy Rich Charter (NOAA-Fisheries Resources, SWFSC).

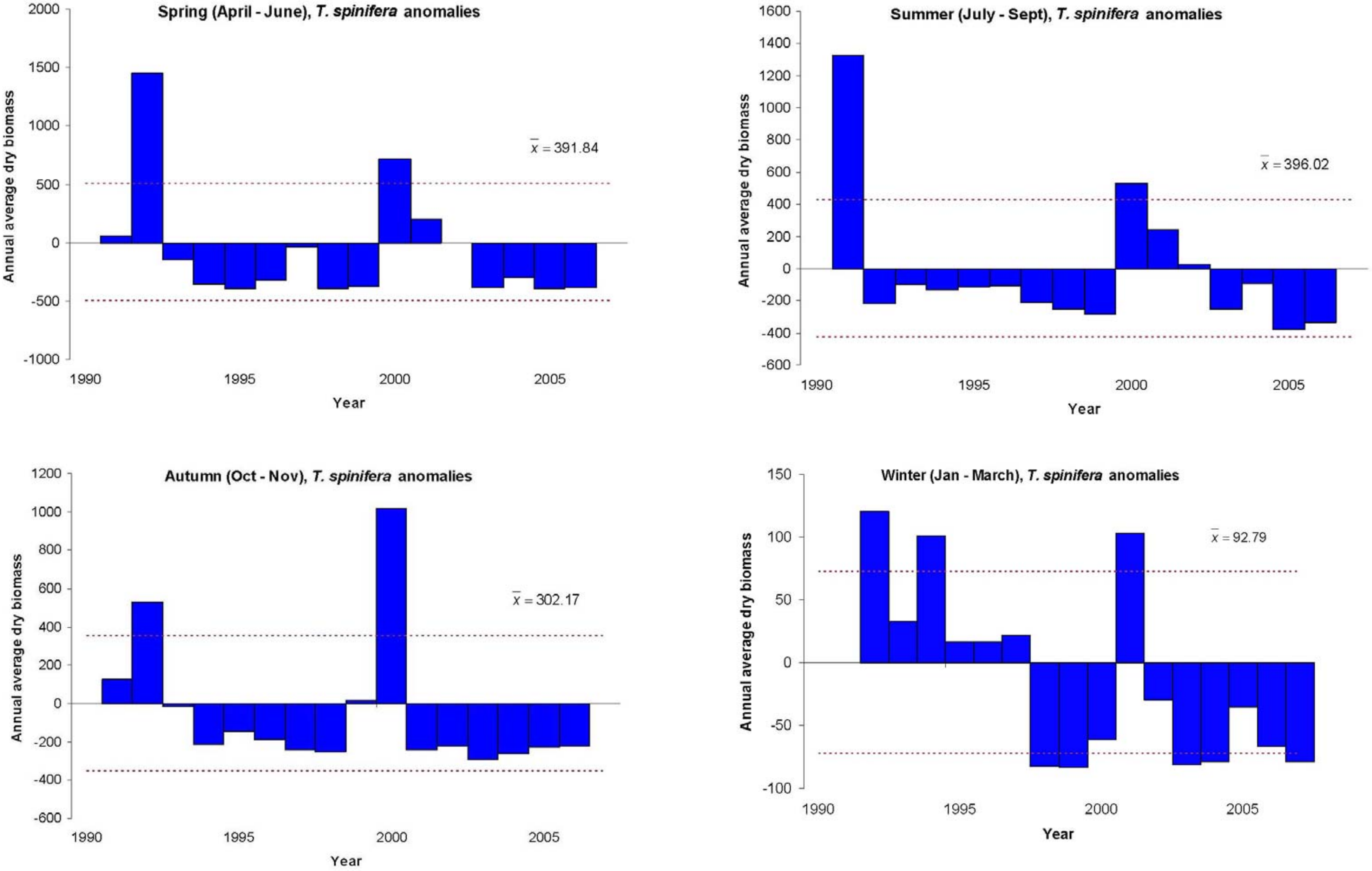


Figure 10. Vancouver Island, Canada, the euphausiid *Thysanoessa spinifera* index based on standardized net samples. Data courtesy Ron Tanasichuk (Department Fisheries and Oceans, Canada).

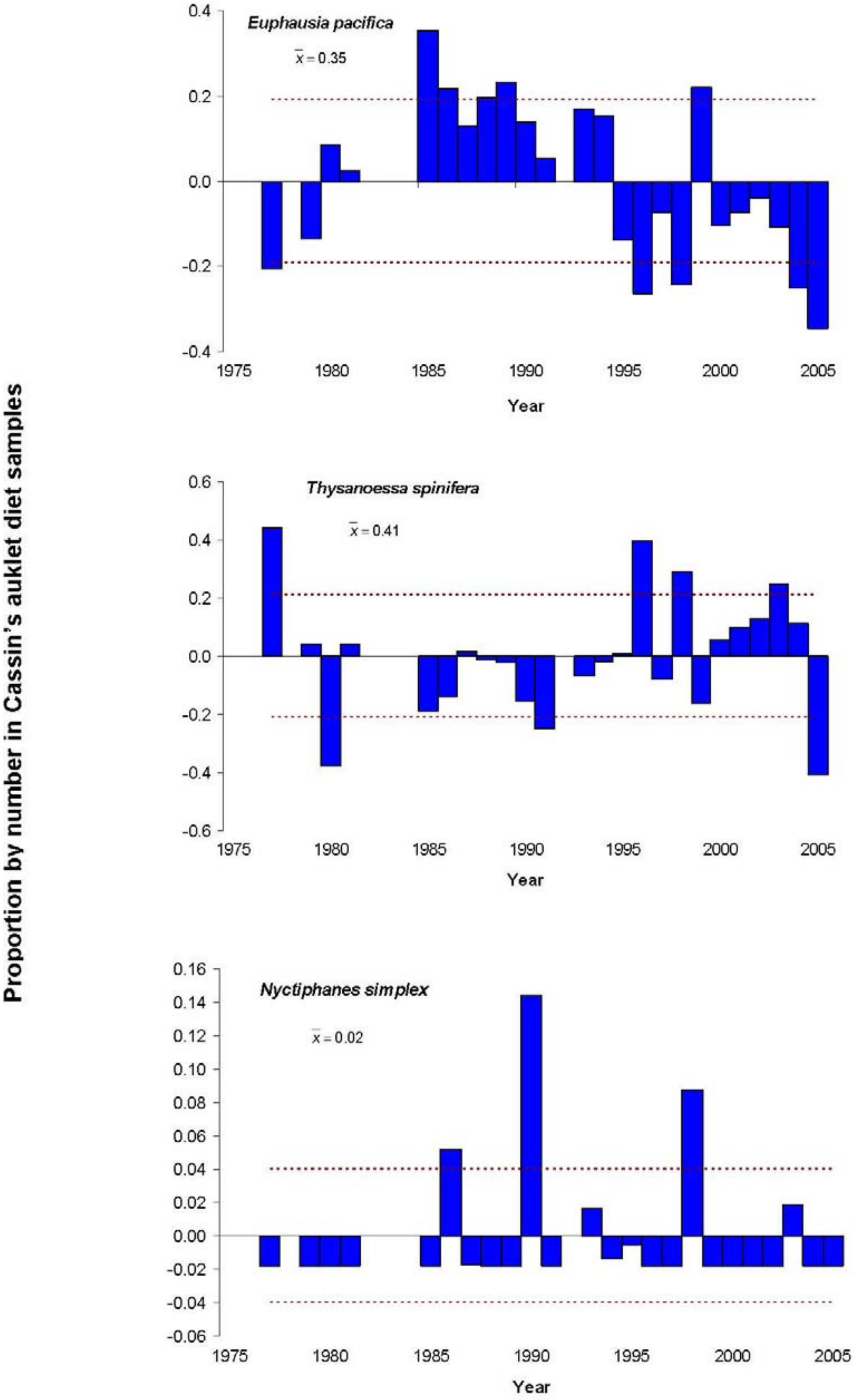


Figure 11. Indices for three euphausiid species (*Euphausia pacifica*, *Thysanoessa spinifera* and *Nyctiphanes simplex)* based on seabird predator (Cassin's Auklet, *Ptychoramphus aleuticus*) diet samples on Southeast Farallon Island, California (1977-2005). Data courtesy Christine Abraham (PRBO Conservation Science).

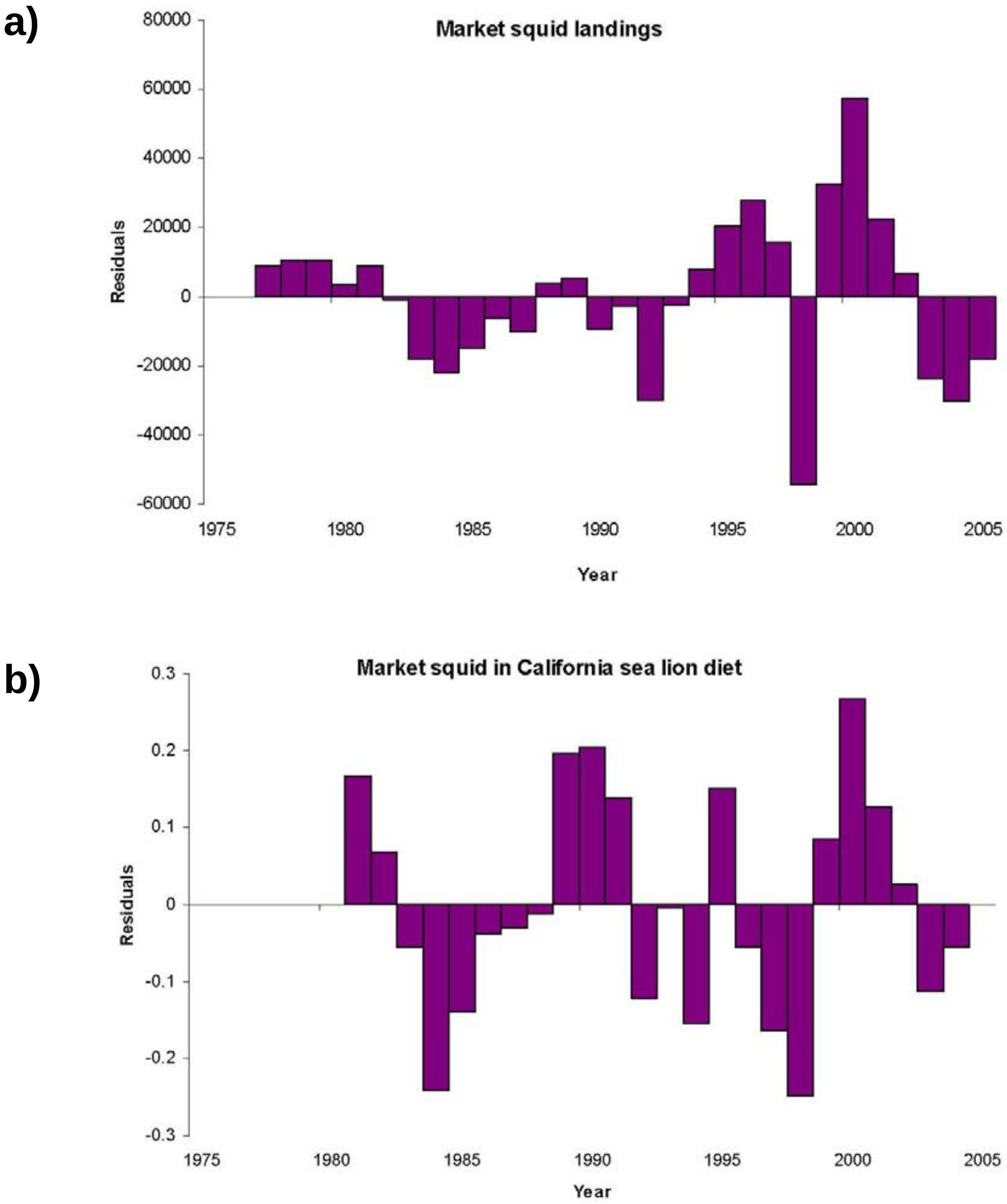
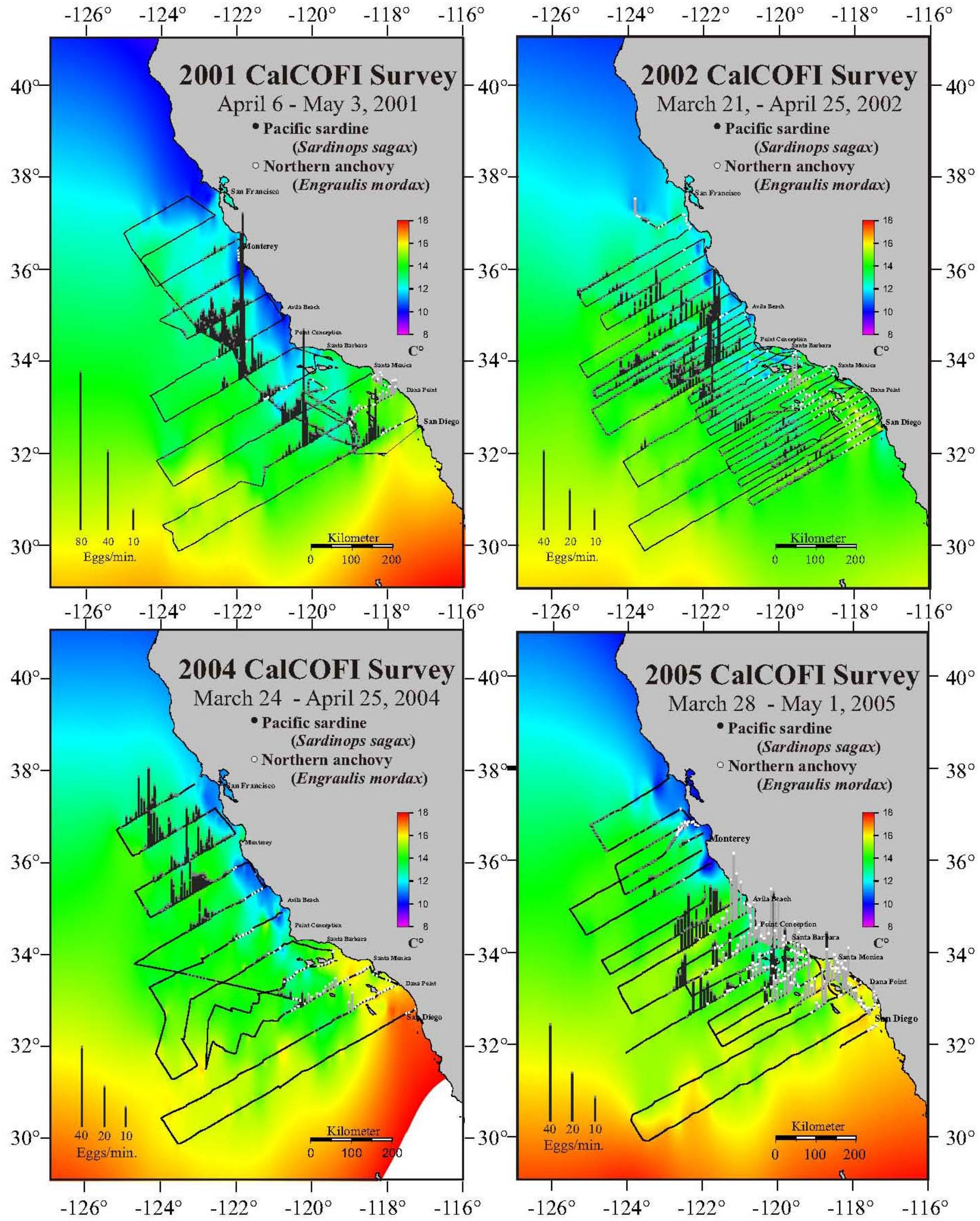
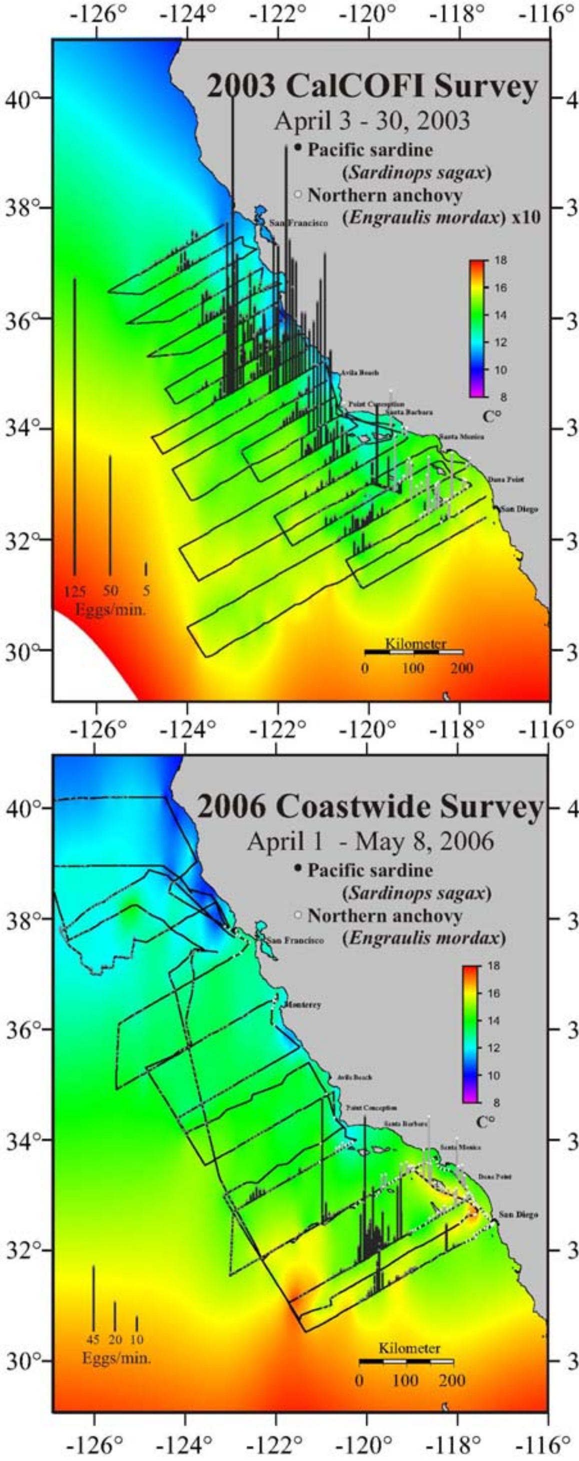
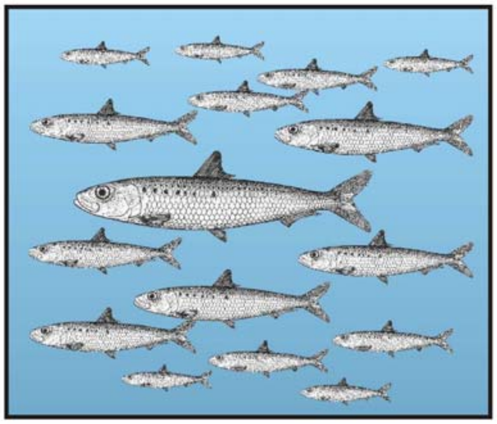


Figure 12. Market squid (*Loligo opalescens)* indices from catch data, and the diet of a marine mammal (California sea lion) Note: the trend of increasing catch due to increasing fishing effort has been removed by quadratic regression. Bars represent residuals after detrending. Catch data courtesy Dale Sweetnam (CDFG). Marine mammal data courtesy Mark Lowry (NOAA-NMFS, SWFSC).

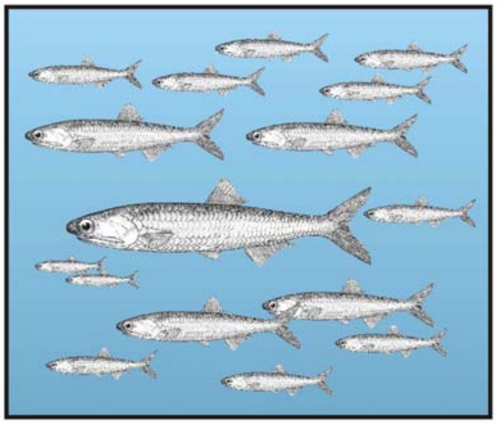

2001 CalCOFI Survey
April 6 - May 3, 2001
• Pacific sardine
(Sardinops sagax)
○ Northern anchovy
(Engraulis mordax)
San Francisco
Monterey
Avila Beach
Point Conception
Santa Barbara
Santa Monica
Dana Point
San Diego
18
16
14
12
10
8
C°
80
40
10
Eggs/min.
Kilometer
0
100
200
2002 CalCOFI Survey
March 21, - April 25, 2002
• Pacific sardine
(Sardinops sagax)
○ Northern anchovy
(Engraulis mordax)
40
20
10
Eggs/min.
2004 CalCOFI Survey
March 24 - April 25, 2004
• Pacific sardine
(Sardinops sagax)
○ Northern anchovy
(Engraulis mordax)
40
20
10
Eggs/min.
2005 CalCOFI Survey
March 28 - May 1, 2005
• Pacific sardine
(Sardinops sagax)
○ Northern anchovy
(Engraulis mordax)
40
20
10
Eggs/min.
-126°
-124°
-122°
-120°
-118°
-116°
40°
38°
36°
34°
32°
30°



Pacific Sardine and Northern anchovy egg counts collected by CUFES (Continuous underway fish egg sampler) for the CalCOFI (California Cooperative Oceanic Fisheries Investigations) Spring quarter surveys.



Pacific sardine
(Sardinops sagax)



Northern Anchovy
(Engraulis mordax)

Figure 13. Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*) egg counts from Southern California CalCOFI cruises (2001-2006). Figure courtesy Dave Griffith, Rich Charter, and Roy Allen (NOAA-NMFS, SWFSC). Note shifting distributions and abundances.

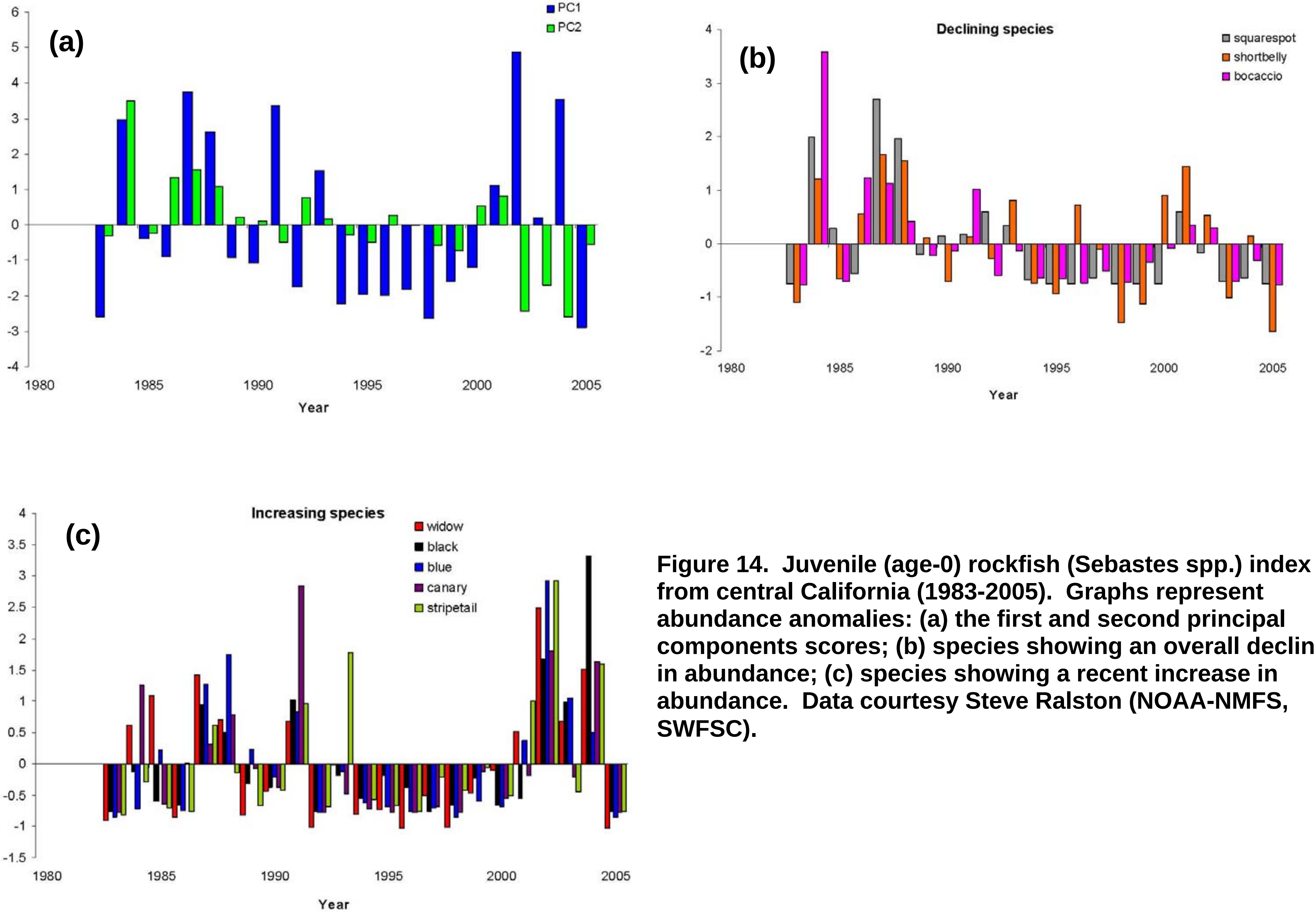


Figure 14. Juvenile (age-0) rockfish (Sebastes spp.) index from central California (1983-2005). Graphs represent abundance anomalies: (a) the first and second principal components scores; (b) species showing an overall decline in abundance; (c) species showing a recent increase in abundance. Data courtesy Steve Ralston (NOAA-NMFS, SWFSC).

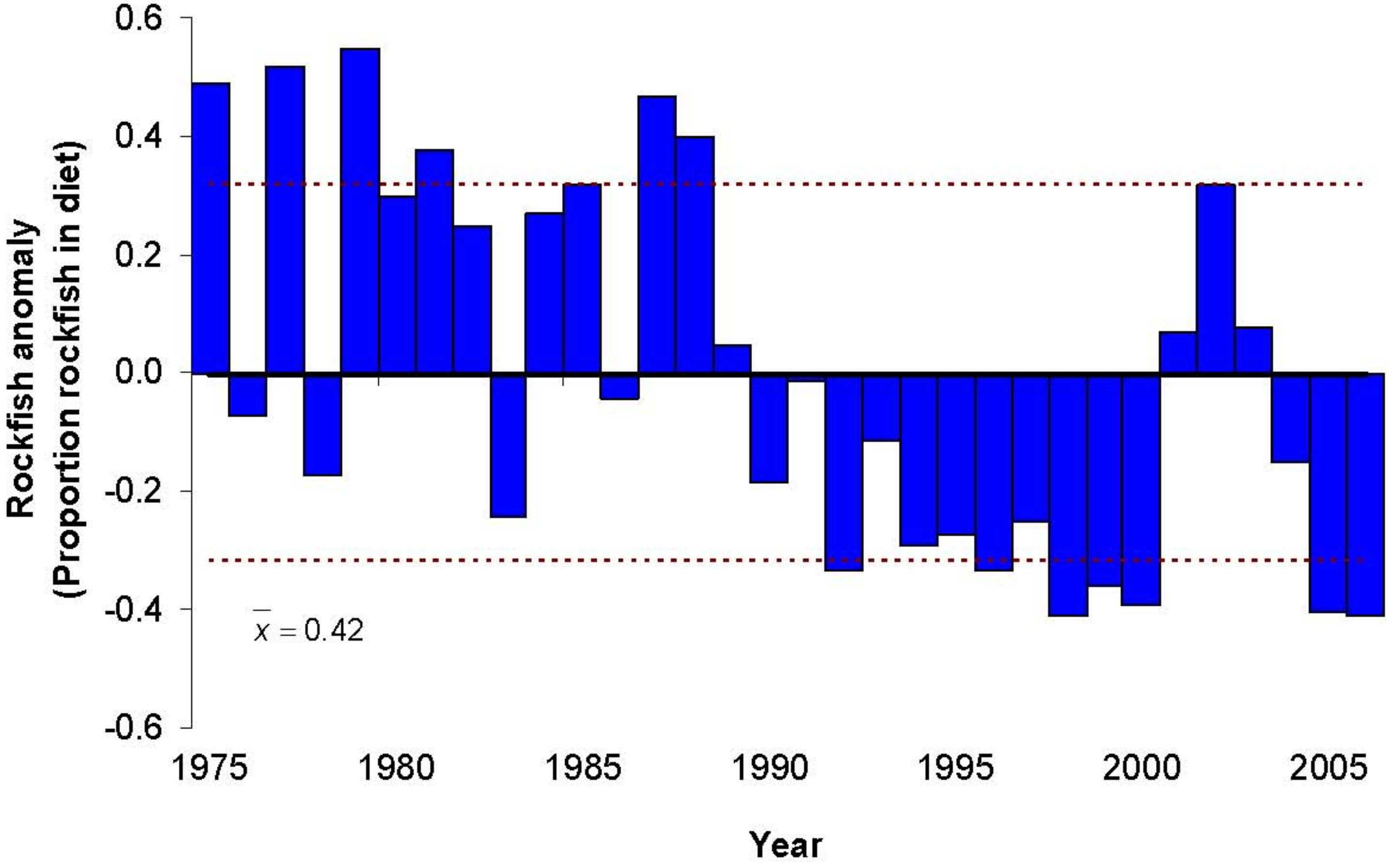


Figure 15. Juvenile (age O) rockfish (*Sebastes* spp.) index based on the diet of a seabird (Common Murre, *Uria aalge*), in central-northern California (1975 – 2006). Data courtesy Pete Warzybok (PRBO Conservation Science).

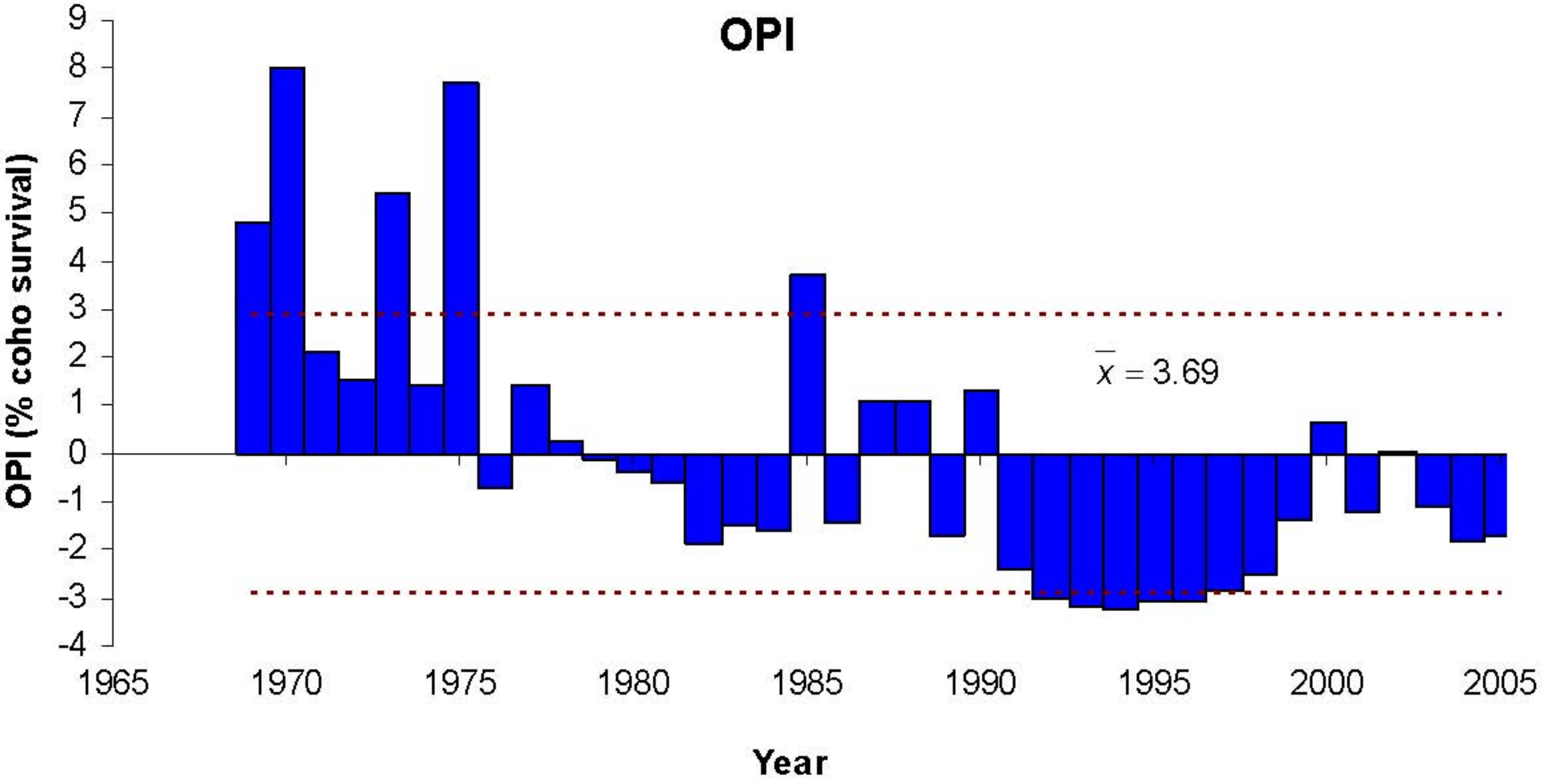


Figure 16. Coho salmon survival at sea as represented by the OPI (Ocean Production Index) anomalies, 1969-2006. Year shown is survival of coho salmon plotted against the year that the fish went to sea (1.5 y before spawning in their natal hatcheries). The 0-line on the y-axis represents the long-term mean (value also shown in graph), and anomalies represent the deviation of each annual value from the long-term mean. Hatched lines represent 1 ± standard deviation from the long-term mean. Data courtesy Bill Peterson (NOAA Fisheries, NWFSC).

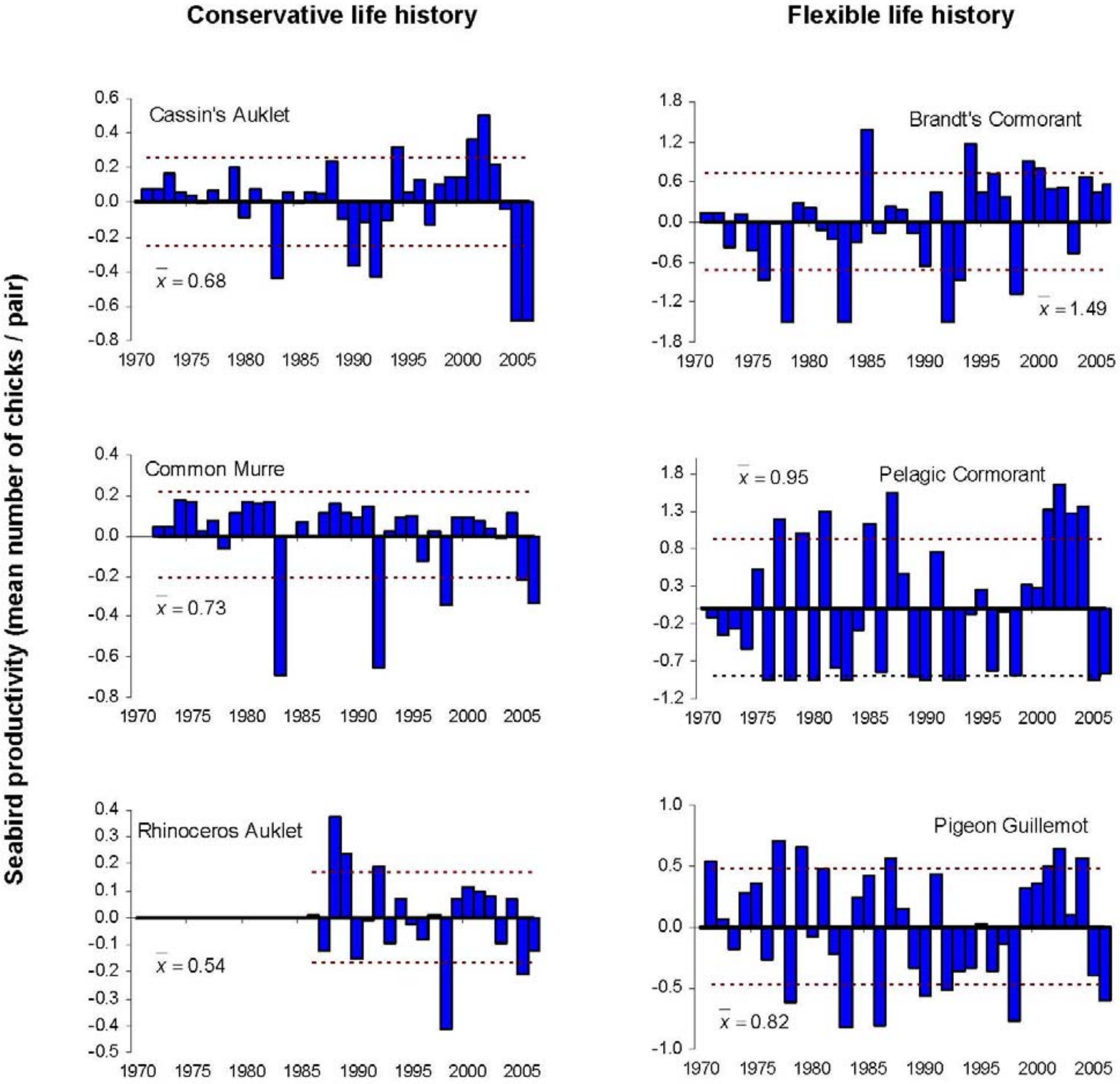


Figure 17. The Farallon seabird productivity index, 1971 - 2006. Data courtesy U.S. Fish and Wildlife Service and PRBO Conservation Science. The annual reproductive success anomalies for 6 species showing varying life history strategies are shown. Auklets and murres lay a single egg per breeding attempt and have great longevity, whereas the cormorants and guillemot lays multi-egg clutches and less longevity. Only the Brandt's Cormorant shows an increase in productivity through time. Data courtesy Russ Bradley, Pete Warzybok, and Bill Sydeman (PRBO).

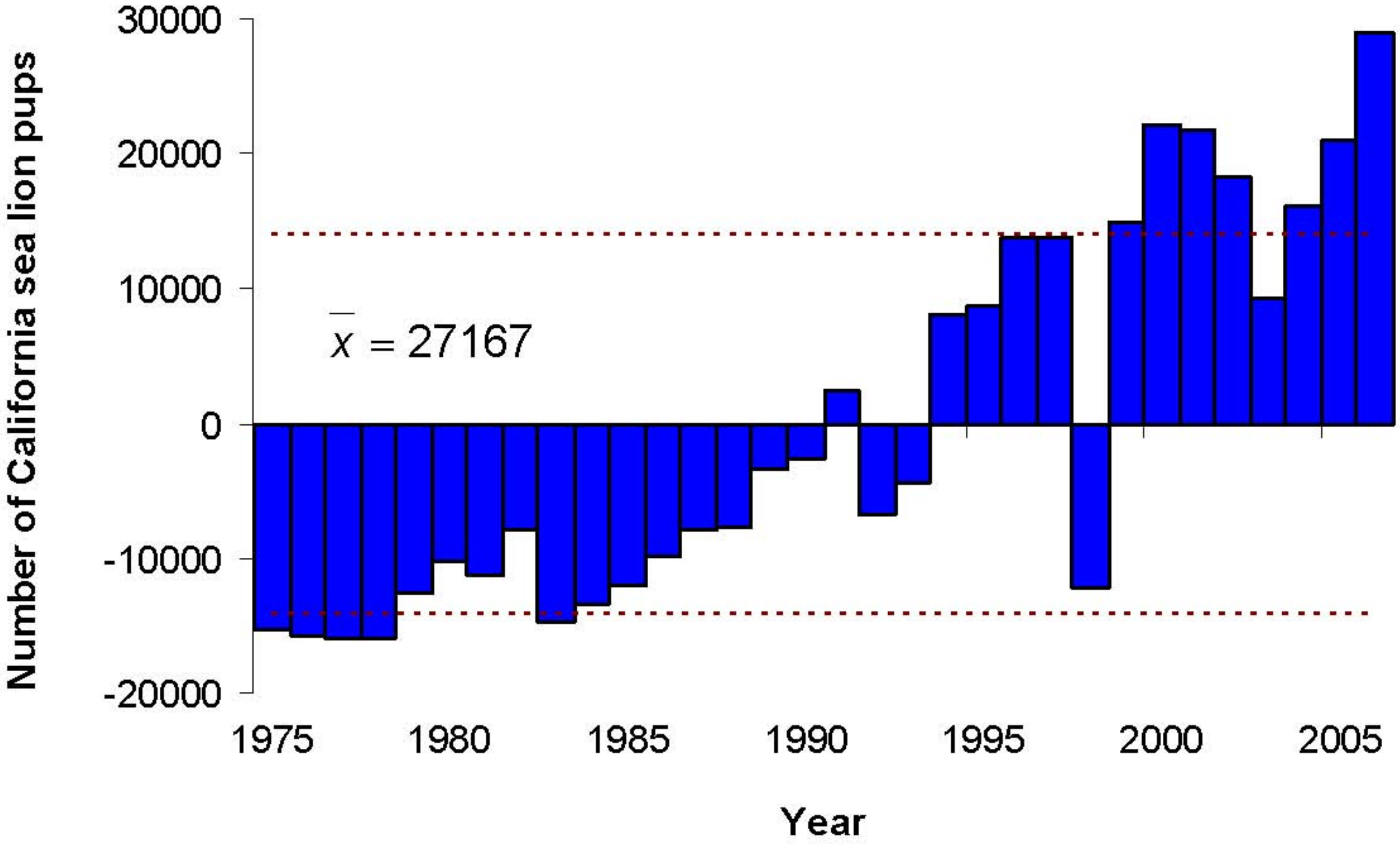


Figure 18. California sea lion production index (number pups) from Southern California (1975 – 2006). Data courtesy of Mark Lowry (NOAA-NMFS, SWFSC).

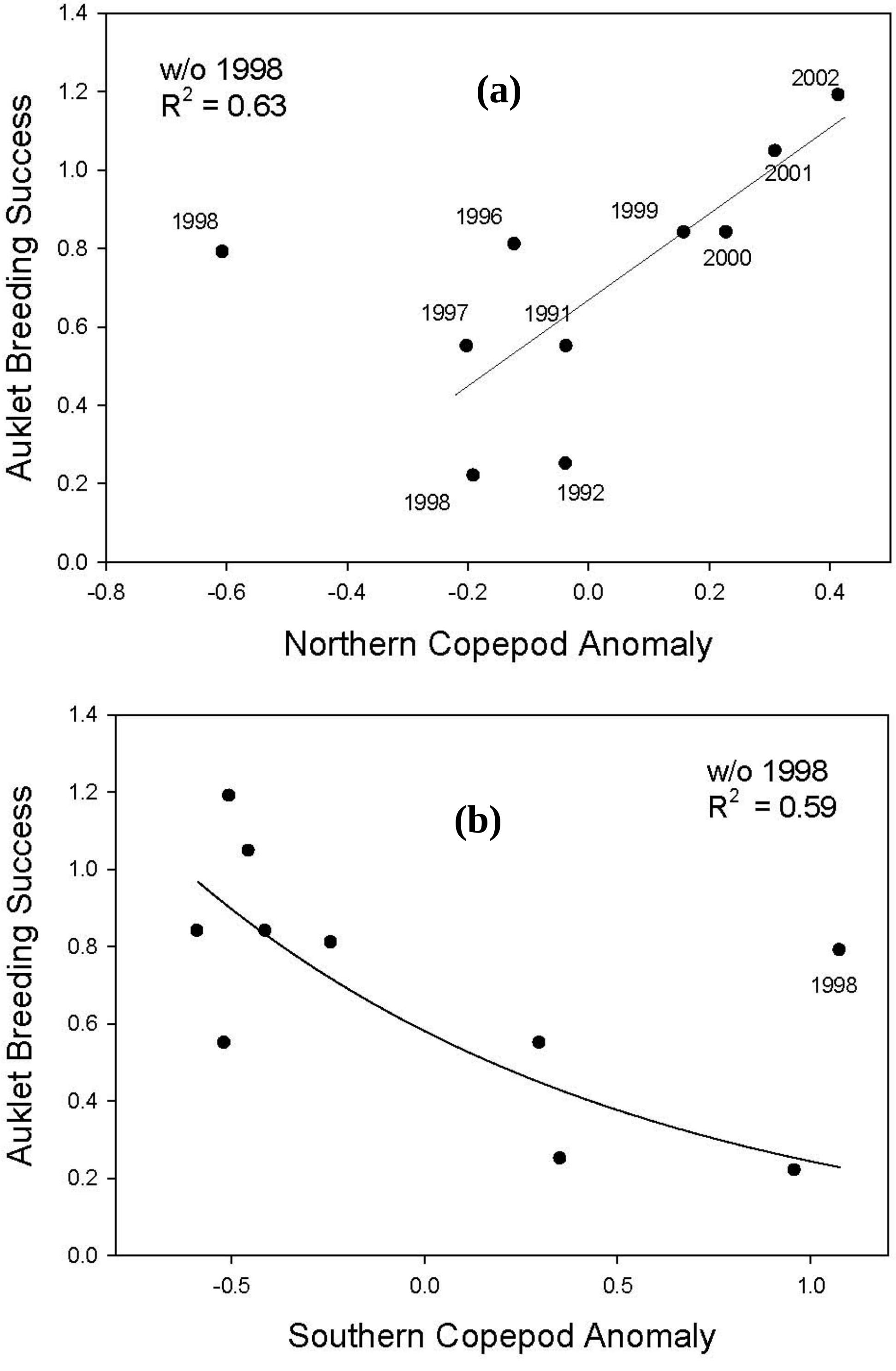


Figure 19. Oregon copepod indices against central-northern California planktivorous seabird productivity. (a) Seabird productivity is positively related to the "northern-boreal" copepod index, and (b) negatively related to the "southern-sub-tropical" copepod index, suggesting co-variation between the northern and central ecoregions illustrated in Figure 5. Figures and data courtesy Bill Peterson (NOAA Fisheries, NWSFC) and Bill Sydeman (PRBO).

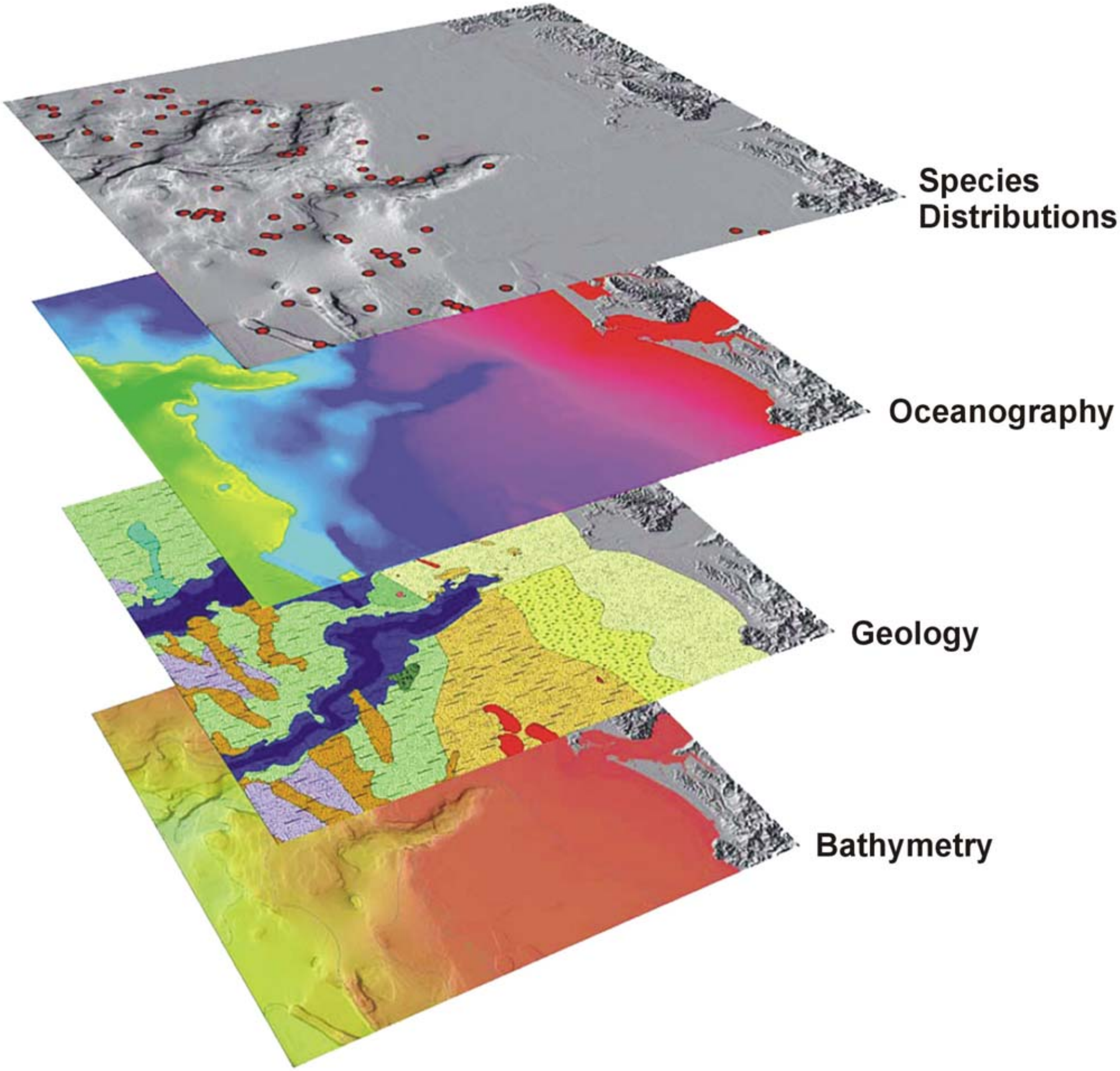


Figure 20. Spatial variability in the CCLME should be evaluated in developing IEA. Strata of ocean properties, including bathymetry, geology, oceanography and species distributions will be considered in future IEA reports. Reproduced with permission from the Pacific Coast Ocean Observing System Science Plan (2004).