THE STATE OF THE CALIFORNIA CURRENT, 2005–2006: WARM IN THE NORTH, COOL IN THE SOUTH

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ABSTRACT

This report summarizes the recent state of the California Current System (CCS), primarily during the period April 2005 through early 2006, and includes observations of ocean conditions made from Washington State south to Baja California. During 2005, the CCS experienced very unusual "ocean weather." For example, off Washington, Oregon and northern California, the start of upwelling was delayed, resulting in anomalously warm sea surface temperatures through the spring and the early summer months. The warming observed in the northern California Current (NCC) in the spring and early summer appeared to be a regional phenomenon, since waters south of approximately 35°N to the California–Mexico border were near the long-term average, and cooler-than-normal temperatures prevailed off Baja California. The extent of the warming and subsequent ecosystem response was similar to that of a major tropical El Niño event. However, we know from observations made at the equator that equatorial waters were in an El Niño-neutral state. The impacts on the NCC pelagic ecosystem were profound with very low biomass of zooplankton observed in Monterey Bay, the Gulf of the Farallones, and off Oregon, accompanied by unprecedented reproductive failure and mortality in several locally-breeding seabird species. Recruitment failure was seen in a variety of fishes as well. The proximate cause was a delay in the initiation of the upwelling season in the NCC (which usually begins in April) to a nearly unprecedented start time of late July. Thus, animals that reproduce in spring and in other years would find bountiful food resources, found themselves faced with famine rather than feast. Similarly, marine mammals and birds which migrate to the NCC upwelling region in spring and summer, which would otherwise find a high biomass of energetically-rich zooplankton and small pelagic fish upon which to feed, were equally disappointed. Moreover, 2005 marked the third year of chronically warm conditions in the NCC, a situation which could have led to a general reduction in physiological condition of fish and birds, rendering them less tolerant of adverse ocean conditions in 2005.

INTRODUCTION

This is the thirteenth in a series of annual reports prepared since 1993 that summarize the climatology, oceanography, and biology of the California Current System (CCS). It is the third to include data from the entire length of the California Current System. Programs or institutions contributing to this report include U.S.

GLOBEC, NOAA/Stock Assessment Improvement Program, Pacific Coast Ocean Observing System (PaCOOS), NOAA/NWFSC/Fish Ecology Division, Point Reyes Bird Observatory, Monterey Bay Aquarium Research Institute, NOAA/SWFSC/Environmental Research Division (formerly known as the Pacific Fisheries Environmental Laboratory), Monterey Ocean Time series and Observatory (MOTO), California Cooperative Oceanic Fisheries Investigations (CalCOFI), and Investigaciones Mexicanas de la Corriente de California program (IMECOCAL).

Three significant climate events have had a profound effect on the California Current System during the past decade: the first was the 1997–98 El Niño event; the second was the dramatic shift to cold ocean conditions that lasted for a period of four years (1999–2002), and the third was the more subtle but persistent return to warm ocean conditions initiated in October 2002. Many publications have described these recent changes in ocean conditions, including a special journal issue focused on the impacts of the 1997–98 El Niño event (Progress in Oceanography, Volume 54, 2002), several papers discussing implications of the four-year cool phase (e.g., Schwing et al. 2000; Peterson and Schwing 2003; Bond et al. 2003), papers discussing general changes in the California Current System (DiLorenzo et al. 2005; Perez-Brunius et al. 2006), and a Special Section of Geophysical Research Letters to be published in November 2006 that discusses the warm ocean conditions during summer of 2005.

The present warm phase has now continued for more than three years in the NCC. Warming which began in late 2002 was probably due to a weak equatorial El Niño event, but continuation of warming through 2005 seems to be related to weaker than normal upwelling (in 2004) and unusual weather conditions that led to a delay in the start of the upwelling season (in 2005). The impacts of these chronic warm conditions in the NCC were clearly manifested in an increase in copepod species diversity off Oregon (Hooff and Peterson 2006) from late 2002 until the present, declines in zooplankton biomass in the northern and central California Current, and a failure of Cassin's auklets to nest successfully in the Gulf of the Farallones in 2005 (Sydeman et al. 2006). The breeding failure appears to be related to the fixed timing of nesting occurring when sufficient krill resources for the seabirds were unavailable, i.e., egg-laying, in May and June. A recruitment failure in several rockfish species off central California was also noted in the summers of 2005 and 2006 (S. Ralston, personal communication; see also Brodeur et al. 2006). In addition, Pacific hake (*Merluccius productus*) migrated farther north in 2005 than in recent years, presumably due to poor feeding conditions in offshore waters (Thomas et al. 2006). Much of the poor survival and recruitment of fishes and birds may be attributed to the failure of the food chain to produce sufficient prey biomass. Zooplankton volumes in the southern California Current have been declining since 1999, and copepod biomass off Oregon was the lowest measured in the past 10 years—20% lower than during the 1998 El Niño event. Also, euphausiid spawning off Oregon (which usually extends from March through October) was restricted to August and September, suggesting recruitment failure of krill in spring and early summer. Very low abundances of adult euphausiids were observed off both the Farallones and Monterey Bay (Sydeman et al. In press).

DATA SETS AND METHODS

Basin- and Coast-Wide Analyses

Large-scale patterns of SST are summarized from the National Center for Environmental Prediction Reanalysis fields (Kister et al. 2001) and from the NOAA-CIRES Climate Diagnostics Center (http://www.cdc.noaa.gov). The reanalysis fields are monthly gridded (approximately 2° × 2°) anomalies of sea surface temperature (SST) and surface winds. The base period is 1968–96. Monthly upwelling indices and their anomalies for the North American west coast (21°–52°N) are calculated relative to 1948–67. The daily alongshore wind component and SST are from the NOAA National Data Buoy Center (NDBC). Values from six representative buoys are plotted against the harmonic mean of each buoy.

Regional Analyses—Oregon and Washington

Regular sampling of the Newport Hydrographic (NH) line along 44.65°N continued on a biweekly basis along the inner portions of the line, at seven stations ranging from 1 to 25 nautical miles from shore. Stations are designated according to distance from shore; e.g., NH05 is the station five miles off Newport. At each station, a conductivity-temperature-depth (CTD) profile is made with a Seabird 19 + that is fitted with a Seabird 43 Oxygen sensor and Wetlabs fluorometer. Seawater samples are collected with a bucket for later analysis of chlorophyll *a* and nutrients. Nutrient data for 1997–2003 are provided by P. Wheeler (Oregon State University, GLOBEC, LTOP Program). Zooplankton is sampled with a 0.5 m diameter ring net fitted with a 200 µm mesh net (and TSK flowmeter) that is towed vertically from near the sea floor (or from a depth of 100 m at deeper water stations) to the sea surface. The cruises depart in late afternoon so as to arrive at the offshore station by nightfall. Zooplankton is sampled during daytime on the outbound leg of the cruise; each station is revisited on the inbound leg, at night, so that euphausiids can be sampled using 60 cm bongo nets fitted with 333 µm mesh nets and a GO flowmeter, which is towed over the upper 20–25 m of the water column. In the labo-

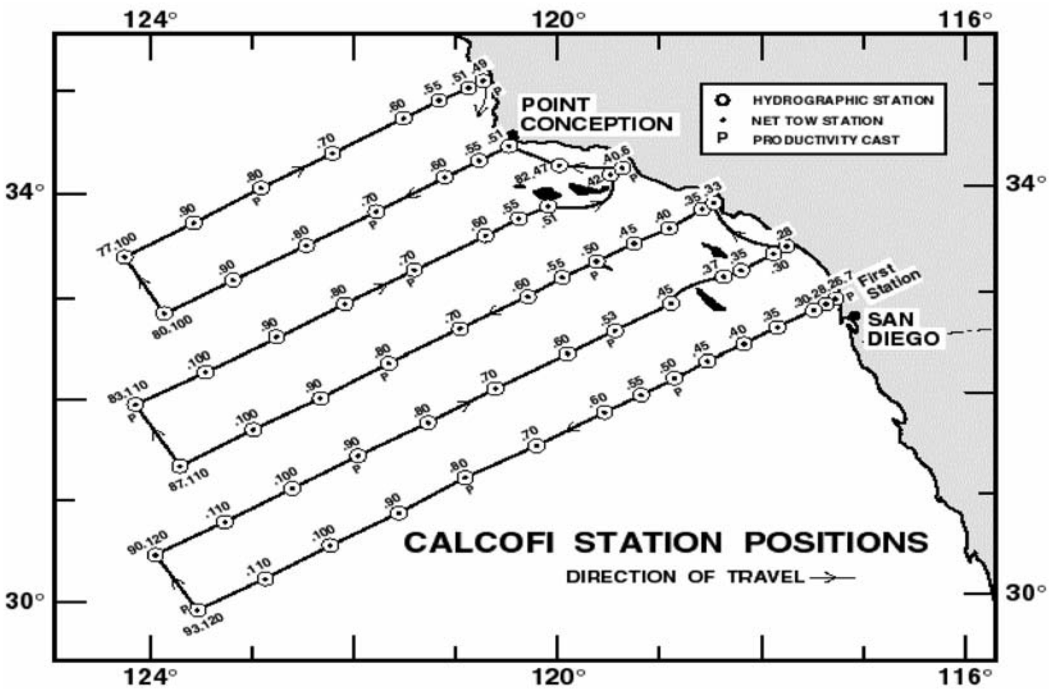


Figure 1. Location of CalCOFI stations.

ratory, zooplankton are enumerated by species and developmental stage, and biomass is calculated by multiplying counts (units of number per cubic meter) by weights of individuals (mostly from literature values). Waters out to 85 miles offshore of Newport were sampled in May 2005. Temperature anomalies along the Newport line are based on the Smith et al. (2001) climatology.

Cruises to sample pelagic fish typically sample every ten days from mid-April through mid-July. Since 1998, pelagic forage and predatory fish have been sampled at night with a pelagic rope trawl (NET Systems 244, 20 × 30 m mouth, 100 m in length; mesh size ranges from 163 cm near the throat of the trawl to 8.9 cm in the cod end; a 6 m long section of 0.8 cm mesh lines the cod end). Trawls are typically 30 minutes in duration, sampling from the surface down to a depth of 20 m. Four stations are sampled along each of two transect lines in shelf waters off Columbia River and Willapa Bay, Washington (for station locations see Emmett et al. 2005).

Regional Analyses—Central California

The Monterey Bay region time series consists of two moored telemetering buoys located in the Bay, hydrographic surveys of the Bay every three weeks, and quarterly surveys along CalCOFI Lines 60 and 67 from the coast out to station 90. Stations are sampled to near bottom or 1012 m where water depth permits. Parameters measured are similar to those for the CalCOFI program (described below), and methods are described more fully in Chavez et al. (2002). Properties are mapped for each section and can be viewed at http://www.mbari.org/bog/projects/secret/default.htm.

The Fishery Ecology Division of the Southwest Fishery Science Center has conducted a standardized midwater trawl survey during May–June aboard the NOAA R/V *David Starr Jordan* every year since 1983. Historically, the survey was conducted between 36°30'–38°20'N latitude (Carmel to Bodega Bay, California), but starting in 2003, coverage has expanded to effectively sample the entire coast of California. The primary purpose of the survey is to estimate the abundance of pelagic juvenile rockfishes (*Sebastes* spp.) and to develop indices of year-class strength for use in groundfish stock assessments on the U.S. West Coast.

Regional Analyses—Southern California

The CalCOFI program conducts quarterly surveys off Southern California, covering 66 stations (fig. 1). Although surveys began in 1949, this pattern was adopted in 1984. CTD/Rosette casts to a depth of 525 m are equipped with sensors for conductivity, temperature, pressure, oxygen, fluorescence, and light transmission. Salinity, dissolved oxygen, nutrients, and chlorophyll are determined on 12 to 20 water samples collected throughout the water column. Standard (505 µm mesh) oblique bongo tows are conducted to 210 m depth at each station, bottom depth permitting. Detailed descriptions of sampling and analytical protocols and data reports from past cruises are archived on the CalCOFI Web site (http://www.calcofi.org).

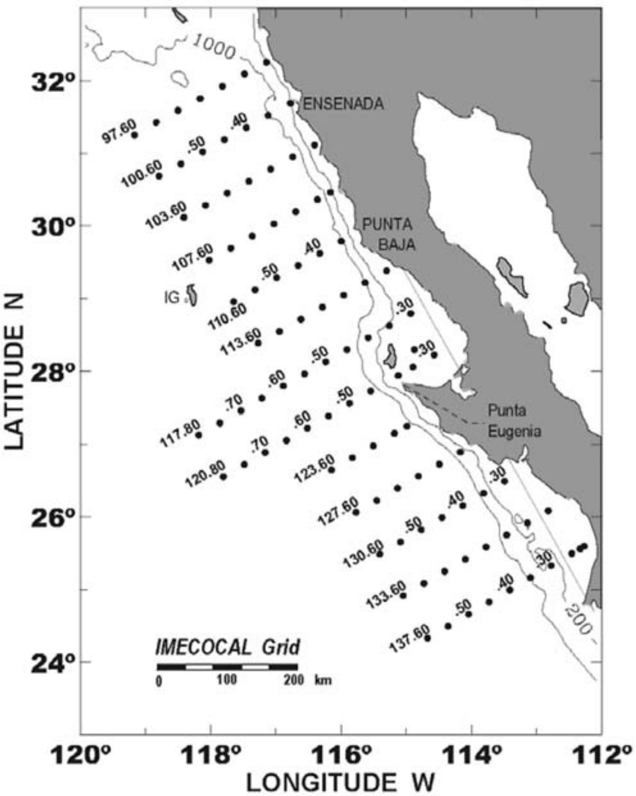


Figure 2. The standard IMECOCAL sampling grid. Black points represent the 93-station pattern (CalCOFI lines 100 to 137) occupied by the IMECOCAL program since 1997 (including line 97 for April surveys since 2003). Depth contours are in meters.

The mixed layer is defined as the layer within which the sigma-theta differential is less than 0.002 kg/m^3. The nitracline depth is defined as the depth where concentrations of nitrate reach values of 1 μM. Climatologies are based on data collected during 1984–2005. Cruise averages and anomalies presented below are based on measurements made at these 66 stations. Unless otherwise stated, anomalies are calculated as the cruise mean value minus harmonic mean. Individual cruise data from 200 m (interpolated standard level) were averaged for offshore stations (station numbers xx.60 and higher) on all lines for cruises since 1984. Annual averages and anomalies, relative to the years 1984–2005, were calculated as described above.

Since 2003, the winter cruise has extended measurements into Central California, primarily to examine distribution of hake larvae. The daily hake larval production at hatching and the instantaneous mortality rate (IMR) were estimated using a Pareto survival curve, because it was evident that the IMR decreases as age of larvae increases (Lo[1] in prep). This was done for years when surveys covered the whole area. For years when hake larval data were collected only from San Diego to Morro Bay (southern area), the larval production for the whole area was computed from mean larvae density from the south.

[1]Lo in prep. Time series of daily Pacific hake larval production off California in 1951–2005.

Regional Analyses—IMECOCAL

Data off northern and central Baja California are collected quarterly with a grid of about 93 stations (fig. 2). At each station a CTD/Rosette cast is made to 1000 m depth, and is equipped with sensors for pressure, temperature, salinity, dissolved oxygen, and fluorescence. Water samples from the upper 200 m are collected with 5 liter Niskin bottles at 0, 10, 20, 50, 100, 150, and 200 m depths to determine dissolved oxygen, chlorophyll *a* and phaeopigments, nutrients (NO_3, NO_2, PO_4, SiO_3), and primary production. Macrozooplankton is sampled with bongo net tows from 200 m to the surface. IMECOCAL cruise schedules, data collection, methods, and analyses are fully described in data reports at the Web site: http://www.imecocal.cicese.mx.

Avifauna

Since 1987, CalCOFI cruises have included systematic surveys of the distribution and abundance of marine birds in relation to oceanographic conditions (Veit et al. 1996; Hyrenbach and Veit 2003). Since the early 1970s the Point Reyes Bird Observatory (PRBO) Marine Ecology Division has monitored the reproductive performance and the diet of seabird populations breeding at the Farallon Islands (central California) (Sydeman et al. 2001; Abraham and Sydeman 2004).

Marine Mammals

Marine mammal populations along the U.S. West Coast are assessed every 2–5 years by means of comprehensive shipboard line-transect surveys. Previous marine mammal assessment surveys were conducted during 1991 and 1993 (California only), and during 1996 and 2001 (entire U.S. West Coast) by the Southwest Fisheries Science Center. The most recent survey, extending along the entire U.S. West Coast and about 550 km offshore, was completed during June–December 2005. For the first time, additional fine-scale surveys were conducted within the National Marine Sanctuaries in central California and Washington. The project, Collaborative Survey of Cetacean Abundance and the Pelagic Ecosystem (CSCAPE), also incorporated extensive ecosystem studies, including underway and station-based oceanographic sampling, net tows, and seabird surveys. All survey data are currently being processed and analyzed by SWFSC staff, but some preliminary marine mammal observations for 2005 are described below and related to previous survey years.

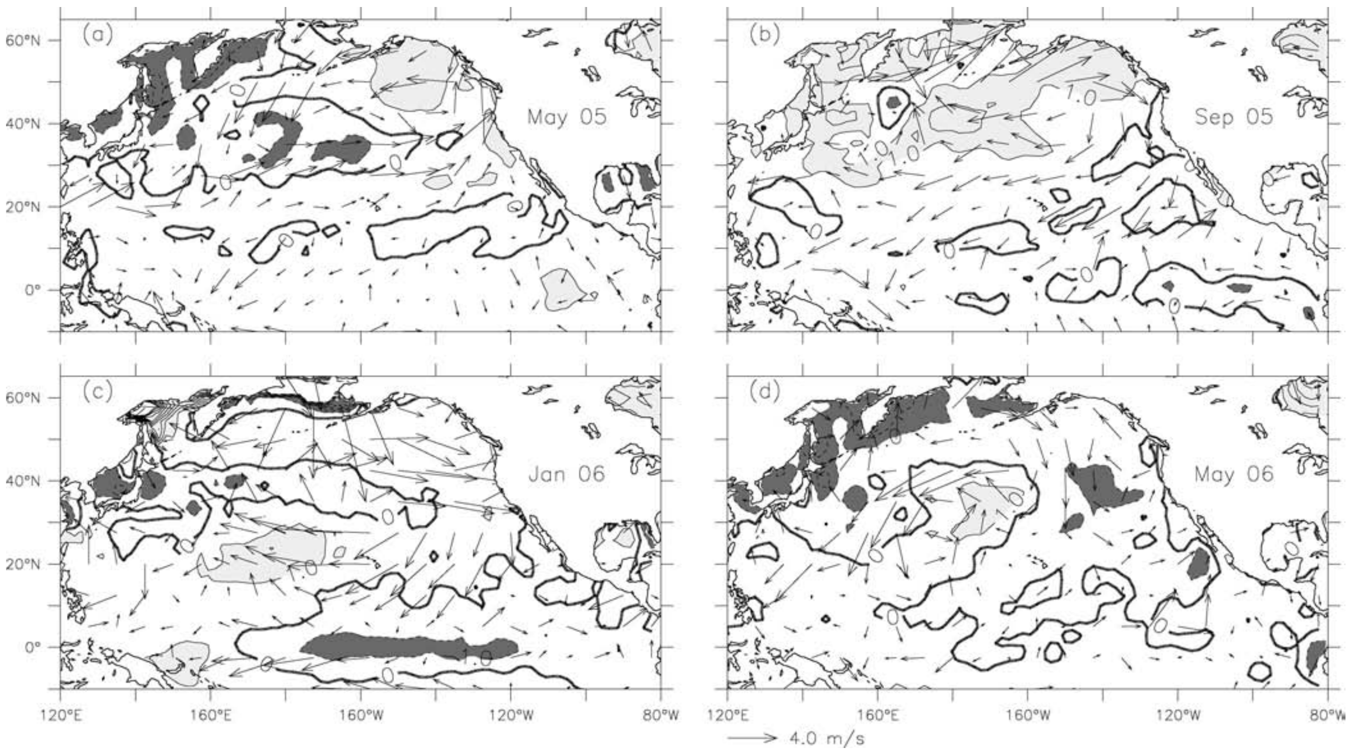


Figure 3. SST anomalies in the North Pacific Ocean for (A) May 2005, (B) September 2005, (C) January 2006, and (D) May 2006. Contour interval is 1.0°C. Positive (warm) anomalies are shaded light grey, and negative (cool) anomalies are shaded dark grey. SST climatology is 1968–96. Monthly data obtained from the NOAA-CIRES Climate Diagnostics Center.

BASINWIDE PATTERNS

Sea surface temperature (SST) anomalies in 2005 and 2006 continued to display a heterogeneous pattern that does not resemble the characteristic spatial patterns defined in previous analyses (e.g., Pacific Decadal Oscillation [PDO]), Mantua and Hare 2002; Victoria mode, Bond et al. 2003). For most of the past 12 months, positive SST anomalies have been maintained northwest of Hawaii, but negative anomalies have prevailed in the Kuroshio/Oyashio region (fig. 3). Northeast Pacific SSTs have been controlled by local wind processes. The North Pacific High (NPH) failed to strengthen as usual in spring 2005, leading to anomalously strong downwelling in the Gulf of Alaska and weaker than normal upwelling along the North American west coast (fig. 3a). However, the NPH remained strong into the fall of 2005, leading to sustained coastal upwelling and cool SSTs in the California Current System (fig. 3b). Warm anomalies again prevailed during much of the winter 2005–06 (fig. 3c).

The most recent assessment (May 2006) shows generally negative SST anomalies in the northeast Pacific, and warm SSTs northwest of Hawaii and off Southern California and Mexico (fig. 3d). California Current System SST anomalies have become more positive since April, indicating that the seasonal development of coastal upwelling in 2006 has been delayed like in 2005. In contrast, SSTs off Peru continue a cool tendency that began in early 2005 (Climate Prediction Center 2005). In contrast to the North Pacific, the Atlantic remains extremely warm, which suggests another active hurricane season.

The tropical Pacific was in a weak La Niña state in spring–summer 2005, but has returned to an ENSO-neutral state during the past several months (Climate Prediction Center 2005). The Multivariate ENSO Index (Wolter and Timlin 1998) has been slightly negative since October 2005, suggesting weak to moderate La Niña conditions. Recent equatorial Pacific SSTs have been near normal, except for cool anomalies (fig. 3) and an associated shallow thermocline near the South American coast. The lack of a clear ENSO signal in the tropics during the past year suggests that equatorial processes have not played a significant role in creating ENSO-like anomalies in the California Current System. ENSO-neutral conditions are forecast for the next three to six months (Climate Prediction Center 2005).

The atmospheric variability has been dominated by the 60–90 day signal of the Madden-Julian Oscillation (MJO). The MJO is reflected in the large-scale winds over the Northeast Pacific and upper ocean anomalies as well, making it difficult to characterize any persistent long-term anomaly pattern. The predominant MJO forcing has also excited atmospheric variability at relatively short wavelengths (sub-ocean basin), which may have

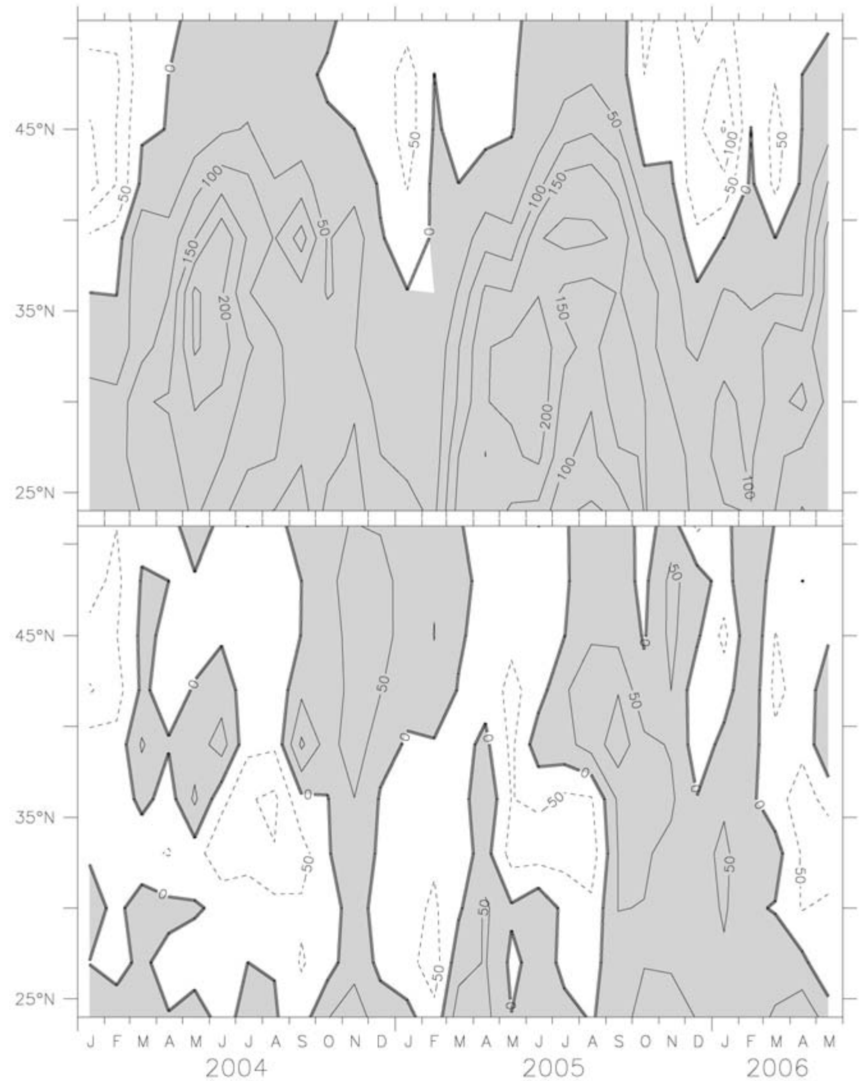


Figure 4. Monthly upwelling index and upwelling index anomaly for January 2004–May. 2006. Shaded areas denote positive (upwelling-favorable) values in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1948–67 monthly means. Units are in m^3/s per 100 km of coastline.

contributed to the continuing spatially complex and heterogeneous anomaly patterns in SST. The MJO pattern is strengthening again in spring 2006.

COASTWIDE CONDITIONS

For 1999–2003, the California Current System had very strong summer upwelling and very cool SSTs (summarized in past CalCOFI Reports). In 2004, this pattern switched, with weaker summer upwelling, but anomalously strong upwelling in the fall and early winter of 2004 north of Monterey Bay (fig. 4). Since the weak El Niño of 2002–04 and through the first half of 2005, upwelling anomalies South of Monterey have been negative with anomalously weak upwelling extending along the entire coast in spring and early summer 2005. These are consistent with winds at the National Data Buoy Center (NDBC) coastal buoys (fig. 5) and anomalously warm coastal SSTs (fig. 6).

Most of the California Current System experienced unusually warm upper ocean conditions in spring–summer 2005. In the Southern California Bight, SSTs were up to 4°C above normal (http://www.pfeg.noaa.gov). However, this warm surface layer may have been quite thin, reflecting low winds and weak mixing, rather than deep warming due to an anomalously deep thermocline and a large change in heat content. Strong upwelling commenced in July–August and continued into early spring 2006, leading to rapid surface cooling and an adjustment of SSTs back to near-normal values. However, with the exception of positive upwelling anomalies off northern California and southern Oregon, upwelling again has been anomalously weak in 2006, strikingly

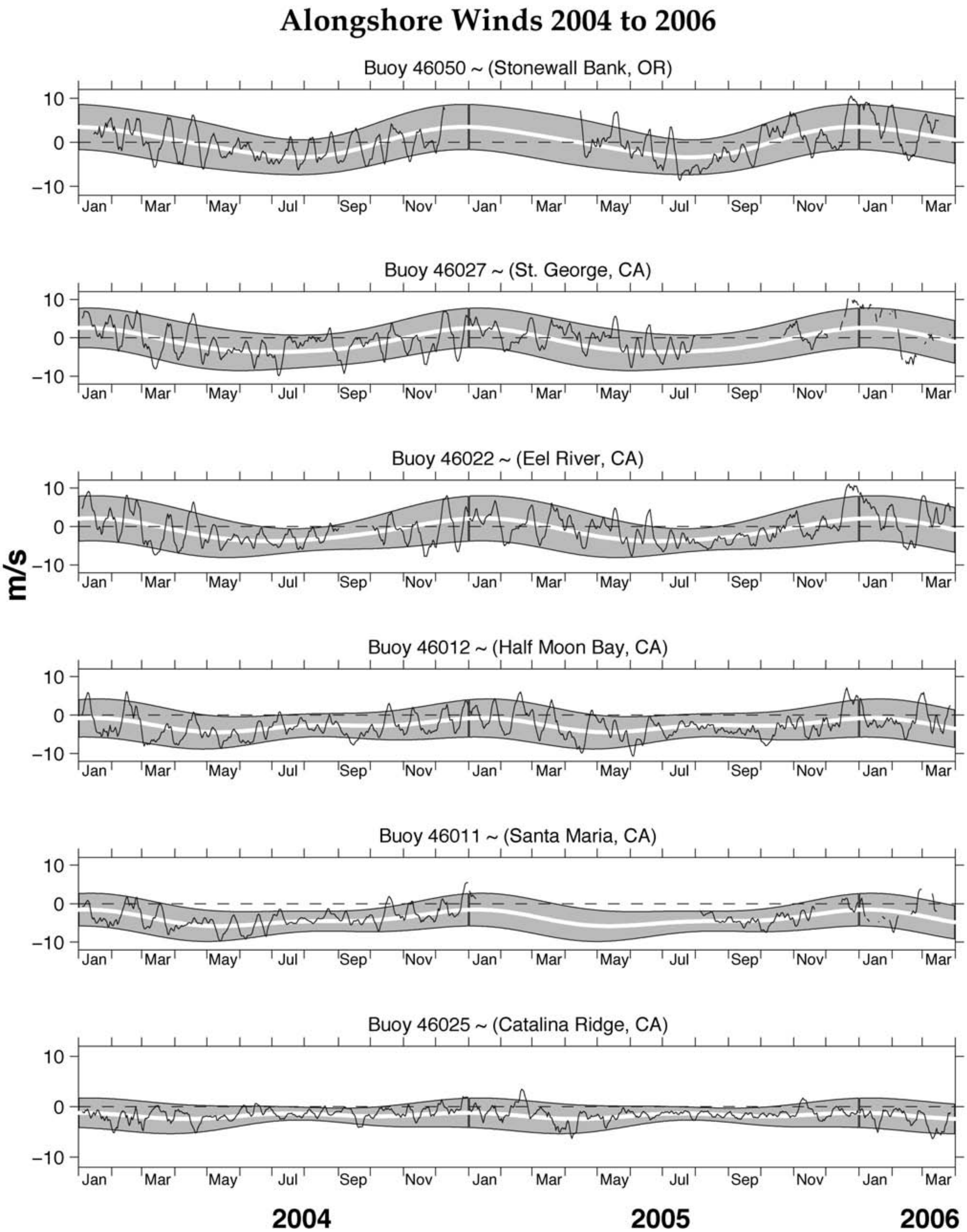


Figure 5. Time series of daily-averaged alongshore winds for January 2004–March 2006 at selected NOAA National Data Buoy Center (NDBC) coastal buoys. Bold lines are the biharmonic annual climatological cycle at each buoy. Shaded areas are the standard errors for each Julian day. Series have been smoothed with a 7-day running mean. Data provided by NDBC.

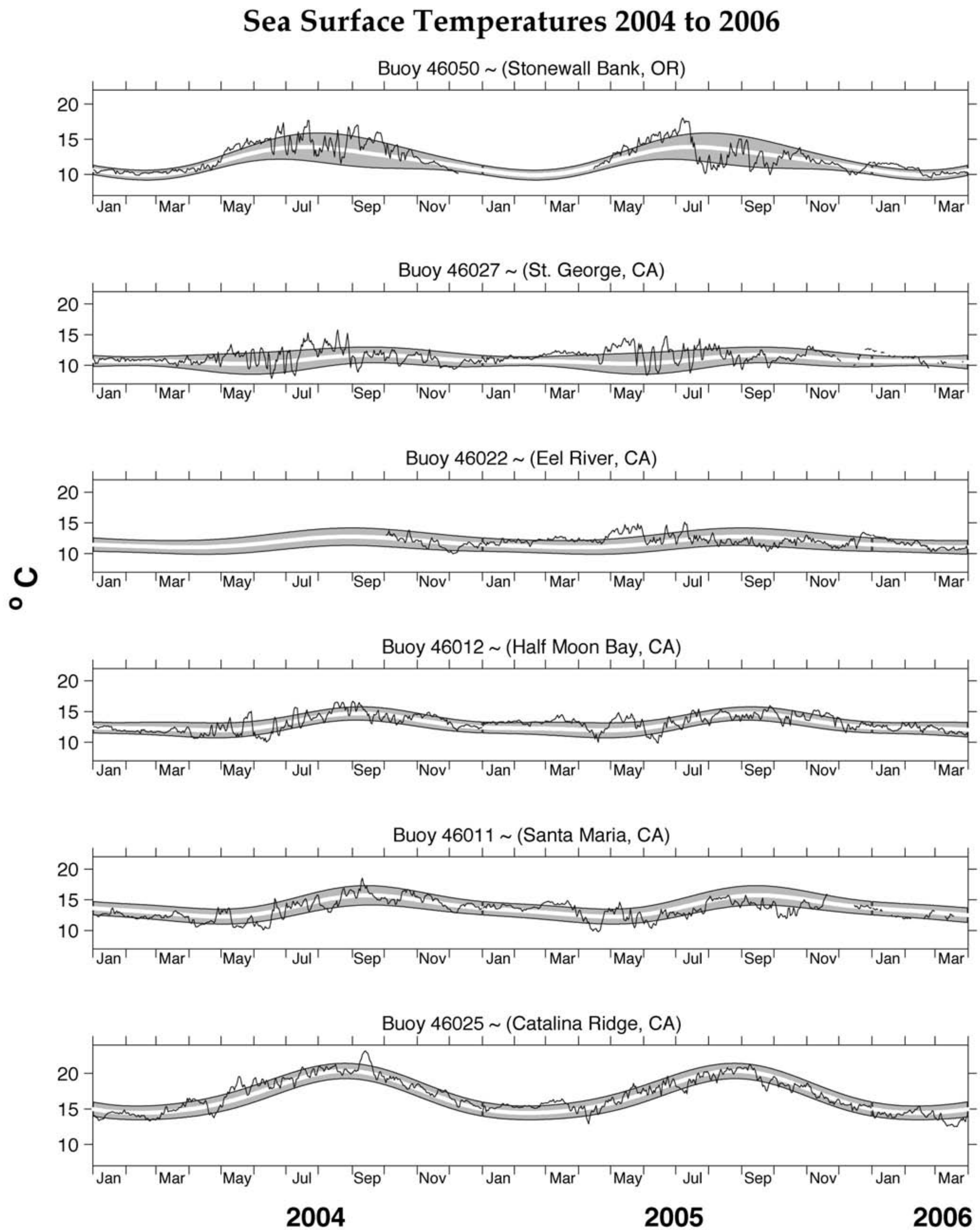


Figure 6. Time series of daily-averaged SST for January 2004–March 2006 at selected NDBC coastal buoys. Bold lines are the biharmonic annual climatological cycle at each buoy. Shaded areas are the standard errors for each Julian day. Data provided by NOAA NDBC.

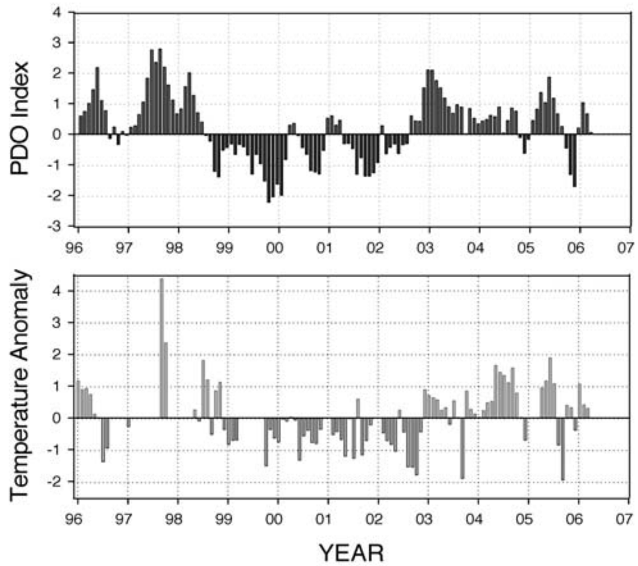


Figure 7. Time series of the Pacific Decadal Oscillation (PDO, upper) and sea surface temperature (lower) at NOAA Buoy 46050, 22 miles off Newport, Oregon. Note that anomalously warm water persisted off the Oregon coast from late-2002 through late-2005; The two time series appear to be correlated, with SST lagging the two major changes in the PDO by about six months.

similar to the pattern in 2005 (fig. 4). There is no apparent surface ocean teleconnection with the tropical Pacific contributing to these warm anomalies.

The predominance of strong intra-seasonal variability in the California Current System is illustrated by a series of ca. 30-day alongshore fluctuations in NDBC winds (fig. 5). These strong fluctuations or reversals in the alongshore winds were observed throughout the 2004–05 period, particularly in the northern California Current System. This anomalous wind forcing is reflected in the SST time series from the NDBC buoys (fig. 6). The intra-seasonal oscillations in alongshore winds in summer and fall 2005 resulted in strong fluctuations in SST, with changes sometimes exceeding 5°C over the course of a few days.

REGIONAL STUDIES

Oregon

The time series of sea surface temperature 22 miles off Newport, Oregon (NOAA Buoy 46050), shows high temperatures during the summer of the 1997–98 tropical El Niño event, and cold temperatures during the negative (cool) phase of the PDO during 1999–2002. Between spring-early summer 2003 and the end of 2005, anomalously warm water was common. Sea surface temperatures at NOAA buoy 46050 (22 miles off Newport in 140 m water depth) were 1° to 2°C above normal for most months after autumn 2002 (fig. 7). Some months in 2004 and 2005 had positive SST anomalies that **exceeded** those seen during the 1998 El Niño event.

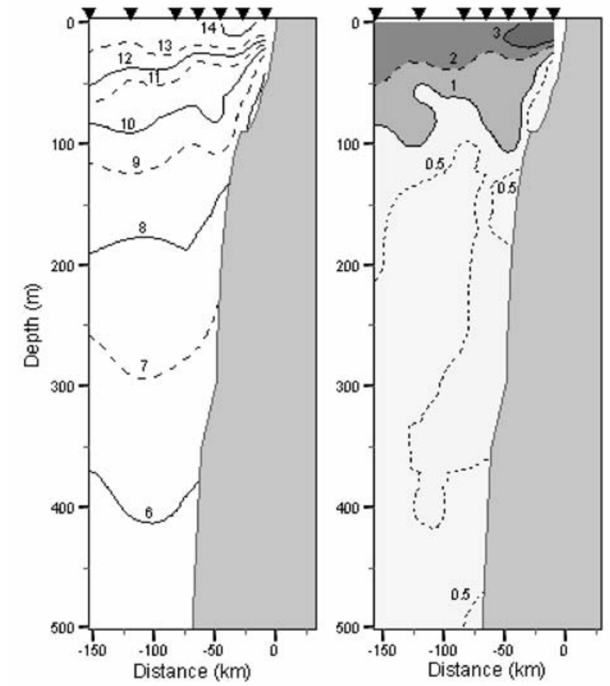


Figure 8. Temperature (left) and temperature anomalies (right) off Newport, Oregon, measured on 10 May 2005. Note that warming was observed chiefly in the upper 100 m of the water column, with +2°C anomalies observed at least as far offshore as 150 km.

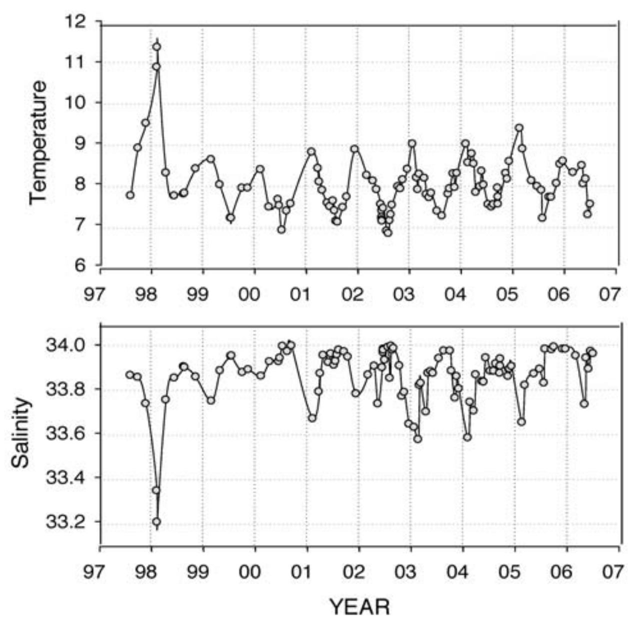


Figure 9. Time series of temperature (upper) and salinity (lower) measured at a depth of 150 m at station NH 25 (25 miles off Newport, Oregon; water depth, 300 m), from July 1997 to present.

There is correspondence between the PDO and local temperature anomalies (fig. 7). The four-year period of negative PDO values from late-1998 until late-2002 is matched closely by negative SST anomalies off Oregon. The positive PDO values from late-2002 until present also match positive SST anomalies. This suggests that changes in the basin-scale forcing result in changes locally (off Oregon), and that local changes may be due to differences in transport of water out of the North Pacific into the northern California Current, as suggested by DiLorenzo et al. (2005). The temperature section along the Newport Line, May 2005 (fig. 8), shows a +3°C anomaly in the upper 20–25 m and a +1°C anomaly in the upper 100 m. Deeper waters only had an anomaly of about +0.5°C. Another temperature section along the Newport Line was completed in mid-July (Pierce et al. 2006) with the same result; Pierce et al. (2006) note that the July 2005 section resembled sections made in July of 1983 and 1997, both El Niño years.

A time series of temperature measured at a depth of 150 m at a shelf break station off Newport shows a strong seasonal cycle (fig. 9). Summertime temperatures show the same pattern as the SST at NOAA Buoy 46050. Temperatures were cool during summers of 1999–2002, with the average ranging from 7.39°C (1999) to 7.24°C (2002). Following this four-year period of cool temperatures, the deep waters began to warm, and average temperatures increased to 7.56°C (2003), 7.71°C (2004), and 7.65°C (2005). Salinity at 150 m at the same station had the opposite pattern, with relatively high values during summers 1999–2002 when the averages ranged from 33.92 to 33.96, decreasing in 2003 to 33.90, then 33.89 (2004) and 33.93 (2005). As of July 2006 the trend is towards colder and saltier water similar to that observed from 1999 to 2002. From this (albeit limited) data set, it appears that relatively warm and fresh water off Oregon occurs during the positive phase of the PDO and colder and saltier water during the negative phase, supporting a hypothesis that different water types occur off Oregon as a function of the PDO phase.

Central California

In Monterey Bay, sea surface salinity anomalies were about 0.2 units fresher from late 2002 until the present, with the strongest anomalies in the winter (fig. 10). Sea surface temperatures were cooler than average from 1999 to late-2002, but were near the long-term average from early 2003 through late-2005, with the exception of about +1°C anomalies during spring 2005.

Temperatures at 200 m were cooler than average from 1999 to late-2001 (fig. 11), but were warmer in winters of 2001–02 and 2002–03. However from early-2004 through late-2005, temperatures were warmer by about 0.2°C, similar to that observed off Oregon. The salinity record was different from that off Oregon in that above average salinities have been observed in Monterey Bay in all years since 1999.

Another significant trend in Monterey Bay (not shown) is a long-term warming of 0.2°C since 1989, or a change of 0.012°C per year. A similar change has been noted for the Newport Line. When historical data from NH 25 at 150 m (from 1961–71) are compared to recent temperatures, the overall temperature increase is 0.006°C per year. Given the lack of measurements between 1972 and 1997, the temperature increase off Monterey and Newport may well be the same.

Southern and Baja California: CalCOFI Overview

This report is based on cruises in April, July, and November of 2005, and February of 2006. In the CalCOFI region, mixed-layer depths (MLD) during the last year were slightly below the long-term average (fig. 12a) with values similar to those observed since 2002. Mixed-layer temperatures during 2005 were 0.5°C below the long-term average, similar to values measured since 1999. The value for February 2006 was slightly above the long-term average (fig. 12b).

Mixed-layer salinity anomalies over the last year were below zero but were higher than those observed during the previous two years (fig. 12c), reversing a trend of decreasing salinities that began in 2003. This increase of salinities was seen throughout the CalCOFI region, but was particularly pronounced at the edge of the Central Gyre of the North Pacific (fig. 13a) and less so in other regions (e.g., figs. 13b, c). Temperatures at a depth of 200 m were close to the long-term average over the last year, continuing conditions observed since 1998 (fig. 14a). Salinities at a depth of 200 m had values similar to those observed since 1999 (fig. 14b), and were similar to salinities observed in Monterey Bay. The large negative salinity anomaly observed over the last few years is not apparent at 200 m and must have been confined to the upper 100 to 150 m.

IMECOCAL Overview

IMECOCAL surveys were completed in April, July, and October 2005, and February 2006. Data shown here are relative to a climatology of 1997–2004. The recent surveys found that 0–500 m temperature-salinity characteristics contrasted to climatological means (Lynn et al. 1982; Ramirez-Manguilar 2005), showing lower-than-normal salinities in the upper layer (σ_t < 25.5) similar to previous years (Goericke et al. 2004, 2005; Durazo et al. 2005). The near-surface salinities were, however, slightly closer to the climatological mean than they were in 2002–04 (fig. 15). Although average TS (Temperature-Salinity) diagrams for each cruise (except July 2005) suggest near normal sea surface temperatures, a closer scrutiny of T and S anomalies (not shown) for each of the hydrographic sections, indicate that California Current flows were generally displaced offshore (see surface flow patterns and property distributions below), and were

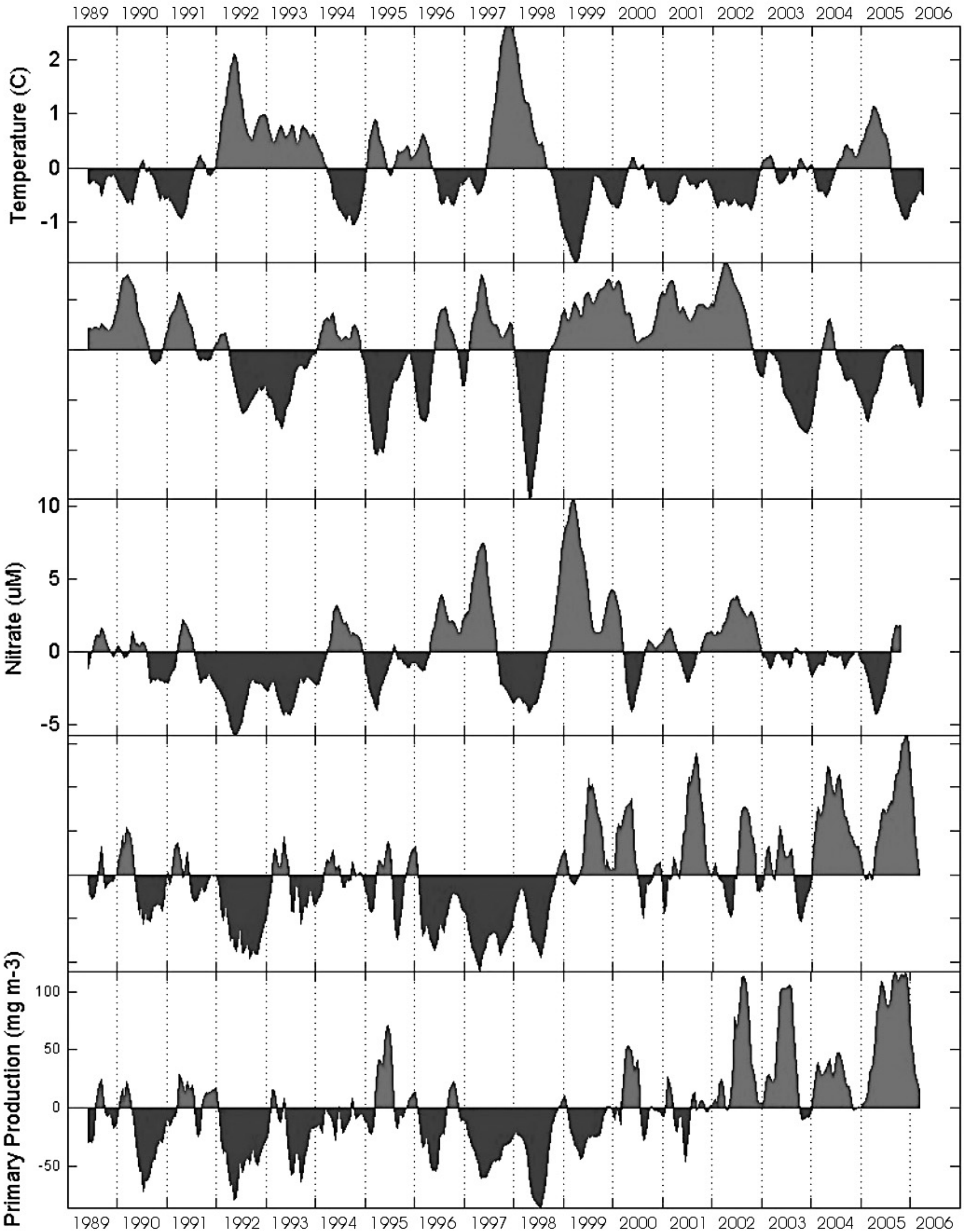


Figure 10. Time series of sea surface temperature, salinity, nitrate, chlorophyll and primary production anomalies in Monterey Bay.

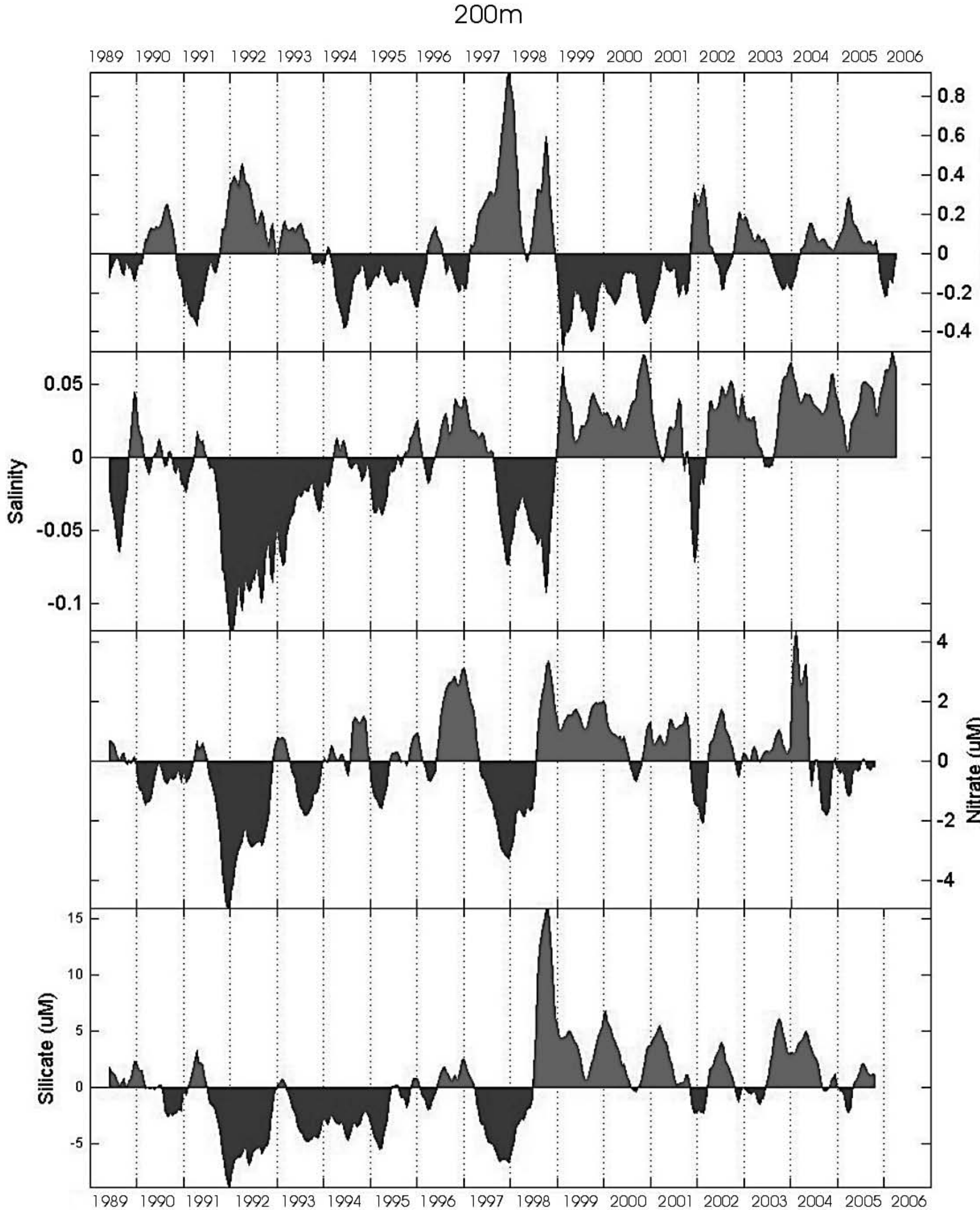


Figure 11. Time series of temperature, salinity, nitrate, and silicate anomalies at a depth of 200 m in Monterey Bay.

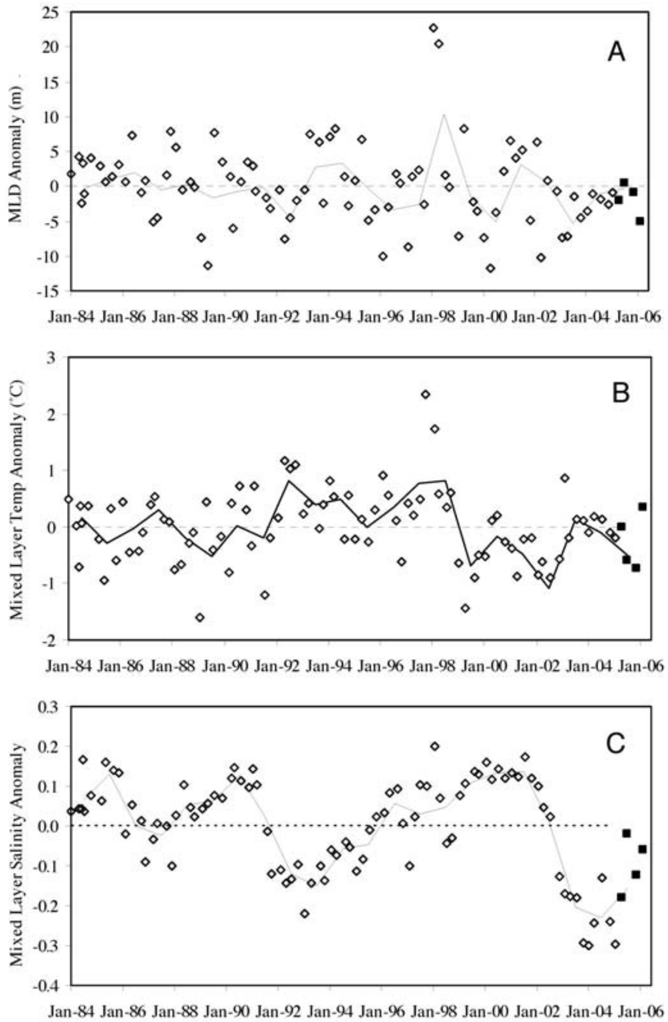


Figure 12. Anomalies of cruise averages for mixed layer depth, (A) temperature (B) and salinity (C) in the CalCOFI area, based on all 66 standard CalCOFI stations. Data from the last four cruises are plotted as solid symbols, data from previous cruises are plotted as open diamonds. The solid lines represents the annual averages and the dotted lines the climatological mean.

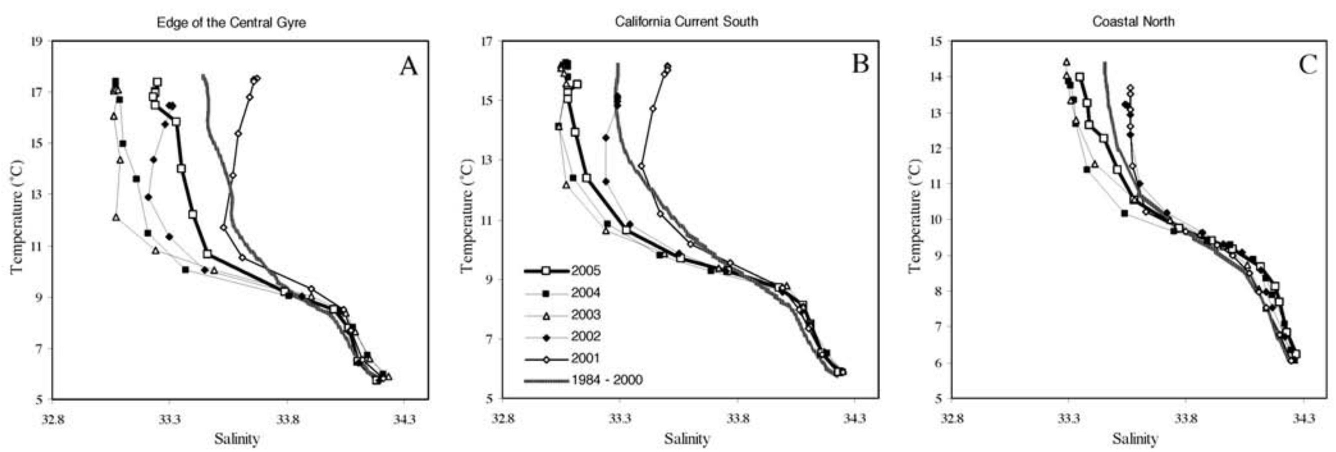


Figure 13. T-S lines for three representative areas of the CalCOFI region. A) The edge of the central gyre (line 90–93, stations 100–120), B) the California Current region (line 83–90, stations 70–90), and C) the northern coastal areas (line 77–80, stations 60 and inshore). Each data point represents the average TS characteristic of one standard depth level for the specified time period, e.g., the year 2002.

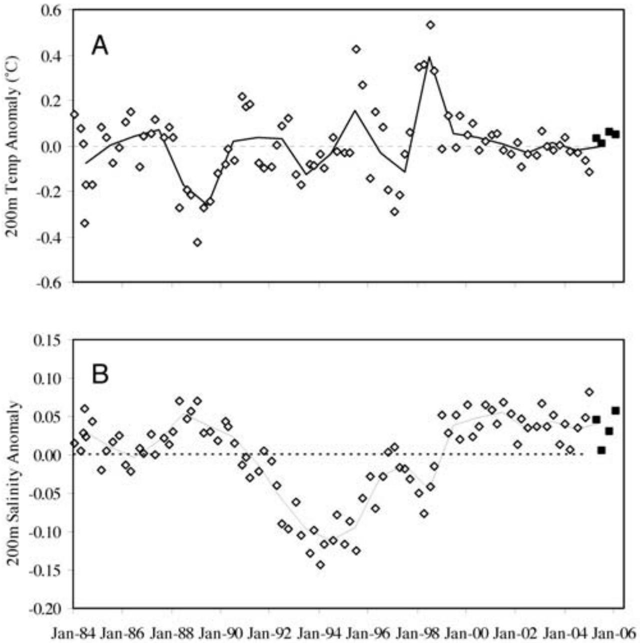


Figure 14. Anomaly of temperature (A) and salinity (B) at 200 m, averaged for data from the seaward end of all CalCOFI lines (stations xx.60 and greater), 1984–present.

usually associated with anomalies of positive temperature (2° to 3°C) and negative salinity (−0.2 to −0.4). The maximum anomalies of T and S were located at the core of the California Current flow, between 40 and 80 m depth. On the other hand, coastal waters generally linked to upwelling regions showed near normal conditions.

More than eight years of sampling (1997–2006) in the Baja California region allows us to establish some general interannual trends. Throughout this period, it has been evident that high positive anomalies of temperature and salinity in the upper layer were associated with the strong 1997–98 El Niño (fig. 16). The following three years were a period of slightly negative temperature anomalies with a strong anomaly (−2°C) in October 2002. Despite the occurrence of cool water in the surface, subsurface water (200 m depth) was warm in fall 2002, representing the beginning of a period with strong stratification of the water column in the Baja California region. The stratification is still more evident in salinity, with negative anomalies indicating the intrusion of subarctic water flowing in the upper layer with an enhanced undercurrent at 200 m depth.

Most of the IMECOCAL stations are located in the offshore domain, but with a few shallow stations near Punta Colonet (31°N), Cabo San Quintin (30.5°N), Vizcaino Bay (28°–29.5°N), Punta San Hipolito (27°N), and the Gulf of Ulloa (25°–27.5°N). Hydrographic variables in continental shelf stations show tendencies similar to those observed in the offshore region (fig. 17). Surface salinity reported negative anomalies despite the coastal upwelling activity, indicating that subarctic water affected a considerable proportion of the upper layer.

Southern and Baja California Cruises: Spring 2005 (fig. 18)

CalCOFI 0504 (15 April–1 May). Dynamic heights indicate that surface currents were dominated by the California Current flowing southeast close to the Channel Island, with branches flowing toward the coast. Close to the coast, poleward currents were observed. A small upwelling plume extended from Point Conception to the southeast, outlined by the 12°C isotherm and characterized by high nitrate and moderate chlorophyll *a* concentrations. The offshore areas were characterized by meandering flows, low salinity, and, as usual, low concentrations of chlorophyll *a*.

IMECOCAL 0504 (14 April–5 May). Dynamic height anomalies for this cruise show an equatorward flow parallel to the coast. The strongest offshore gradients were located at about 100–150 km from the coast

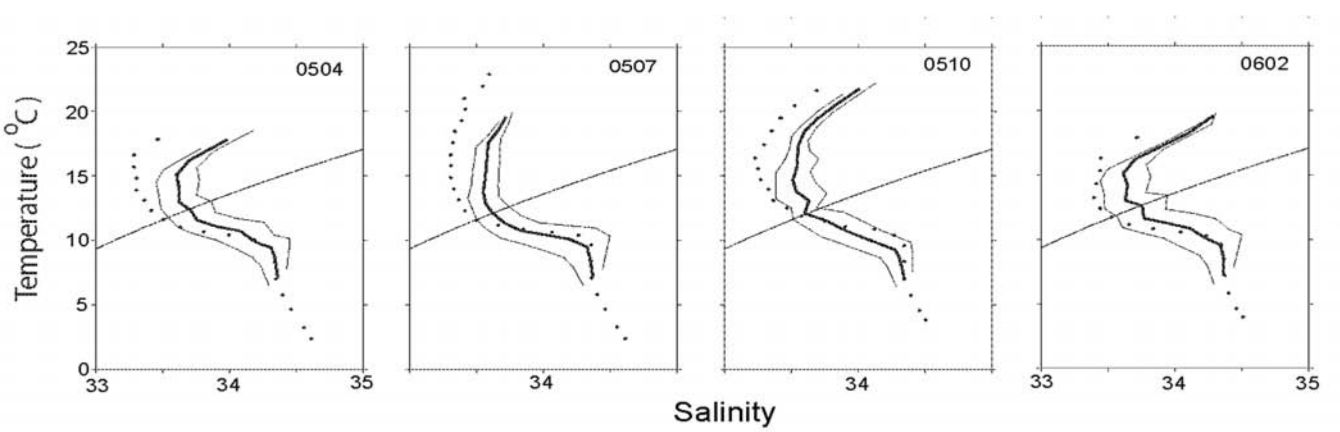


Figure 15. Temperature-salinity diagrams for the spring, summer, and fall 2005 and winter 2006 data collected in the IMECOCAL grid. Bold continuous line represents the climatological mean computed at standard depths from historical (1948–78) and recent (1997–2005) data sets, from 0 to 500 m. Continuous thin lines depict one standard deviation along the salinity axis. Heavy dots indicate the mean temperature-salinity for each cruise. Both cruise and climatological mean profiles were obtained using the same stations on each case. Thin dashed line marks the σ_t = 25.5 isopycnal contour.

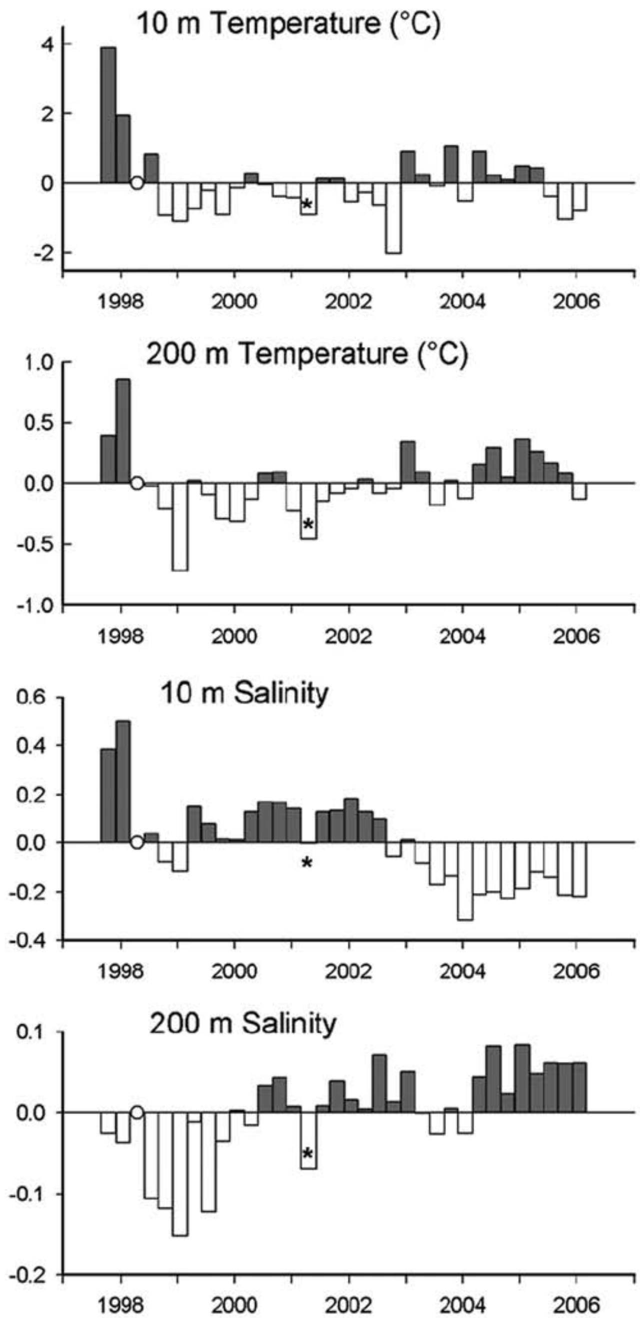


Figure 16. Time series of temperature and salinity anomalies at 10 m and 200 m, estimated for the entire area off Baja California (upper two panels) and for coastal waters (lower two panels). Anomalies were calculated removing the seasonal means of the period 1997–2006. Open circles indicate missing or non-analyzed cruises; the asterisk indicate data available only from north Baja California.

and associated to the lowest 10 m salinities which indicate water of the California Current. As indicated by the 10 m (minimum) temperature and (coastal relative maximum) salinity distributions, this water was separated from the coast by two regions of coastal upwelling, one running from Ensenada (32°N) to Punta Baja (30°N) and another south of Punta Eugenia. Coastal upwelling

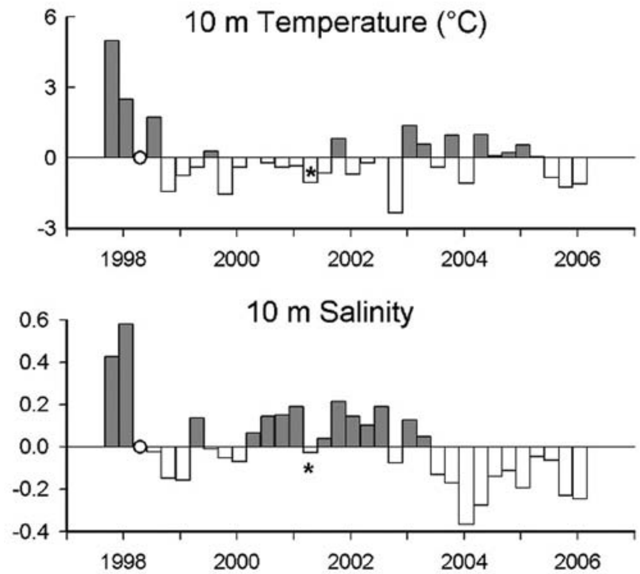


Figure 17. Time series anomalies of hydrological properties (temperature and salinity) estimated in shallow water (shelf) stations along Baja California. Anomalies were calculated removing the seasonal means of the period 1997–2006. Open circles indicate missing or unanalyzed cruises; the asterisk indicate data available only from north Baja California.

was also associated with high chlorophyll-*a* concentration, with the higher values at the northern locations. Zooplankton volume (not shown) presented high values along the coast. Westward of the California Current jet, dynamic height anomalies indicated a meandering current with weak offshore gradients.

Summer 2005 (fig. 19)

CalCOFI 0507 (1–17 July). The California Current, close to the coast during the spring, was further offshore in the summer and had spread into two branches farther south. Strong poleward flow was observed close to the coast. The Southern California Eddy (SCE) was strongly expressed, centered on station 87.45. A lens of unusually cold, saline- and nutrient-rich water extended from Point Conception to station 87.45, suggesting upwelling in this area. High concentrations of chlorophyll *a* were found slightly to the west of this lens of cold and saline water, supporting the upwelling interpretation. Unusually high concentrations of chlorophyll *a* were also found close to the coast; at stations 90.28 and 87.33 values were the highest summer values on record for these stations. The large extent in these regions of high chlorophyll *a* contributed to the larger than normal chlorophyll-*a* concentration cruise average. Floristic analyses will determine if these areas are extensions of the unusually persistent dinoflagellate blooms observed last year in the nearshore.

IMECOCAL 0507 (14 July–4 August). The California Current flow, as depicted by the dynamic height contours, appeared slightly displaced offshore during this

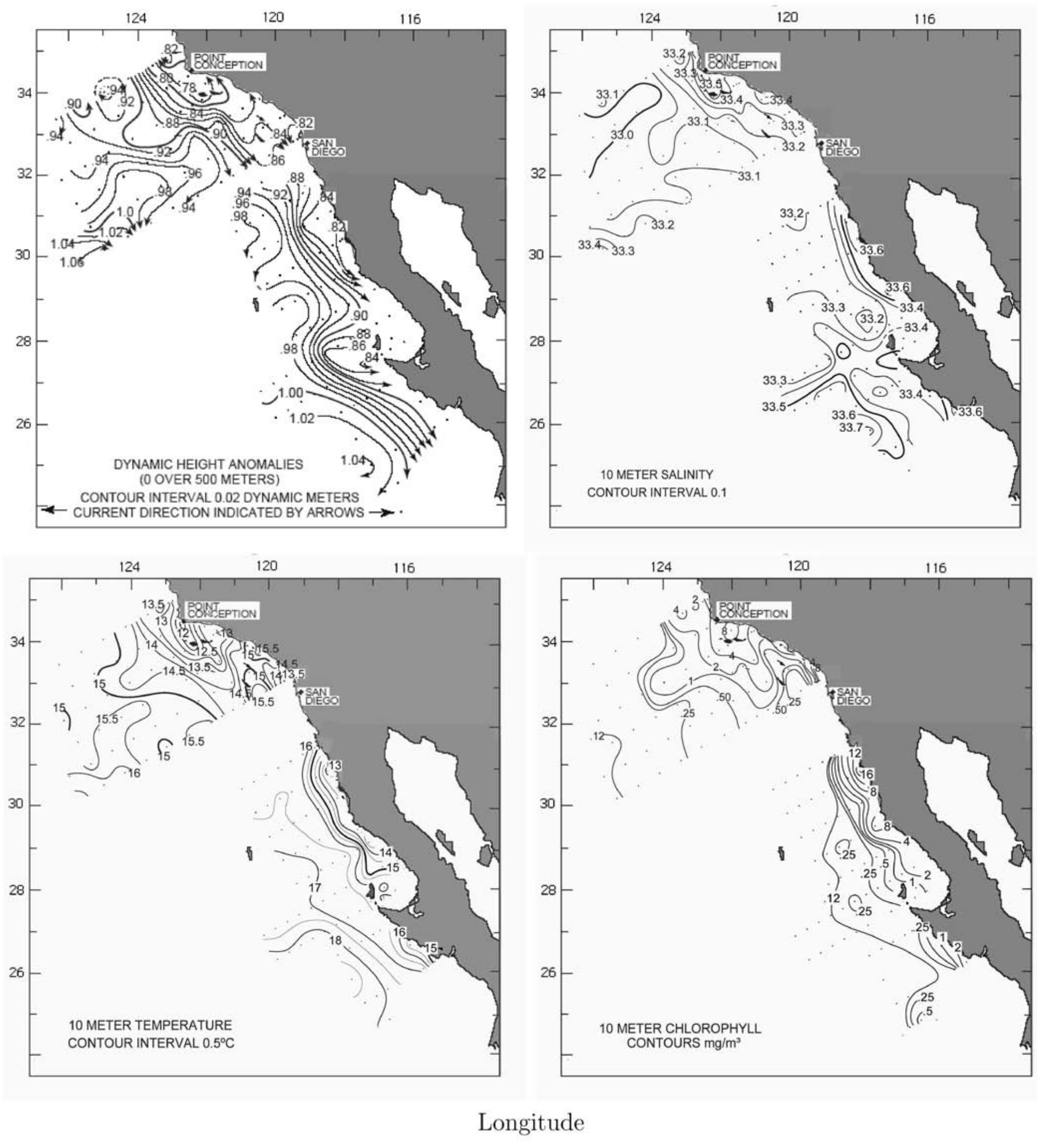


Figure 18. Spatial patterns for CalCOFI and IMECOCAL cruises in spring 2004, showing upper ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

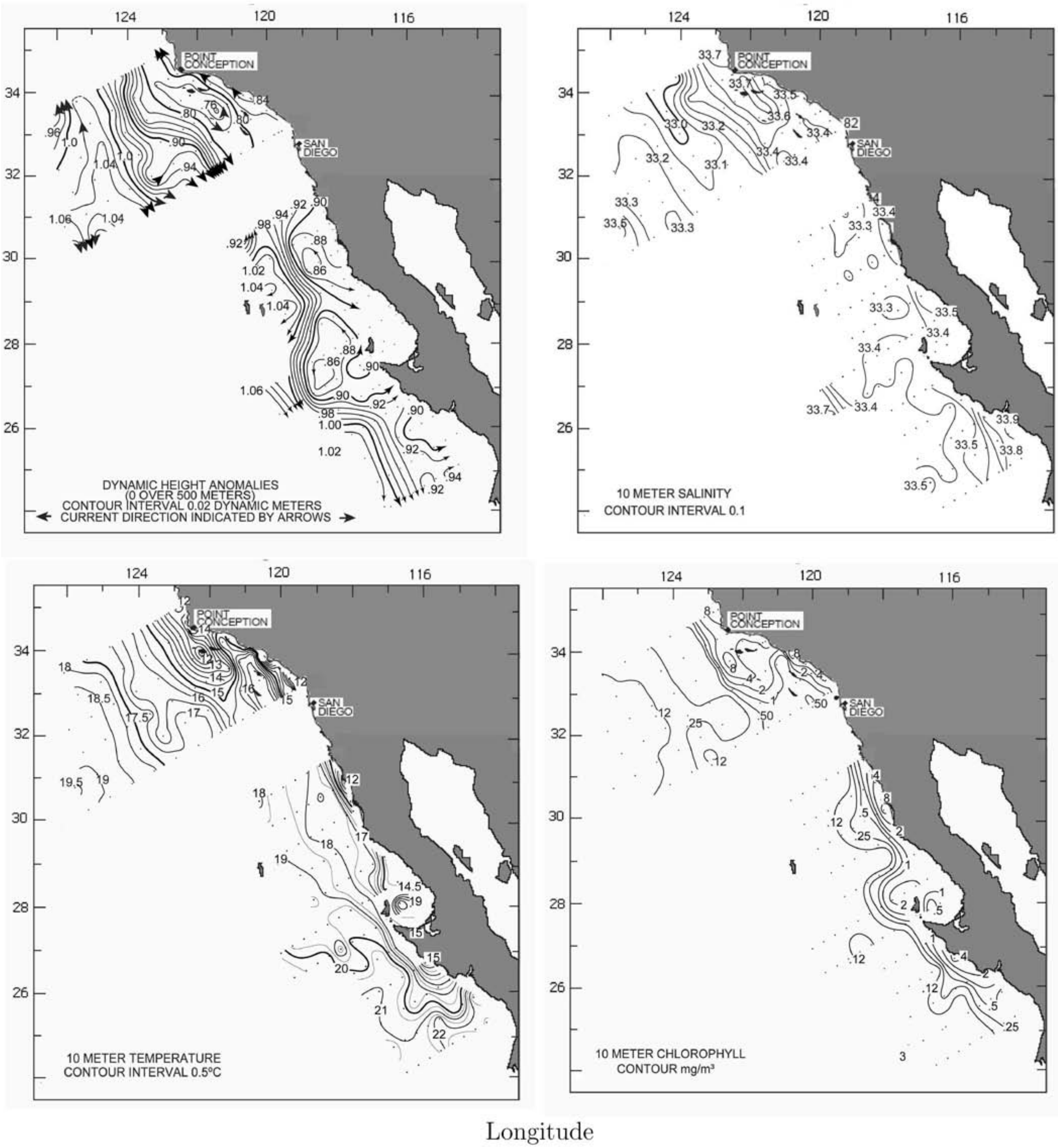


Figure 19. Spatial patterns for CalCOFI and IMECOCAL cruises in summer 2005, showing upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

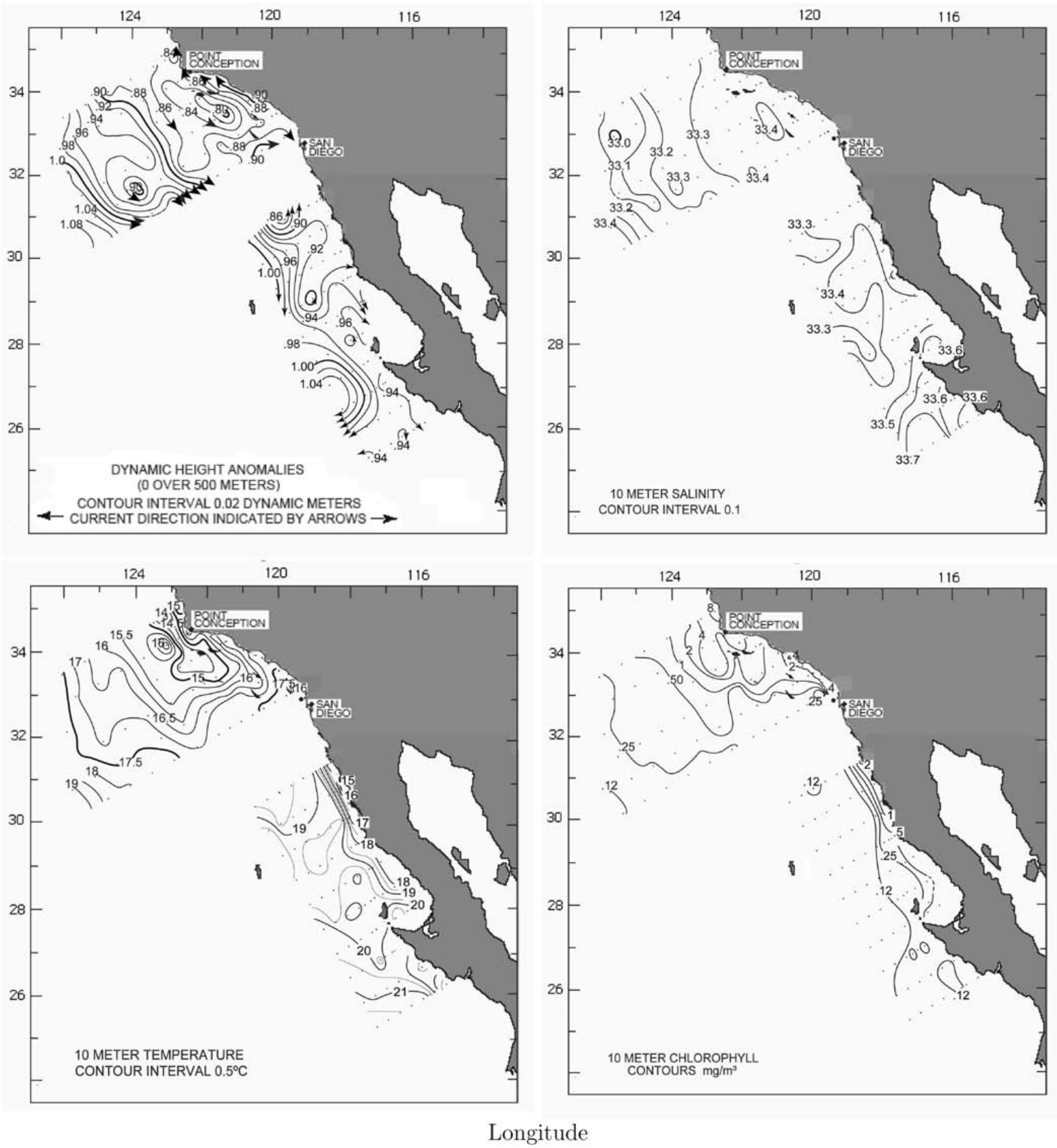


Figure 20. Spatial patterns for CalCOFI and IMECOCAL cruises in fall 2005, showing upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*. Data used for these plots are still preliminary.

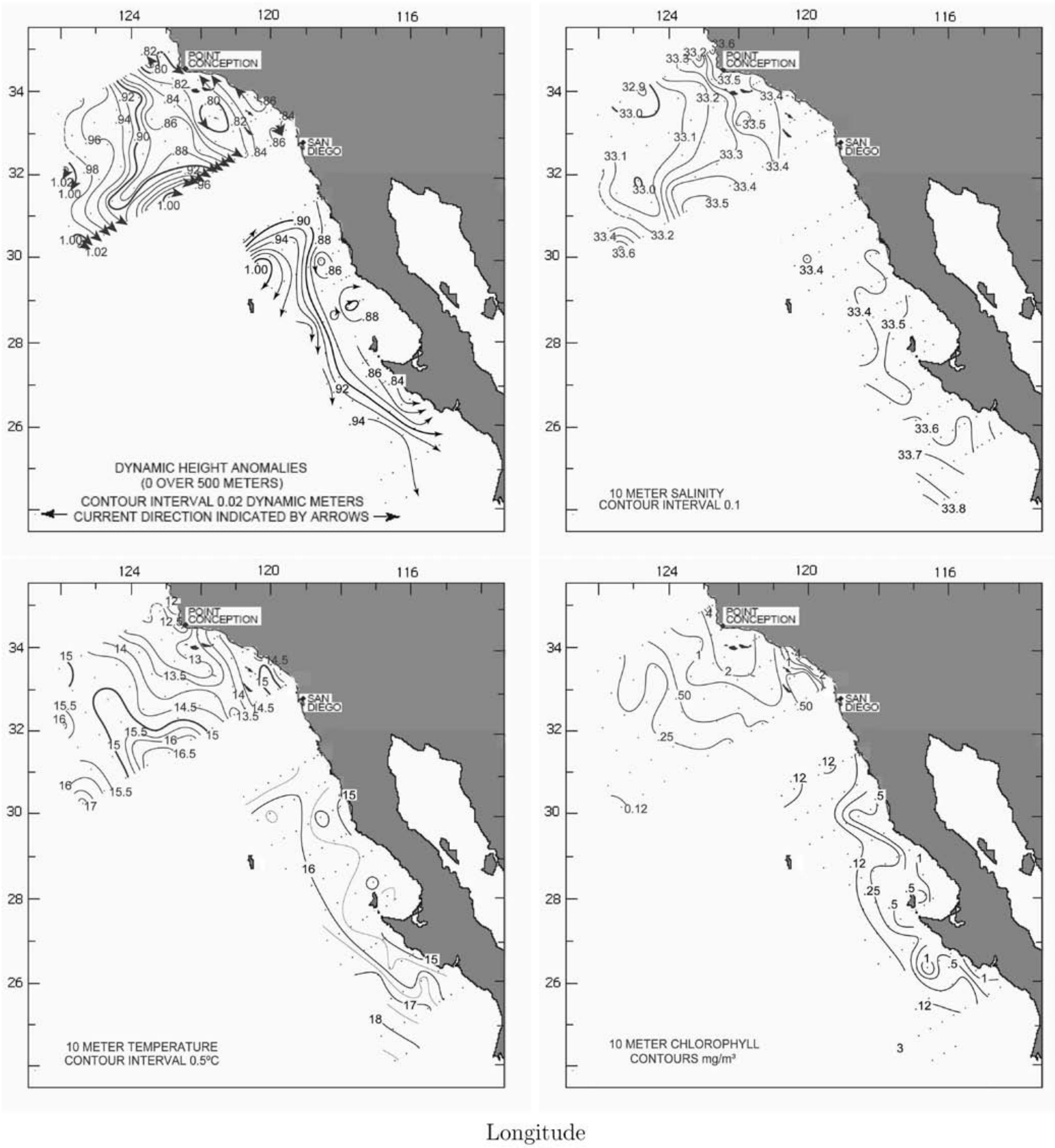


Figure 21. Spatial patterns for CalCOFI and IMECOCAL winter in February 2006 showing upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*. Data used for these plots are still preliminary.

season, and ran southward west of stations xxx.45. The jet was narrow and meandered around coastal cyclonic eddies that might have shed from recently upwelled water on the coast. Minimum temperatures (~12°C) occurred at the coast south of Ensenada (32°N), associated with pigments higher than 8 mg chlorophyll *a* m^{-3}. Zooplankton volume (not shown) follows the same pattern as that of chlorophyll, with the highest volume on record found at the Gulf of Ulloa (26.5°N). The eddy structures were linked to relatively high chlorophyll-*a* concentration and to slightly higher near-surface salinities. Temperature and salinity anomalies along the California Current jet indicated warmer and fresher waters, while those eastward, associated with eddies, indicated colder and saltier waters.

Fall 2005 (fig. 20)

CalCOFI 0511 (4–21 November). Compared with its location in April and July 2005, the California Current was found even farther offshore, still split in two branches with a cyclonic eddy between these branches centered on station 90.90. The Southern California Eddy, centered on stations 87.45 and 87.50, was as strong as it was during the summer. Water was flowing poleward along the coast, as is typical of this time of the year (Bograd et al. 2000). Somewhat elevated concentrations of chlorophyll *a* were found along the coast and off Point Conception.

IMECOCAL 0510 (13–27 October). Dynamic height contours portrayed a more diffuse, weaker, and meandering California Current. The 10 m salinity distribution suggested that the California Current core (S ~33.3) had been displaced off the limits of the survey region in most of the area. Coastal upwelling, as suggested by the 10 m temperature coastal minimum (T ~15°–17°C) and a chlorophyll *a* coastal maximum (chlorophyll *a* ~2 mg m^{-3}), was restricted to the northern portion, between Ensenada and Punta Baja.

Winter 2006 (fig. 21)

CalCOFI 0602 (3–22 February). Data for this cruise are preliminary. The flow patterns are similar to those observed during July and November 2005, with a strong California Current entering the area along the center of line 77 and splitting into two branches with an extended meander in the southern part of the study area. The Southern California Eddy was strong, still centered on stations 87.45 to 87.50. Low temperatures and high salinities were observed off Point Conception and farther north, suggesting localized upwelling. However, concentrations of chlorophyll *a* were still low, typical of winter conditions.

IMECOCAL 0602 (4–25 February). Property distributions for winter 2006 are mostly uniform throughout the survey region, typical of this season (e.g., Lynn and Simpson 1987). Temperatures ranged from 15° to 18°C, while salinities varied from 33.4 to 33.8. Chlorophyll-*a* values were low, also typical of the season, with highest (~1 mg m^{-3}) values inside Vizcaino Bay and south of Punta Eugenia.

BIOLOGICAL PATTERNS AND PROCESSES

Macronutrients, Chlorophyll *a*, and Primary Production

Oregon: The year 2005 was characterized by very low nutrient concentrations during spring months. At station NH 05, the average surface nitrate concentrations (March–June) were the lowest measured for our 10-year time series at 0.67 μM. This compares to 1.91 μM in spring 1998 (during the El Niño), and 5.03 ± 1.55 (95% CI) for March–June, averaged for the years 1997 and 1999–2004. After upwelling was initiated in July 2005, nitrate concentrations increased to 14.5 μM, the highest average concentration observed in our time series for July–August. This compares to the July–August average for 1997 and 1999–2004 of 10.53 ± 1.77 μM. The average for 1998 was only 2.3 μM. Table 1 summarizes these results.

Chlorophyll-*a* concentrations for April–June in 2005 were 2.9 μg per liter, the median value for the 10-year time series. The lowest chlorophyll values for the April–June period were from 1997–2000, averaging 1.7 μg per liter over this four-year period. Thus, although very low concentrations of nitrate may have limited phytoplankton growth in spring 2005, chlorophyll-*a* concentrations were not strongly affected.

The chlorophyll *a* values averaged over the upwelling season (May–September) ranged from 3.7 (1997) to 8.5 (2002) μg per liter; the 2005 value was near the median at 6.3 μg per liter. Thus, there is no evidence for any dramatic effect of warm ocean conditions on either

TABLE 1
Average nitrate (μM) and chlorophyll (μg chl-*a* L^{-1}) concentrations measured at the sea surface at station NH 05, five miles off Newport, in spring (April–June) and summer (July–August) for the years 1997–2005.

	Nitrate (μM)		Chlorophyll-*a* (μg chl-a L-1)	
YEAR	April–June	July–August	April–June	July–August
1997	5.21	7.95	1.14	6.1
1998	1.91	2.25	2.23	10.5
1999	4.95	10.20	1.79	5.5
2000	8.65	12.00	1.93	8.4
2001	4.16	9.43	6.59	9.0
2002	4.28	11.49	6.09	10.9
2003	4.37	10.30	2.99	9.7
2004	3.62	8.41	4.92	8.1
2005	0.67	14.49	2.94	8.7

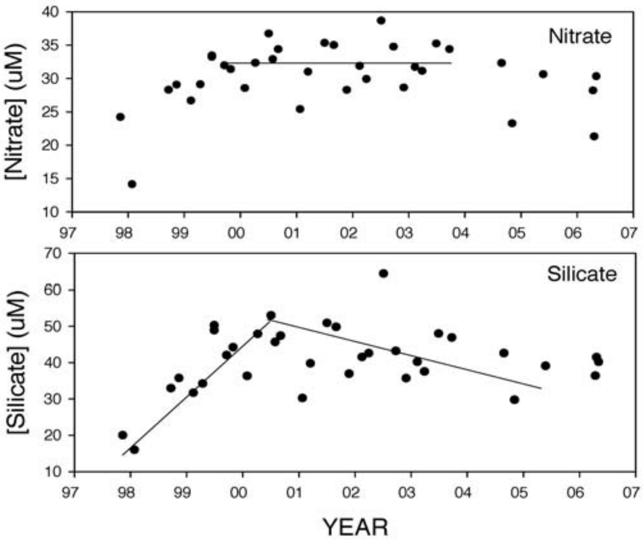


Figure 22. Time series of silicate and nitrate concentration from station NH 25 (25 miles off Newport, Oregon). Station depth is 300 m; sampling depth is 150 m. Note that in any given year, concentrations are lower in winter than summer.

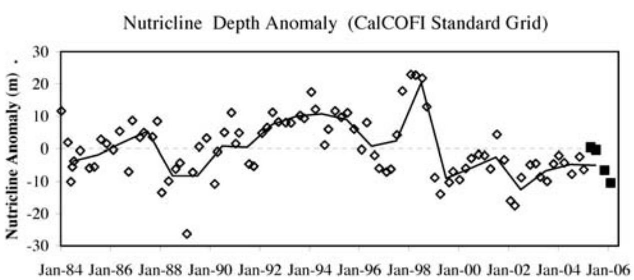


Figure 23. Cruise mean nitracline depth anomalies in the CalCOFI area. The nitracline depth is defines as the depth where nitrate reaches values of 1 µM. Data from the last four cruises are plotted as solid symbols. The solid line is the annual mean.

spring-averaged or seasonally-averaged chlorophyll concentrations in shelf waters off Newport in 2005.

Nitrate and silicate measured at a depth of 150 m at NH 25 are shown in Figure 22. One clear pattern is the increase in nitrate and silicate concentration from the 1997–98 El Niño period until 2002; since then, there has been a tendency toward lesser concentrations of each nutrient. These trends match the trend observed at 200 m both in the Monterey region and Southern California Bight (see below). Since late-2003, nitrate and silicate concentrations seem to have declined sharply. However there are too few data points to draw any firm conclusions. In 2006, we added water-bottle sampling from a depth of 150 m at our NH 25 station during our biweekly cruise, to allow us to measure the deep-water nutrients with greater certainty.

Central California: In Monterey Bay, sea surface nitrate concentrations were lower than average by 1 to 4 µM from early-2003 through late-2005 (fig. 10). The lowest values measured in spring 2005 (−4 µM anomaly) were similar to those measured during the 1998 El Niño event. By spring 2006, nitrate concentration were about 2 µM above average.

Sea surface chlorophyll *a* concentrations have been higher than average since 1999, and that trend continues (fig. 10). Slightly reduced concentrations were seen in summer 2002 and 2003; however, values in 2005 were among the highest measured. Thus, the warm ocean of 2005 did not have a dramatic negative effect on phytoplankton biomass, as indexed by chlorophyll-*a* concentrations, the same result as seen off Newport, Oregon. A similar pattern is seen with the primary production measurements with maximum above-average rates seen in the summers of 2002, 2003, and 2005.

Nitrate and silicate measured at a depth of 200 m in Monterey Bay (fig. 11) showed that concentrations of both nutrients were above average from 1999–present, except early in 2005 when silicate concentrations were slightly below normal, and from summer 2004 until the present when nitrate concentrations were below normal by 1–2 µM.

CalCOFI: Nitracline depth anomalies for the whole CalCOFI region were slightly below the long-term average over the last year (shallower nitricline; fig. 23), continuing patterns observed since 2000. Concentrations of mixed-layer nitrate varied over the past year; the annual average was close to the long-term average (fig. 24). It appears that concentrations of phosphate have been declining since 2003, a trend that requires further observations for confirmation. Over the last three cruises, concentrations of silica have been close to the long-term average, in contrast to observations during the previous two years which had the lowest silicate anomalies observed over the 23-year observation period. It is probable that silicate and salinity anomalies are linked since these have co-varied over the last six years. Last year's report suggested that these are linked to the possibly increased transport of subarctic waters into the CalCOFI area (Goericke et al. 2005).

Concentrations of all macronutrients at a depth of 200 m (e.g., nitrate, fig. 25a) co-vary strongly with salinity at depth (fig. 14), i.e., these have been relatively constant and above their long-term average since 1998. Nitrate-silicate ratios at 200 m were relatively constant over the last year (fig. 25b).

Temporal changes in nitrate concentration at the bottom of the Santa Barbara Basin (not illustrated) show that the basin flushed during the winter/spring of 2004 and the winter of 2005–06. Subsequent rates of denitrification, however, were sufficiently high to draw nitrate at the bottom of the basin down to values of 6.8 µM in November 2005. Concentrations of nitrite reached levels of 3.5 µM. These values for nitrate and nitrite during the fall of 2005 are similar to the

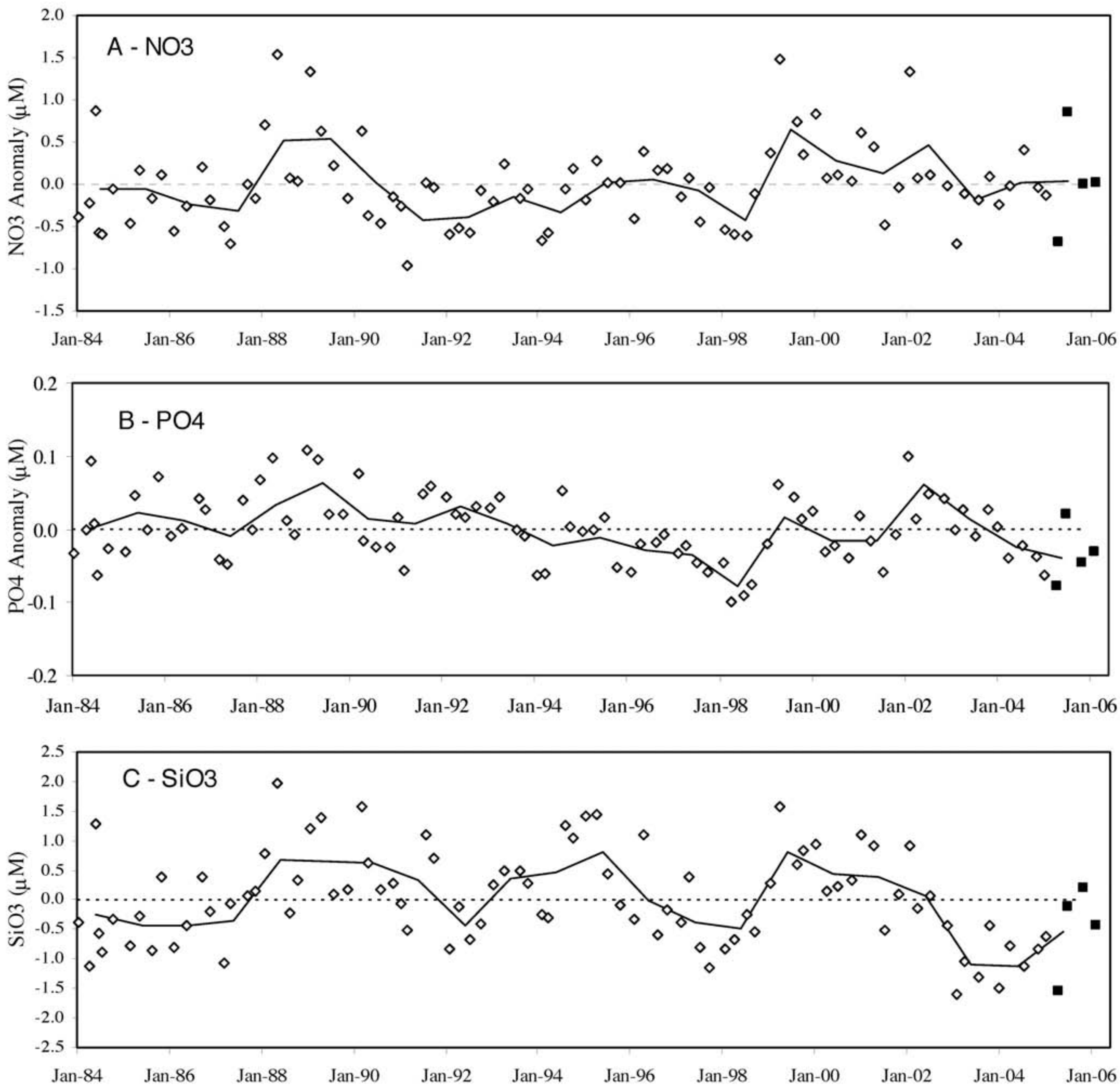


Figure 24. Anomalies of concentrations of (A) nitrate, (B) phosphate, and (C) silicate in the mixed layer of the CalCOFI area. Data from the last four cruises are plotted as solid symbols. The solid lines are the annual means.

record levels, lowest and highest, respectively, observed during late-2004 and early-2005 (Goericke et al. 2005). Corresponding rates of denitrification during 2005, approximately 0.09 µM day^{-1}, were similar to those observed during 2004, 0.06 µM day^{-1} (Goericke et al. 2005).

Standing stocks of chlorophyll *a* over the last year were similar to values observed over the last five to 10 years (fig. 26a). The values are consistent with the trend of increasing chlorophyll *a* observed since measurements began (for annual means, the $r^2 = 0.42$). Standing stocks during the summer and fall were among the highest measured during these time periods (fig. 26b). Depth-integrated rates of primary production over the last year were well within the range of rates measured over the last two decades (fig. 26c) and follow the previous seasonal pattern (fig. 26d). In contrast to annually averaged standing stocks of chlorophyll *a*, annually averaged rates of primary production have not increased over the last two decades ($r^2 = 0.01$).

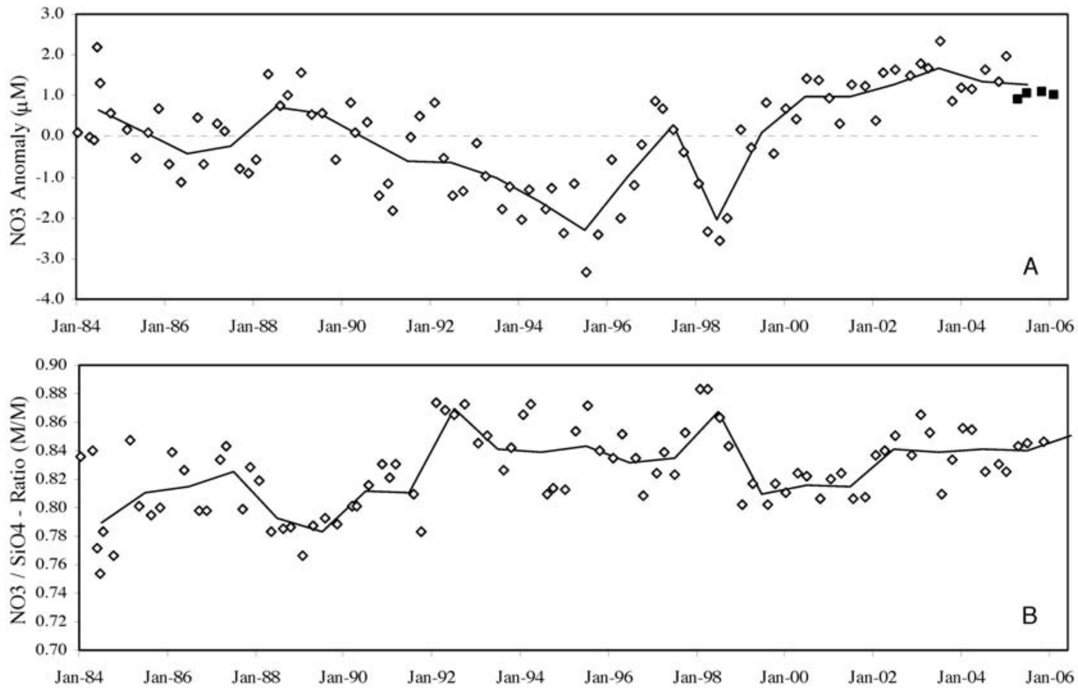


Figure 25. Nitrate (A) and nitrate/silicate ratios (B) at a depth of 200 m in the CalCOFI area. Data from the last four cruises are plotted as solid symbols. The solid lines are the annual means.

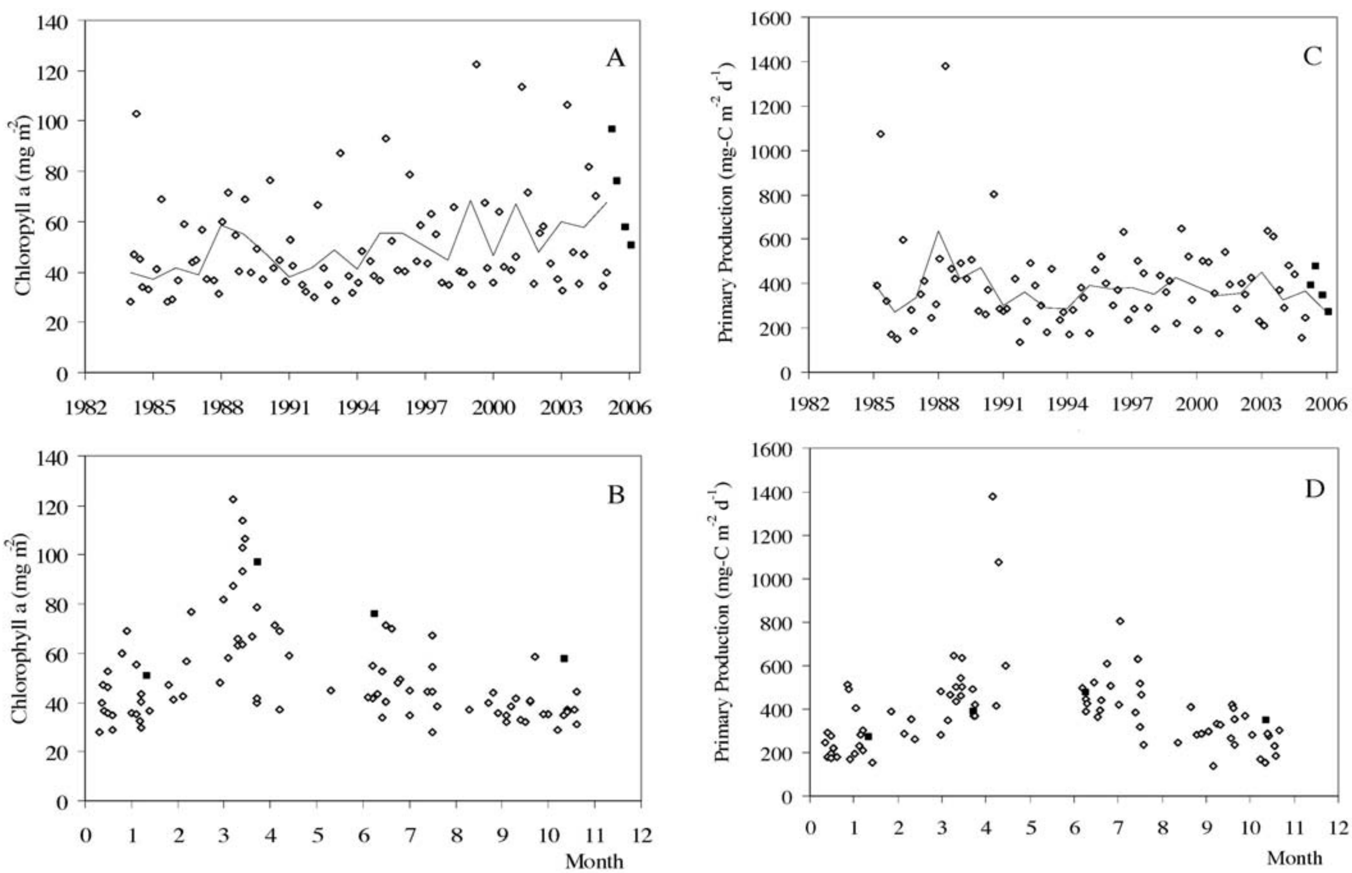


Figure 26. Averages for standing stocks of chlorophyll *a* in the CalCOFI area, plotted against time (A) and the day of the year (B), rates of primary production integrated to the bottom of the euphotic zone plotted against time (C) and day of the year (D). Data from the last four cruises are plotted as solid symbols. The solid lines represents the annual averages. Days within months are defined as fraction of the full month, i.e., January takes on values ranging from 0.0 to 1.0.

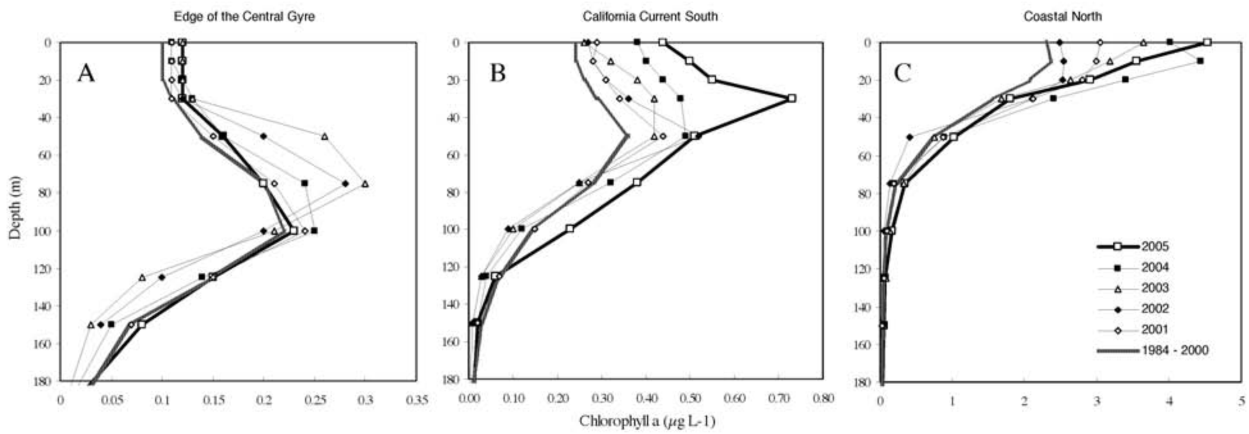


Figure 27. Depth profiles of chlorophyll *a* for the three areas of the CalCOFI region. (A) The edge of the central gyre (Line 90–93, Stations 100–120), (B) the California Current region (Line 83–90, Stations 70–90) and (C) the coastal areas in the north (Line 77–80, Stations 60 and inshore). Each data point represents the mean at one standard depth for the specified time period.

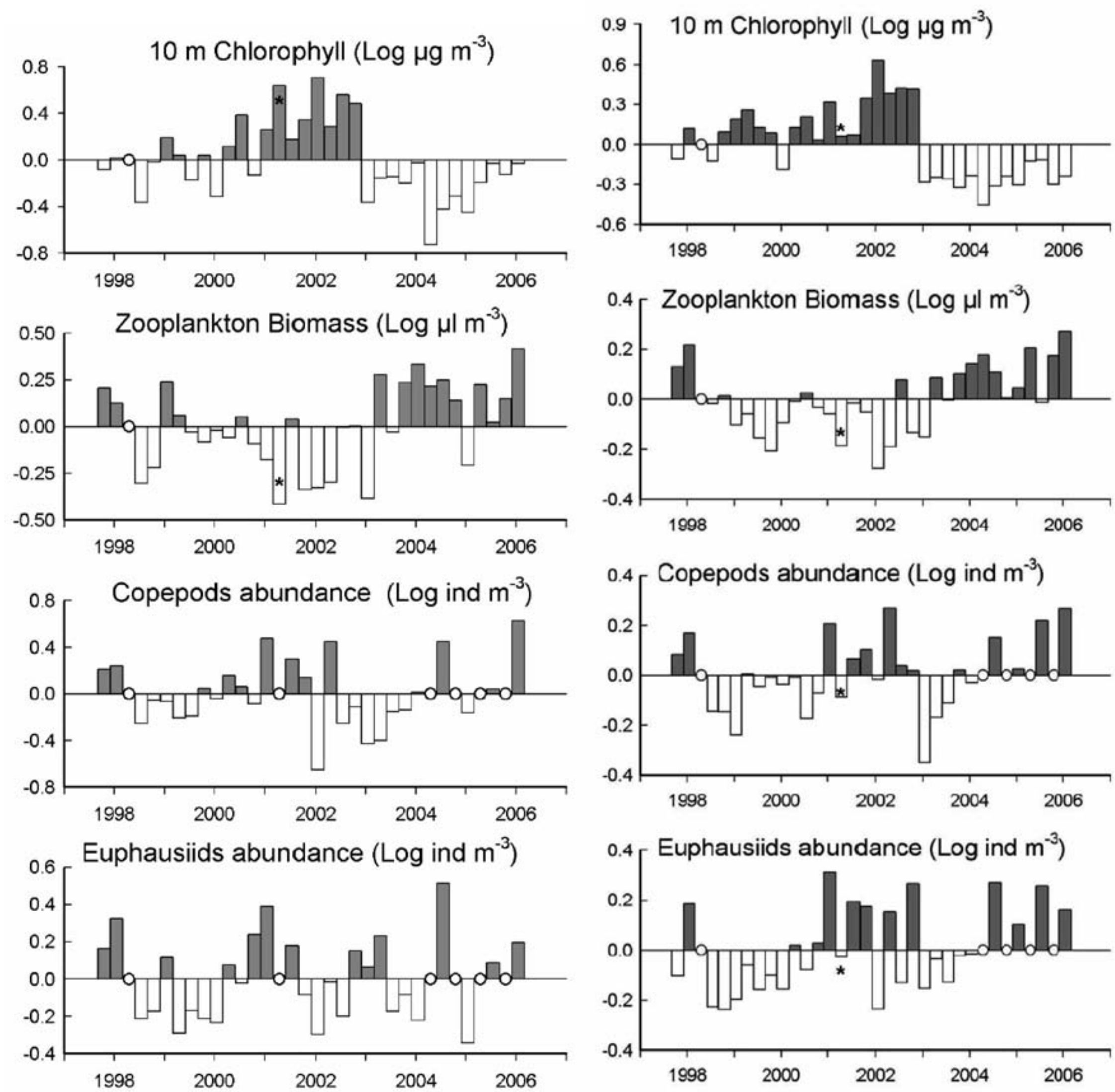


Figure 28. (Left) Plankton biomass (chlorophyll and zooplankton displacement volume), and nighttime zooplankton abundance (copepods and euphausiids) measured at offshore stations in IMECOCAL grid. (Right) Plankton biomass (chlorophyll and zooplankton displacement volume), and nighttime zooplankton abundance (copepods and euphausiids) at inshore stations in the IMECOCAL grid. Open circles indicate missing or un-analyzed cruises; the asterisk indicate data available only from north Baja California. Biological variables have been transformed to logarithms.

In most regions, the vertical distribution of chlorophyll *a* was close to the long-term average profile (fig. 27). At the edge of the central gyre (fig. 27a), where the deep chlorophyll-*a* maximum had been about 20 m above the climatological average during 2002 and 2003, the profile had returned to normal. The exception was seen in the southern portion of the California Current where concentrations of chlorophyll *a* in the upper 40 m were elevated relative to the long-term average (fig. 27b).

IMECOCAL: At the offshore stations, surface chlorophyll-*a* concentrations have dropped since January 2003, as is shown by a shift from positive to negative anomalies (fig. 28), changes associated with increased stratification. At the inshore stations, chlorophyll *a* showed a similar decrease, although the anomalies were more variable in time. The most negative anomalies occurred through 2004, and there was a progressive tendency toward zero anomalies between April 2005 and January 2006.

Zooplankton

Oregon: The 10-year time series of copepod biomass measured at Newport shows that a strong seasonal cycle with peaks in July–August prevailed during the summers of 2000–04. However, there was only a very weak seasonal signal in 1997–99, and in 2005 (fig. 29). Seasonally-averaged (May–September) copepod biomass measured in 2005 had the lowest value of the recent 10-year time series (fig. 29)—about 9 mg carbon m^{-3}—and the lowest value compared to data from 1969–73 and 1983. We attribute this decline in biomass to a lack of significant levels of copepod production in spring 2005 due to the delayed spring transition.

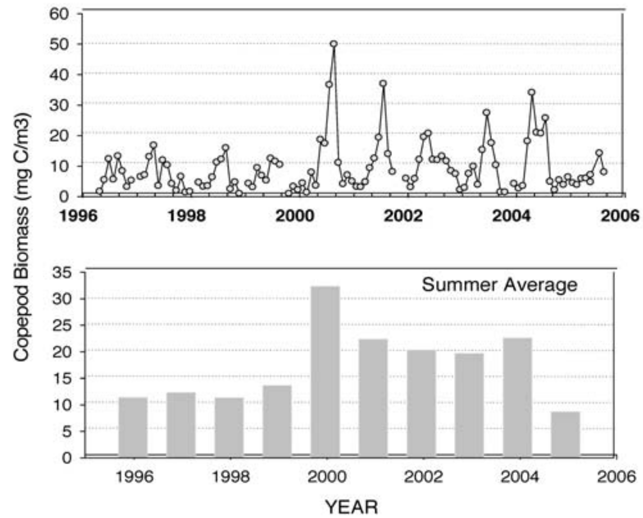


Figure 29. Time series of monthly-averaged values of copepod biomass measured at a mid-shelf station (NH-05), off Newport, Oregon, 1996–present (UPPER). Summer-averaged values of copepod biomass measured at NH-05 (LOWER). Note that the summer of 2005 had the lowest average biomass for any summer in our 10-year time series.

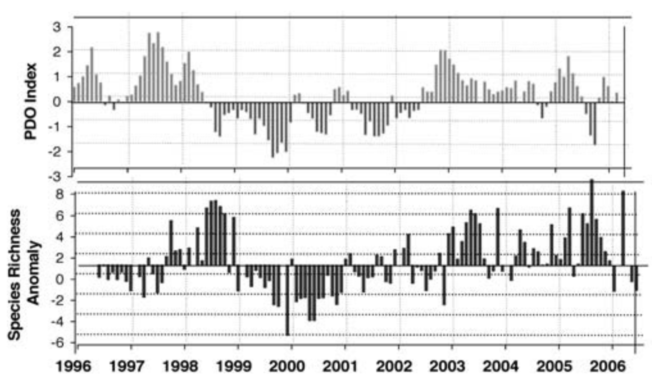


Figure 30. Time series of copepod species richness at station NH-05 off Newport, Oregon, and the Pacific Decadal Oscillation, from 1996 through May 2006.

Figure 30 shows that copepod species richness was anomalously high from autumn 2002 through spring 2006, during the period of warmer-than-average sea surface temperatures. Copepod species richness was very high in 2005, and remained anomalously high throughout spring and summer months. Thus, despite strong upwelling from late-July through September 2005, the copepod community did not immediately change from one dominated by a highly-diverse warm-water community to one dominated by a low-diversity cold-water community. Instead there was a time lag of several months, with high species richness prevailing until November–December of 2005. We suggest that anomalously low numbers of copepod species are associated with the transport of coastal subarctic water into the coastal waters of the NCC (as in 1999–2002), whereas anomalously high numbers of species are associated with either a greater amount of onshore transport of warm, offshore, subtropical water, or northward transport of subtropical coastal neritic water along a coastal corridor (as in late-2002 to early-2006).

The two persistent changes in copepod species richness in late-1998 and late-2002 lag the PDO by about six months (fig. 30). The two transition points were: (1) the change to a negative anomaly of species richness in December 1998, which was preceded by a change in sign of the PDO in July–August 1998, and (2) a change to a positive anomaly of species richness in November 2002, which followed changes in the PDO in August and April 2002. The same lag was seen when PDO and SST were compared (fig. 7). Thus, comparing the PDO, SST, and copepod species richness indicates that the coastal ecosystem in the northern California Current off Oregon was warmer than usual two years prior to the warm summer of 2005, with a dominance of subtropical neritic zooplankton species (see Hooff and Peterson 2006 for details). The warm summer of 2005 was the third such year in a row, suggesting the possibility that

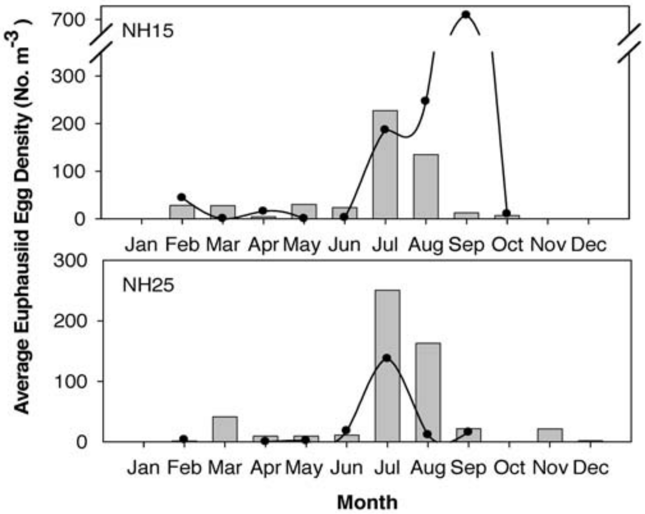


Figure 31. Monthly averages of euphausiid eggs for all samples at two stations along the Newport Line from 1996–present (bars), compared to abundances observed during the warm summer of 2005 (spline). Note the one month delay in the peak in egg production in 2005 (from July–August to August–September).

TABLE 2

Abundance of euphausiid eggs (number m^{-3}) along the Newport Line at stations 5, 15, and 25 miles from shore, averaged for spring (March–June) and summer (July–August). Water depths at these stations are 62 m, 92 m, and 300 m respectively. The dashes (—) indicate that samples were not collected during that year.

	March–June			July–August		
	NH 05	NH 15	NH 25	NH 05	NH 15	NH 25
1996	0.4	—	—	45.2	—	—
1997	0.6	5.1	—	50.0	97.2	—
1998	0.2	8.5	—	0.5	84.1	—
1999	99.3	15.3	—	27.3	75.4	—
2000	22.9	8.0	—	437.7	332.2	—
2001	11.4	11.2	1.7	52.1	366.8	102.9
2002	3.8	13.0	23.4	112.5	107.4	215.6
2003	0.2	84.1	14.4	18.2	101.1	515.3
2004	6.9	39.9	28.5	154.1	212.8	251.4
2005	0.2	3.4	4.4	38.8	231.5	143.2

deleterious effects on the ecosystem observed during summer 2005 may have been due to three years of chronic warming.

The seasonal cycle of euphausiid egg abundances at stations NH 15 and NH 25 along the Newport Line is shown in Figure 31. A minor peak in abundance can occur in winter (in either February or March), but the major spawning time is clearly during summer (July–August). This pattern corresponds to the tendency of *Thysanoessa spinifera* to spawn in winter-spring and for both species (*T. spinifera* and *Euphausia pacifica*) to spawn in summer. Interannual variability is very high, with seasonal averages of egg abundances ranging over an order of magnitude (tab. 2). The year 2005 was exceptional in that few eggs were found at any station in spring, but an average number of eggs were found in July–August. The appearance of large numbers of eggs in summer of 2005 did not occur until after the onset of strong upwelling in mid-July.

Monterey Bay: Sampling of zooplankton along CalCOFI Line 67 has been sporadic since 1985, but has been carried out on a regular basis for the past three years. Zooplankton displacement volumes measured in 2005 were very low, similar to values measured during the tropical El Niño events of 1983 and 1998 (not shown; see Mackas et al. In review). Strong negative biomass anomalies were seen for both transition zone copepods and central/equatorial copepods. The two most common euphausiids, *Euphausia pacifica* and *Thysanoessa spinifera*, also had negative biomass anomalies (not shown: see Sydeman et al. 2006).

CalCOFI: Data for macrozooplankton displacement volumes are available up to November 2005. The annual average for 2005 (86 ml/1000 m^3) was close to the long-term average (horizontal line in fig. 32). The decline in zooplankton biomass from the early sixties until the late nineties has been extensively described (McGowan et al. 1998 and previous reports in this series). Zooplankton displacement volumes recovered with the advent of the 1999 La Niña conditions and have since been at levels similar to those observed during the 1980s. However, the annual averages since 1999 show a declining trend with a regression coefficient that is similar to that characteristic of the 1984–98 time series (fig. 32). Considering the high cruise-to-cruise variability of these data it is prudent to wait for more data before attempting detailed interpretations of these trends.

Like copepods in Monterey Bay, both transition-zone and central/equatorial copepod species had negative biomass anomalies (not shown; see Mackas et al. In review). On the other hand, for the more common euphausiid species, *E. pacifica* biomass was equal to the long-term mean, whereas *T. spinifera* had a positive biomass anomaly (Sydeman et al. 2006).

IMECOCAL: Zooplankton biomass in 2005 was **higher** than average during the IMECOCAL surveys, in contrast to measurements made in the rest of the California Current. This was due to higher-than-average biomass of both copepods and euphausiids (fig. 28). Zooplankton biomass has increased since April 2003. However, a closer inspection of the abundance for the main suspension feeding crustaceans indicated a dramatic decrease from October 2002 to January 2003 (not shown), with a progressive recovery for copepods, but a step-response for euphausiids, since July 2004.

The zooplankton biomass in shallow-water stations showed positive anomalies that were relatively high in 2003–06, with negative anomalies observed only in the winters of 2003 and 2005 (fig. 28). Negative abundance

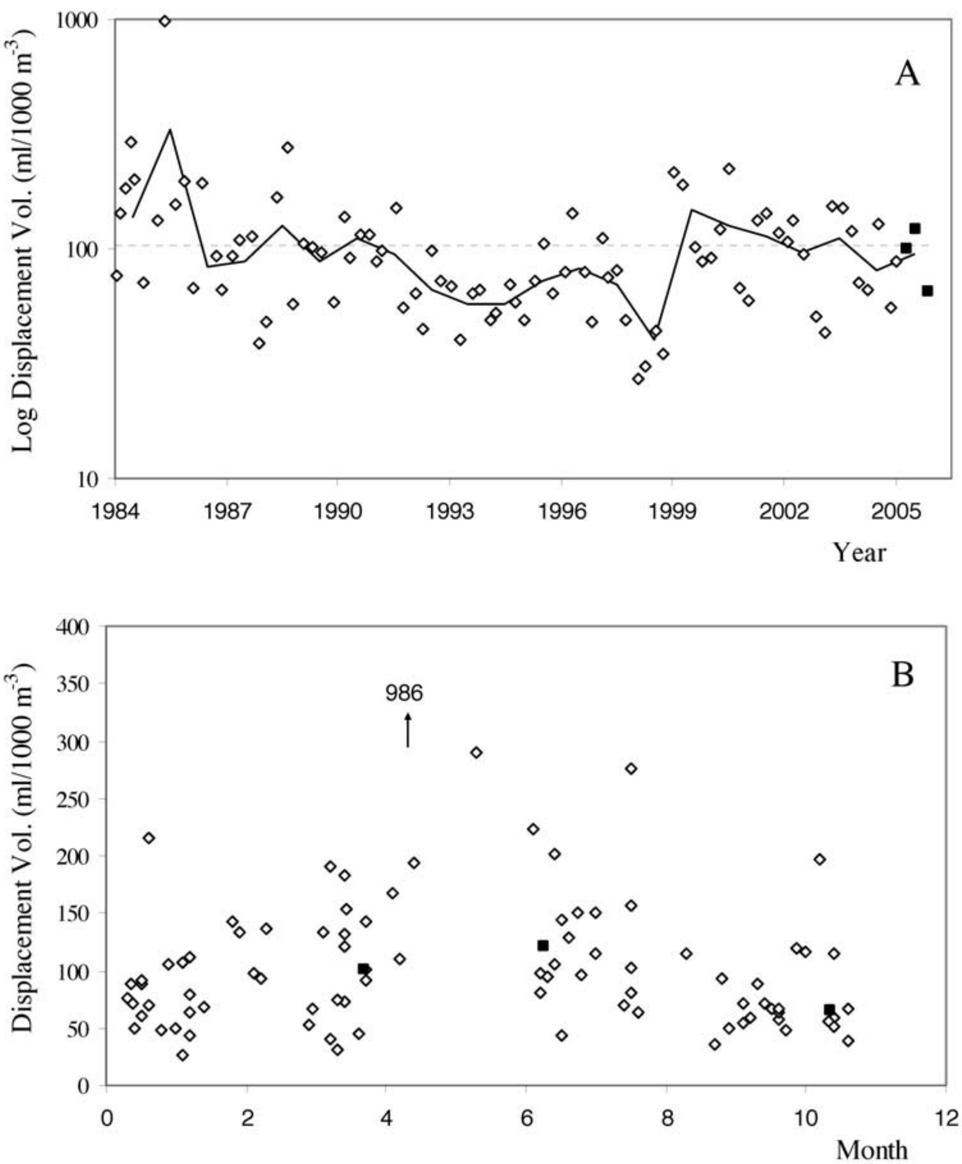


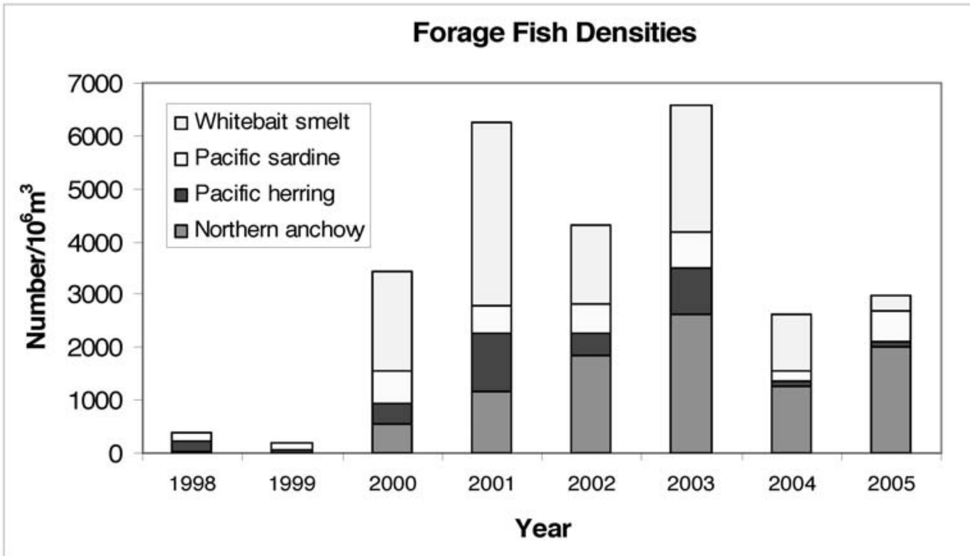
Figure 32. CalCOFI cruise mean macrozooplankton displacement volumes plotted against the year (A, log axis) and the month of the year (B, linear axis). The climatological average is shown by the horizontal striped line in A. Annual averages are connected by the solid line. Linear regressions of values vs. time for the time periods 1984 to 1998 and 1999 to 2005 have identical regression coefficients (−0.035).

anomalies of copepods and euphausiids were seen during January 2005 near the coast, while offshore the anomalies were positive (fig. 28). By July 2005, strongly positive anomalies occurred offshore, but anomalies were close to zero on the shelf. However, we found huge abundances of copepods and euphausiids in Vizcaino and the Gulf of Ulloa, but low abundance along the northern coast.

Another interesting feature of the offshore and inshore plankton time series is that zooplankton biomass seems to be inversely related to both salinity (fig. 16) and chlorophyll (fig. 28). This relationship could reflect either the transport of different plankton communities into Mexican waters as reflected by higher or lower salinity, or a strong coupling between phytoplankton and zooplankton through grazing.

Fish

Oregon and Washington: Forage Fish (whitebait smelt, herring, anchovies, sardines). Pelagic rope-trawl surveys off the Columbia River and southern Washington state captured very low numbers of forage fishes during the 1998 tropical El Niño event and during 1999 (fig. 33). By 2000, stocks had increased greatly by factors ranging from 5.6 (sardines) to 240 (whitebait smelt), and continued to grow through 2001. Forage fish densities peaked



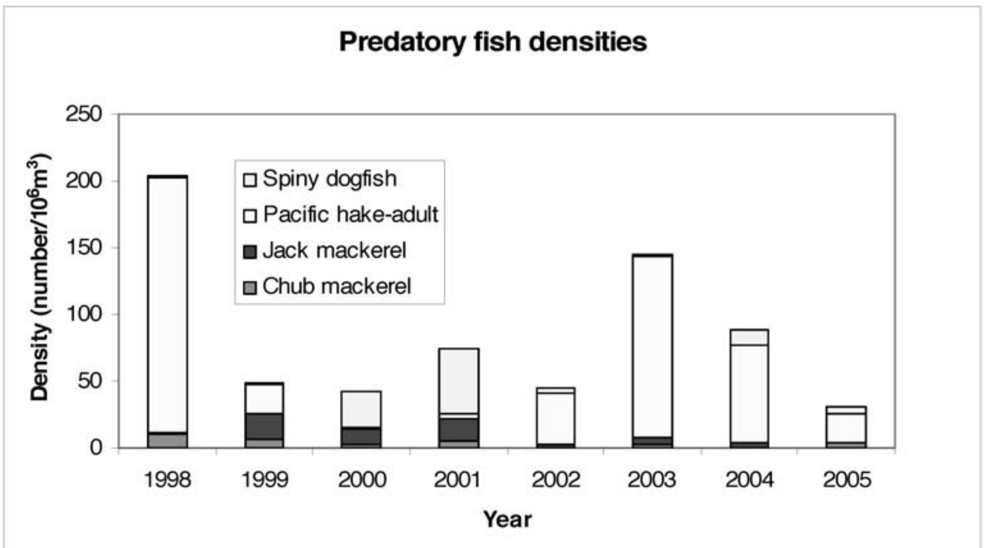


Figure 33. Densities of forage fish and predatory fish from rope trawl surveys conducted in coastal waters off southern Washington.

in 2003 after four years of cool, productive ocean conditions (1999–2002), but then declined in 2004–05 following the change to warm-ocean conditions in 2003 (fig. 7). Despite the return to warm-ocean conditions in 2003–05, numbers of anchovies and sardines remained high through 2005, whereas herring and whitebait smelt declined to only 10% of their maximum numbers observed in 2001. Because most forage fish recruitment (i.e., the larval-to-juvenile transformation, which occurs in summer and fall) happens after our survey period (spring and early-summer) we do not catch most forage fishes until they are at least one year old. Thus, forage fish densities appear to reflect oceanographic conditions from the previous year. For example, during the 1998 El Niño the forage fishes had little if any recruitment success and this was shown by the extremely low forage fish densities in 1999. However, the excellent ocean conditions in 1999 (cool ocean, early spring transition, etc.) resulted in very high forage fish densities in 2000.

Preliminary results of the 2006 surveys suggest forage fish densities as low as those observed in 1998. Herring populations appear to be particularly low in 2006. This indicates very poor forage fish recruitment from spawning that occurred in 2005, and that the very warm and poor ocean conditions in 2005 will correlate very strongly with the decline in forage fish densities in 2006.

Oregon and Washington: Predatory Fish (Pacific hake, Jack and chub mackerel, and spiny dogfish). Catches

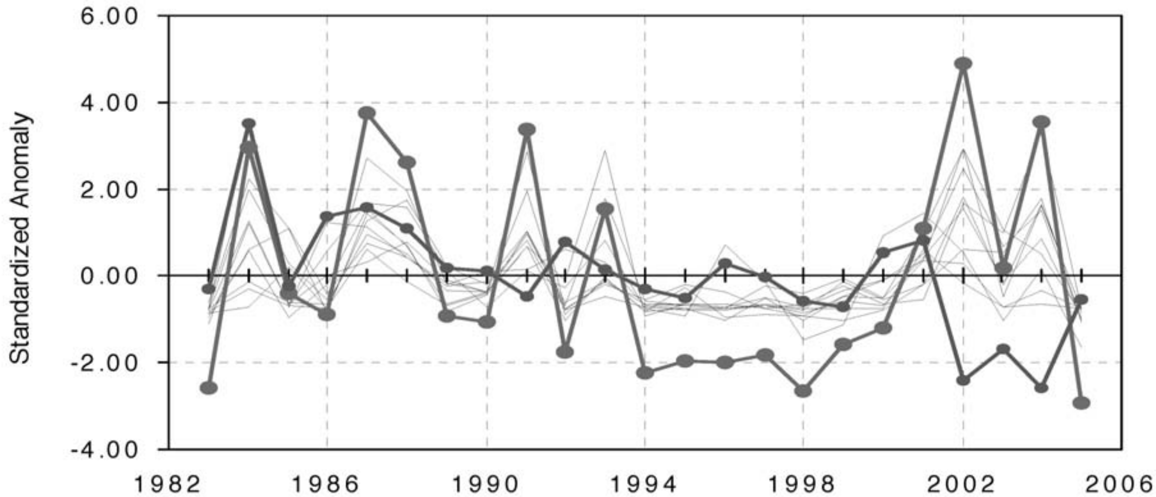


Figure 34. Time series of juvenile rockfish within the core area off central California. Long term trends in reproductive success of 10 species of rockfish (genus *Sebastes*) are shown on log-scale (individual species patterns are shown as thin black lines). The bold lines represent the first and second principal components scores, respectively, which together account for 75% of the total variance.

of adult Pacific hake with the rope trawl were somewhat related to ocean conditions, with highest catches during the warm 1998 tropical El Niño event, low catches during the four cool years (1999–2002), but with increasing abundances during the warm years of 2003–04 (fig. 33). We had expected to see increased numbers of adult Pacific hake in 2005 both because numbers were building in 2003 and 2004, and because hydrography and zooplankton in the Pacific Northwest in 2005 resembled the 1998 El Niño event. However, this expectation was not met; it is not known why numbers were low although it is possible that the bulk of the adult hake population is living more to the north, in Canadian waters (Thomas et al. 2006; see also the discussion of larval hake, central and southern California, below). Both Jack mackerel (*Trachurus symmetricus*) and spiny dogfish (*Squalus acanthias*) had highest abundances during the cool years, 1999–2002. Abundances of chub mackerel (*Scomber japonicus*) did not seem to be related to either cool- or warm-ocean conditions since they were most abundant during the warm 1998 El Niño and the cool years of 1999 and 2001.

Central California: Pelagic Juvenile Young-of-the-Year Rockfish (**Sebastes** ***spp.).*** During 2005, the standardized midwater trawl surveys conducted by SWFSC indicated that pelagic juvenile rockfish catches in the core area (Carmel to Bodega Bay, California) were at an all time low when considered in relation to the 23 years the survey has been conducted (fig. 34). However, it is important to note that with the new data available from the expanded survey coverage in 2005 (spanning San Diego, California to Westport, Washington), two types of shifts in distribution were revealed. Specifically, species characterized by a more southerly geographic range (e.g., bocaccio, shortbelly, and squarespot rockfish) were caught in relatively large numbers south of Point Conception. Conversely, species with more northerly distributions (widow, canary, and yellowtail rockfish) were caught in moderate numbers north of Cape Mendocino. The near absence of fish in the core survey area was associated with a redistribution of fish, both to the north and the south, as well as overall lower abundances.

There has been tremendous interannual variability in the abundance of the 10 species that are routinely indexed in the survey. The overall pattern in the survey (fig. 34) is one of very high concordance in abundance among the 10 species. A number of striking patterns are evident including: (1) substantial high-frequency interannual variation (e.g., 1991–92), and (2) obvious low-frequency variability, as evidenced by the protracted period of low abundance from 1994–2000. The first of these conclusions is consistent with very poor reproductive success for these winter-spawning species during El Niño years, including the 1983, 1992, and 1998 events. The second observation is likely related to "regime"-scale variability, as evidenced by the PDO, wherein rockfish reproductive success is poor during the "warm" phase.

Figure 35 shows the first two principal component scores for the collective rockfish assemblage within the core survey area. Note the divergence in the relationship between the first and second principal components, which are positively correlated early in the time series (through ~1993) but are negatively correlated thereafter. This change in relationship may be due to a shift in the species composition of survey catches towards a more northern assemblage, particularly during the last four years, as evidenced by relatively higher catches of blue, black, widow,

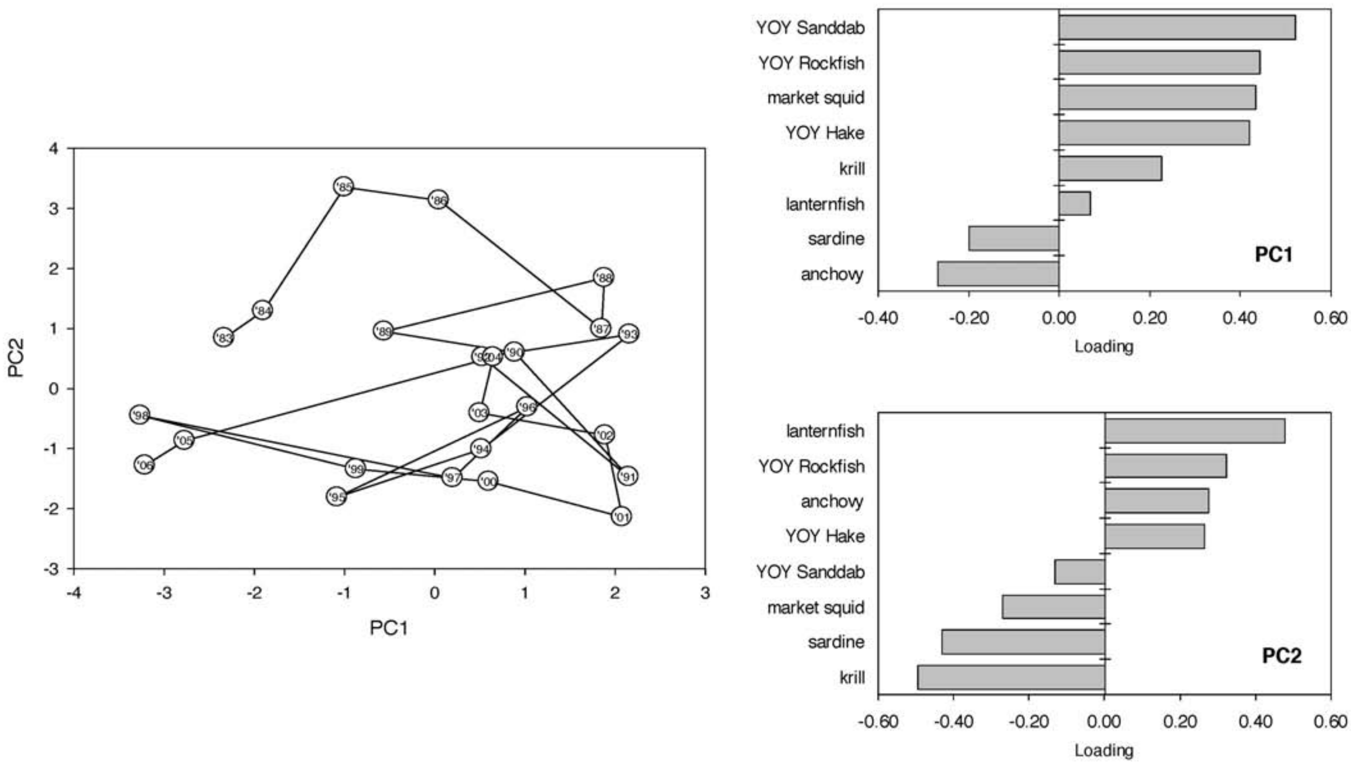


Figure 35. Principal components analysis (PCA) of the eight most important rockfish taxa within the core area; 2006 was similar to 2005 in terms of overall abundance patterns and species composition. Note similarity to the 1998 El Niño event as well.

and canary rockfish in relation to catches of shortbelly, bocaccio, chilipepper, and squarespot rockfish.

The extremely low abundances of juvenile rockfish in 2005 are consistent with an anomalously warm ocean state. The production of many populations was extremely low in 2005, perhaps a result of a delayed onset of seasonal coastal upwelling in spring and low primary production. Populations were also redistributed to the north. Given the lower production of rockfish, management must consider the long-term impacts of future warm conditions on annual recruitment. It is also noteworthy that preliminary indications are that the spring 2006 was equally anomalous.

Central and Southern California: Pacific Hake (**Merluccius productus*****).*** Since 2003, five sampling lines north of Morro Bay have been reinstated into the CalCOFI sampling pattern in the January survey, primarily to collect hake larvae for comparison with samples collected before the range restriction post-1984. Pacific hake is a migratory species occurring off the west coast of the American continent between Baja California and British Columbia. Pacific hake larvae live below the mixed layer in colder water and have been obtained as far offshore as 200–250 miles. Conventional wisdom is that adult hake migrate south in autumn from the Pacific Northwest to the waters off California and Baja California in order to spawn, then return north in spring where they feed during summer months (Hollowed 1992). It is believed that during warm years, the spawning center moves northward where they may spawn as far north as Oregon (R. Emmett, personal communication, NMFS/Newport, Oregon), whereas during cool years the spawning center is located between mid-Baja California and San Francisco. The expansion of winter CalCOFI sampling for hake larvae is designed to test the idea of a northward-shifting spawning center.

The time series of daily larval production at hatching (P_h) from 1951–2005 (earlier years from Moser et al. 1993) is shown in fig. 36 for the area between San Diego and San Francisco in January–April, the peak spawning period.

The daily larval production fluctuated with a grand peak in 1987 and minor peaks at 1952, 1958, 1966, and 1972. The larval production has been declining since 1987 in this survey area. The comparison between the larval production and the temperature at 57 m depth where yolk-sac larvae concentrate (fig. 36), shows that the temperature has been increasing from mid-1970 to mid-1990 and decreasing since 1997. Peaks of larval production tend to coincide with the low points of temperatures. The high production off California may be partially related to migration of a large biomass of hake that migrated to the California waters from the north when the water temperature decreased dramatically. Hake larval produc-

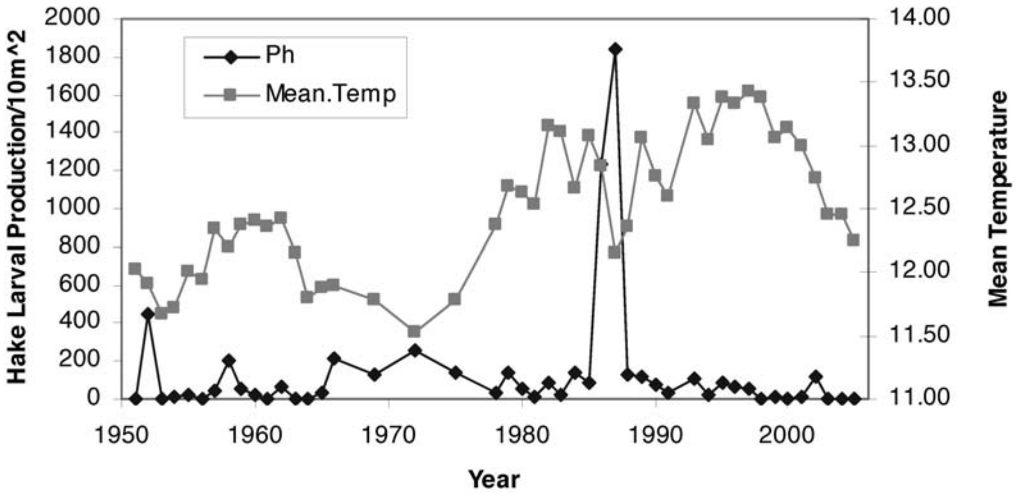


Figure 36. Time series of daily hake larval production /10m² (P_h) between San Diego and San Francisco, California, and mean the temperature at the 57 m depth experienced by yolk-sac larvae in 1951–2005.

tion has been declining since 1987. (See also the discussion of adult hake, Oregon and Washington, above.)

Southern California: Spawning by Sardines, Anchovy and Jack Mackerel. In spring 2005, eggs of sardine and Jack mackerel were not abundant compared to other recent spring values, while anchovy eggs seemed to be quite abundant (fig. 37). Sardine eggs were most abundant between San Diego and Avila Beach in a narrow strip and fewer were observed in the north than in 2004 (Goericke et al. 2005). Anchovy eggs were relatively abundant and were confined to the Southern California Bight; Jack mackerel eggs were offshore of the sardine eggs, with relatively little overlap, a pattern seen in other years. Like sardine eggs, both anchovy and Jack mackerel eggs were centered in the area south of Avila Beach. Overall, sardine and anchovy eggs were more abundant than Jack mackerel eggs. In 2005, sardine eggs were found in temperatures ranging between 12°C and 18°C; the majority of eggs were found between 13°C and 16°C. The mean sea surface temperature weighted by abundance of sardine eggs was 14.2°C. In 2003 and 2004, sardine eggs were found in the area between 12°–14°C sea surface temperature, and the mean weighted temperatures were 13.7°C and 13.4°C, respectively. (For more information, see http://swfsc.nmfs.noaa.gov/FRD/CalCOFI/CurrentCruise/sardmaps.htm.)

The spawning biomass of Pacific sardine is a fishery-independent population index, useful for examining the past relationship between spawning and sea surface temperature (Lo and Macewicz 2006). The spawning biomass of Pacific sardine is positively related to the daily egg production, in particular if the number of oocytes per biomass weight remains constant (Lo et al. 2005). The relationship between the daily egg production per $0.05m^2$ and the average sea surface temperature (°C) during 1994–2005, indicated that in most years, except in 1997 and 2002, the increase of daily egg production coincides with the increase of sea surface temperature (fig. 38). This relationship is consistent with high temperature being favorable for the Pacific sardine (Jacobson and MacCall 1995).

Southern California: Lanternfish and Lightfish Larvae. *Stenobrachius leucopsarus*, the Northern Lampfish, is a subarctic-transitional, midwater species that inhabits California Current waters south to the central Baja California Peninsula and ranges westward in the transitional zone. Larvae are present year-round, but with a strong winter-spring maximum and very low incidence and abundance during summer and fall. During the 1977–98 warm regime its larval distribution off southern California contracted shoreward and northward compared with the preceding cool period, although no consistent long-term change in larval abundance was apparent. With the advent of cool-ocean conditions following the strong El Niño of 1997–98, both frequency of larval occurrence and larval abundance off southern California began to increase and the distribution began to expand seaward and southward, much like the pre-1977 pattern. However, these trends were short-lived, with both abundance and incidence declining in 2003 and 2004, and the larger catches once again being made at more northern and shoreward stations. In 2005, larval abundance was lower again, about half of 2004 abundance, with the largest decline off central California (~40% of the 2004 abundance). Most of the largest catches in 2005 were at more shoreward and northern stations. Similar patterns were seen for the blue lanternfish, *Tarletonbeania crenularis*, another subarctic-transition-zone species.

The Panama lightfish, *Vinciguerria lucetia*, is a **tropical-subtropical**, midwater species that ranges from Chile to

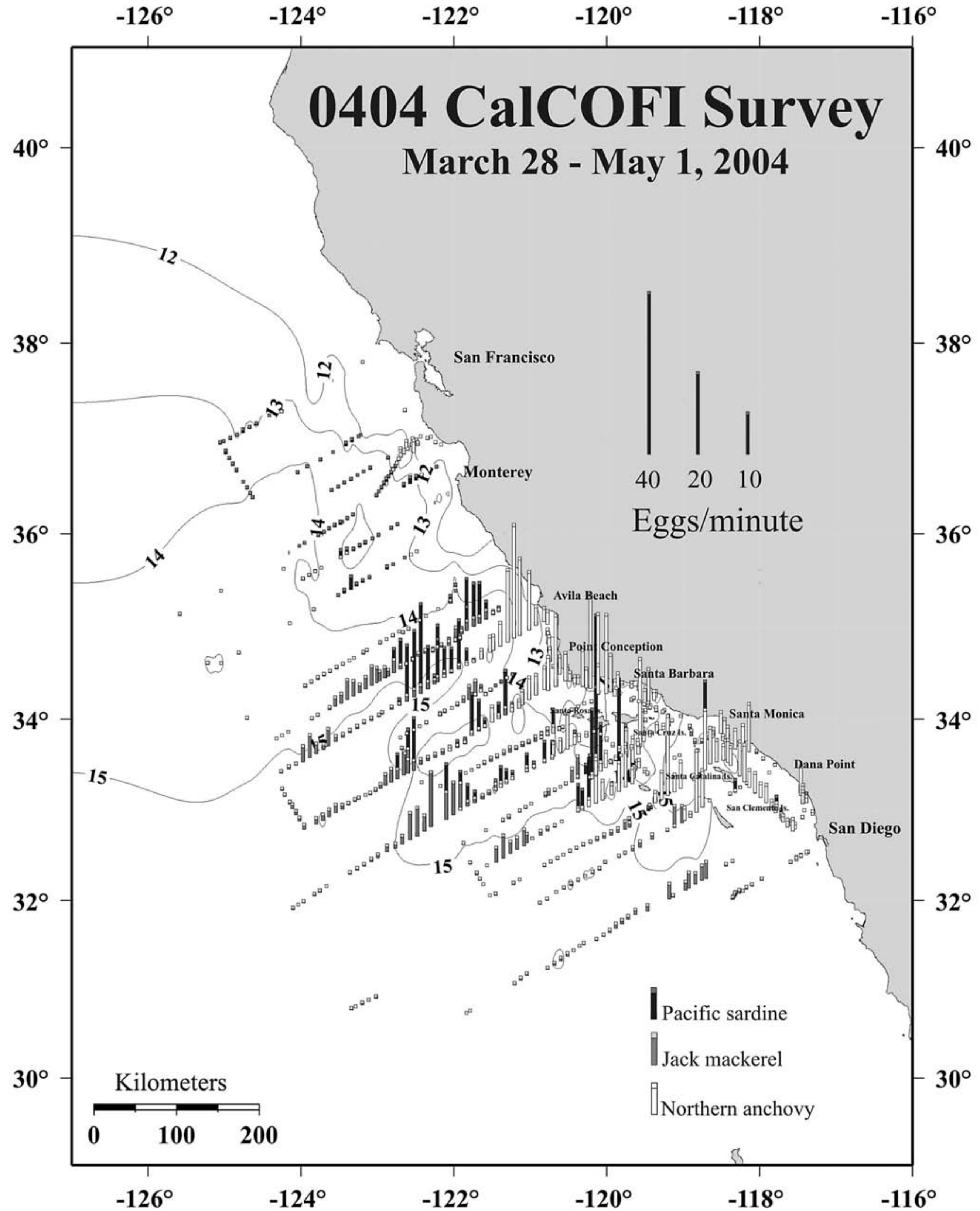


Figure 37. Rate of occurrence of eggs of Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and Jack mackerel (*Trachurus symmetricus*) sampled with the continuous underway fish egg sampler (CUFES) and sea surface temperatures in 28 March–1 May 2005. One egg per minute corresponds to approximately five eggs per cubic meter.

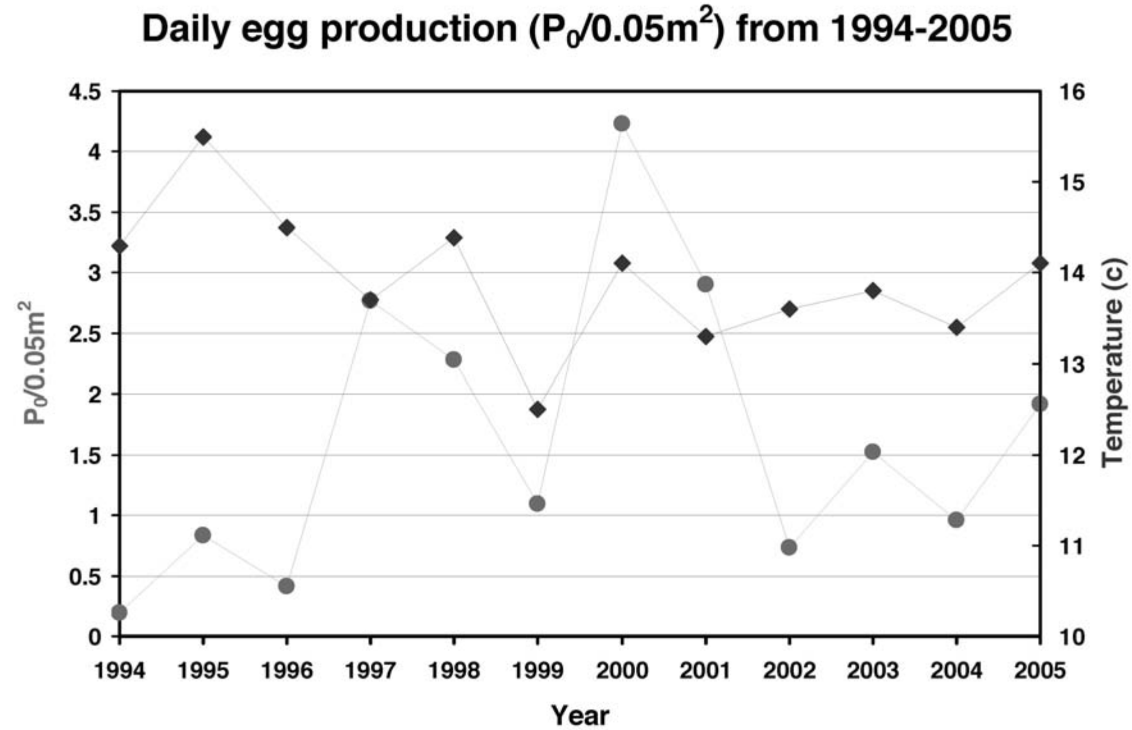


Figure 38. Daily egg production/0.05m² of Pacific sardine (circle) and average sea surface temperature (°C) (diamond) during March–April CalCOFI cruises from 1994–2005.

central California. Larvae are present year-round off southern California, with a maximum in summer–fall and low incidence and abundance during winter–spring. Larval incidence and abundance often increase during El Niño events and decrease during La Niña events. Following the 1976–77 regime shift from cool- to warm-ocean conditions, both abundance and incidence increased substantially, peaking during the 1997–98 El Niño, then declining dramatically in 1999. During the warm regime, the larval distribution expanded shoreward and northward as abundance increased. Concurrent with declining abundance beginning in 1999, the larval distribution returned to its pre-1977 pattern of higher catches largely restricted to offshore, southern CalCOFI stations. Larval Panama lightfish abundance rebounded briefly in 2001, declined again in 2002, then increased from 2003–05. Incidence also increased a little each year from 2003–05.

The 2005 larval abundances of these mesopelagic fishes are consistent with those seen during previous warm-water events, including El Niño. The declines in larval abundance of the subarctic species and the higher incidence of the subtropical species in 2005 may indicate an increasing percentage of subtropical water entering the California Current. This is probably a result of a weaker southward transport of the California Current, and an enhanced poleward undercurrent transport. The mid-water adjustments may be part of the region's interannual variability, or they could signal the demise of the cool regime that began following the 1997–98 El Niño.

Turtles

Central California: Leatherback Turtles. The critically endangered leatherback turtle (*Dermochelys coriacea*) occurs seasonally along the U.S. Pacific Coast. The huge marine reptiles migrate from nesting beaches in Papua, Indonesia, to forage on jellyfish (*Scyphomedusae*) that are usually present during late-summer and fall months. The Southwest Fisheries Science Center monitors the abundance and distribution of leatherback turtles at foraging grounds off the coast of California. Results of aerial surveys conducted during 1990–2003 revealed that the coast of central California is a key destination for leatherbacks, because great densities of jellyfish develop in areas where alternating upwelling and relaxation events create suitable habitat in nearshore retention areas.

Fine-scale aerial surveys of leatherbacks and jellyfish have been conducted annually during August–October within Monterey Bay and the Gulf of the Farallones since 2002. Leatherbacks were generally most abundant off the San Mateo coast, but during 2002–04 they were also encountered throughout the study area. The composition of Scyphomedusae was diverse, including sea nettles (*Chrysaora fuscescens*), purple stripe jelly (*Chrysaora colorata*), egg-yolk jelly (*Phacellophora camtschatica*), and moon jelly (*Aurelia labiata*). In contrast, during 2005

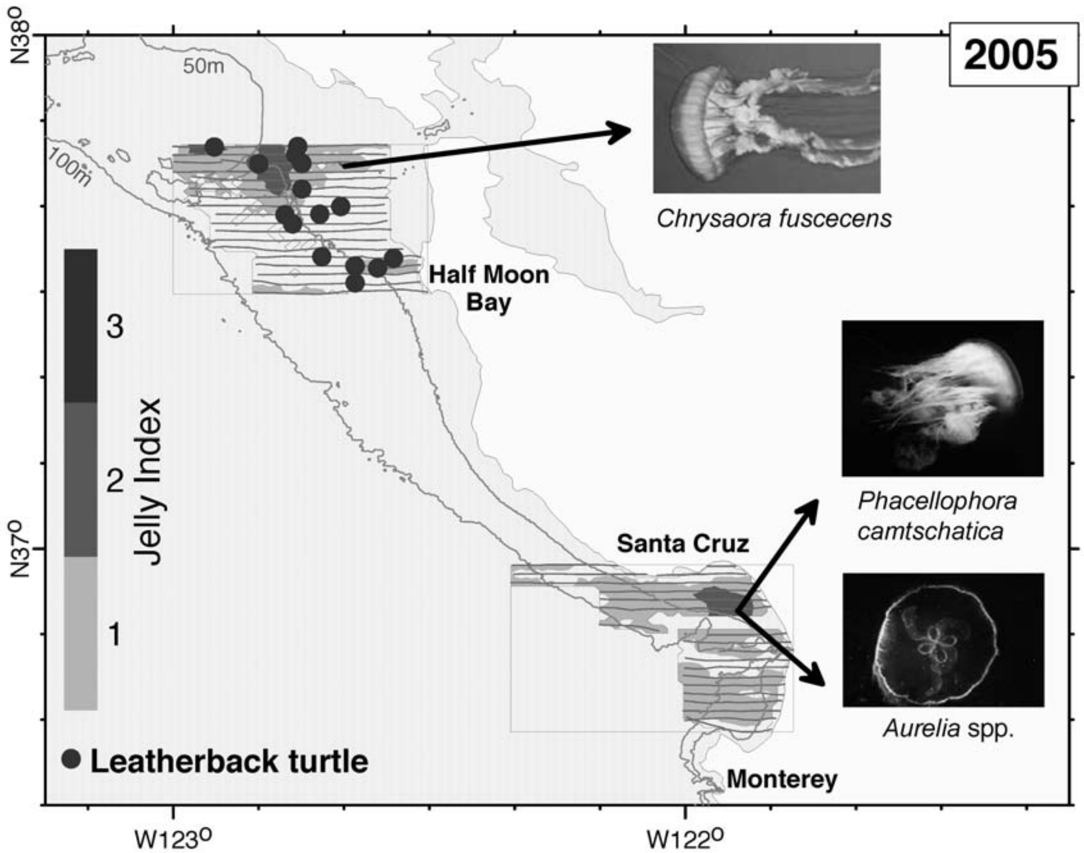


Figure 39. Distribution of leatherback turtles in 2005 in relation to distribution of jellyfish. Turtles were only found in association with *Chrysaora fuscecens*.

(fig. 39) leatherbacks were found only in a small area off San Francisco, although sea surface temperature and chlorophyll-*a* concentrations were similar throughout the study area. Results of shipboard net sampling revealed that there was a difference in jellyfish species composition compared to previous years. Egg-yolk jellies and moon jellies dominated the assemblage in Monterey Bay, whereas sea nettles were densely aggregated only in a limited area off San Francisco where the leatherbacks were seen (fig. 39). Thus, leatherbacks appear to favor sea nettles over other available jellyfish species. The pattern of jellyfish distribution may have been affected by the later onset of upwelling during late-spring and fewer prolonged wind relaxation events during late-summer 2005. Studies are currently underway to examine potential benefits of sea nettle consumption, and to understand the oceanographic and trophic processes that lead to foraging habitat for leatherbacks.

Avifauna

Central California: Cassin's Auklet (*Ptychoramphus aleuticus*). Cassin's auklets are among the best harbingers and sentinels of ecological change in the California Current (fig. 40). Breeding failures of auklets in the Farallones have been associated with ENSO conditions, which affect the pelagic food web structure of northern California (Ainley et al. 1995). Significant positive anomalies in breeding success occurred during the cold-water years of 1994, 2001, and 2002. Significant negative anomalies in breeding success occurred in 1983, 1990, 1992, and 2005. The decrease was much greater during the 1982–83 El Niño than during the 1997–98 event. Breeding success rates during a somewhat weaker El Niño event in 1992 were similar to those observed in 1983 (~0.25). The abandonment rate during 1983 and 1992 El Niño mirrored the low breeding success, and peaked at roughly 65% of the breeding pairs. The long-term mean breeding success for the period 1971–2004 for this population is 0.70 offspring per breeding pair, and the correlation between breeding success and abandonment rate is negative (Spearman $r = -0.306$, $p = 0.076$, $n = 34$).

The complete breeding failure of the Cassin's auklet observed in 2005 was the first indication of major changes in the ecosystem (fig. 40). The population initiated egg-laying within the "normal" nesting period (April), but by mid-May, all adults had essentially abandoned the colony. A small second pulse of egg-laying was observed

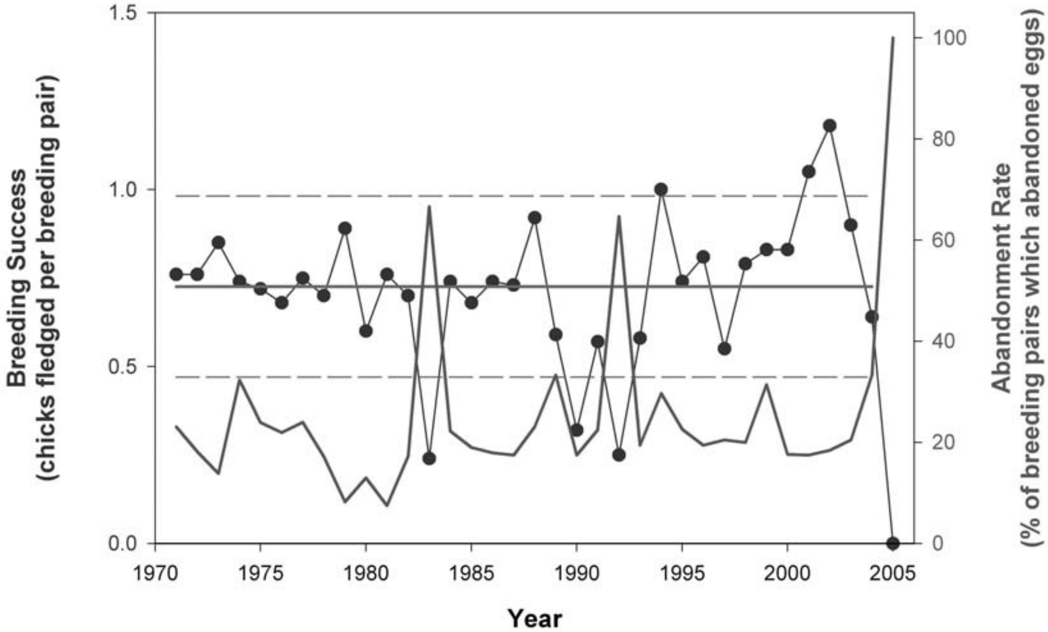


Figure 40. Time series of breeding success and abandonment rate of Cassin's auklets at Southeast Farallon Island, California, 1971–2005 showing interannual variability (dots), and the long-term mean breeding success (solid line) +/−80% confidence intervals (dashed lines).

in late-June, again followed by rapid colony abandonment. Breeding propensity was low for auklets in 2005 compared to 2004, with a 45% reduction in nesting burrows in 12 study plots (Sydeman et al. In press).

The unusual breeding failure of the auklets appears related to the timing of a climate disruption which caused a mismatch in prey resource availability for the seabirds during the egg-laying period of high energetic needs. Phenological mismatches between predator and prey have been invoked to explain climate effects on other marine species (Cushing 1990). While the ocean-surface temperatures were warm, the climatological record in 2005 does not reflect any "extreme" warming, even during May, when colony abandonment occurred. The seabird's reliance on euphausiids during reproduction coupled with the acoustic surveys in the region indicates that the climate disruption of 2005 caused a reduction in zooplankton biomass (Sydeman et al. 2006) as was observed off Newport, Oregon. Therefore, we conclude that the unprecedented breeding failure was the result of "bottom-up" climate forcing on the auklet's prey base during a critical time period.

Central California: Other Seabirds. Five other seabirds are monitored in the Farallones, thus the colony-based data provides a broader perspective to interpret the observed anomaly in the at-sea abundance of the Cassin's auklet. The seabird productivity data for six species breeding at Southeast Farallon Island revealed that 2005 was a peculiar year (fig. 41). We considered three species with conservative life-histories (Cassin's auklet, common murre [*Uria aalge*], rhinoceros auklet [*Cerorhinca monocerata*]) and three species with flexible life histories (Brandt's cormorant [*Phalacrocorax penicillatus*], pigeon guillemot [*Cepphus columba*], pelagic cormorant [*Phalacrocorax pelagicus*]). Hierarchical clustering of the productivity data revealed that 2005 was most similar to 2003, another year with depressed productivity (fig. 42). Marine bird populations experienced a pervasive breeding failure in 2005, with only the Brandt's cormorant performing at a level comparable to the long-term average (1999–2004). Most notably, the pelagic cormorant and Cassin's auklet experienced complete breeding failures (productivity = 0 chicks/breeding pair) (fig. 42). While the pelagic cormorant breeding failures during warm-water conditions are common, with complete failures in 1990, 1992, and 1993, this species had experienced high productivity (>2 chicks per breeding pair) in the last four years (2001–04) (Goericke et al. 2004). The Cassin's auklet experienced the lowest productivity ever recorded, after unusually high values (>1 chick per breeding pair) in 2001–02, and a slight decline thereafter (Goericke et al. 2004).

Southern California: Pelagic Seabirds. Seabird communities off southern California have been characterized during the springtime CalCOFI cruises since 1999. To quantify interannual fluctuations in community composition, we used hierarchical clustering (fig. 43) to assess the similarity of the avifauna over the seven-year data set (1999–2005). We focused on the abundance of four indicator species with different water mass prefer-

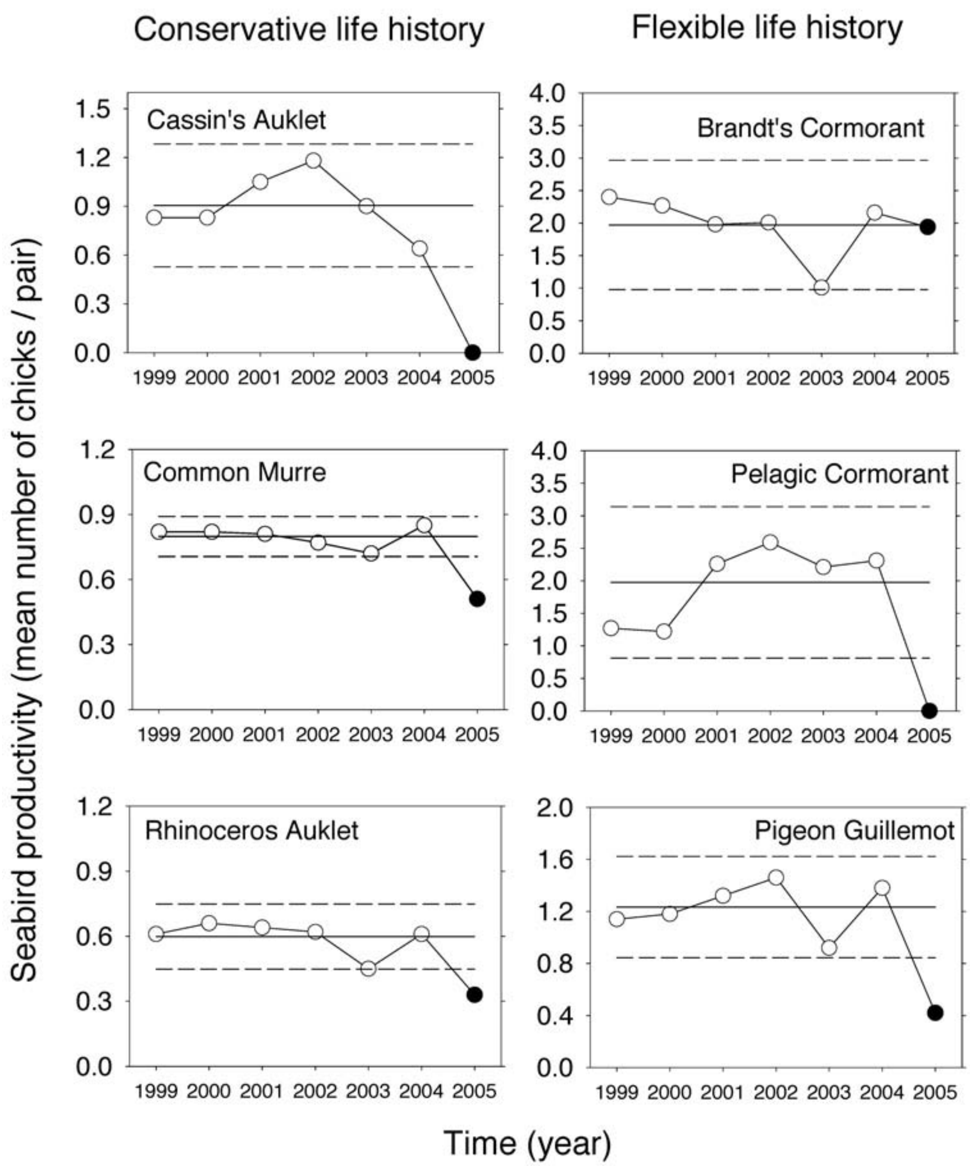


Figure 41. Anomalies of productivity for six seabird species breeding at the Farallon Islands (central California). The long-term averages (1999–2004) are depicted by the solid horizontal lines and the hatched lines illustrate the variability (mean +/−2 standard deviations). Filled circles highlight productivity anomalies in 2005.

ences and biogeographic affinities. The subtropical black-vented shearwater (*Puffinus opisthomelas*) and pink-footed shearwater (*Puffinus creatopus*) shift their distributions northwards into the CalCOFI study area during warm-water years. The Cook's petrel (*Pterodroma cookii*) is an offshore spring–summer visitor, which moves shoreward during warm-water periods and increased significantly in abundance off southern California between 1987–98. The once numerically-dominant cold-water species, the sooty shearwater (*Puffinus griseus*), is a spring–fall visitor which declined in abundance by 74% between 1987–98, and rebounded slightly thereafter (Veit et al. 1996; Hyrenbach and Veit 2003). We also considered two locally-breeding species with an affinity for cold water, the planktivorous Cassin's auklet and the piscivorous common murre.

At-sea surveys off southern California revealed that 2005 was a peculiar year, with a seabird community structure which did not closely resemble the avifauna during warm-water years (2002–04) or during the cool spring of 1999 (fig. 44). Instead, the 2005 avifauna was most similar to that observed during the spring of 2001, a year with warm-water and cold-water anomalies (fig. 7). The abundances of the six indicator seabird species (fig. 44) suggest that 2005 was an intermediate year, without the sudden appearance of warm-water species characteristic of El Niño years (Veit et al. 1996; Hyrenbach and Veit 2003). The abundance of the three

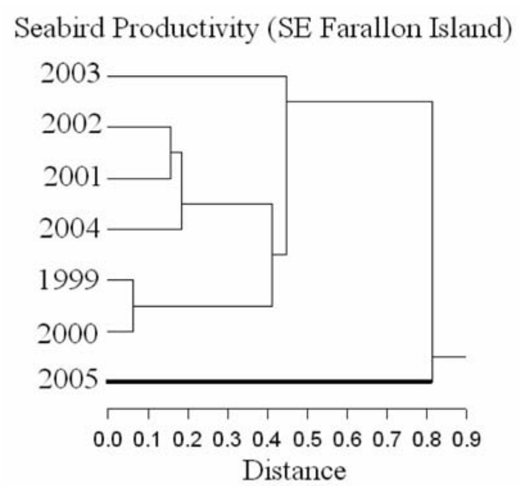


Figure 42. Cluster tree of marine bird community structure for the sea bird colonies in the Gulf of the Farallones. The Euclidean distances are based on the hierarchical clustering technique, with the median linkage algorithm. The thickness of the lines identifies those years in the same cluster.

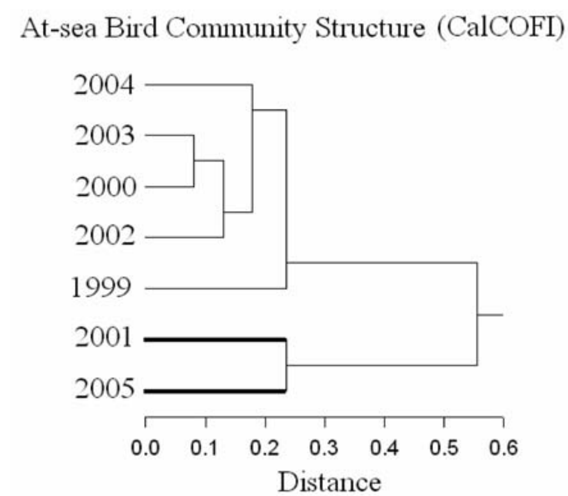


Figure 43. Cluster tree of marine bird community structure at-sea off southern California during spring CalCOFI cuises (1999–2005). The Euclidean distances are based on the hierarchical clustering technique, with the median linkage algorithm. The thickness of the lines identifies those years in the same cluster.

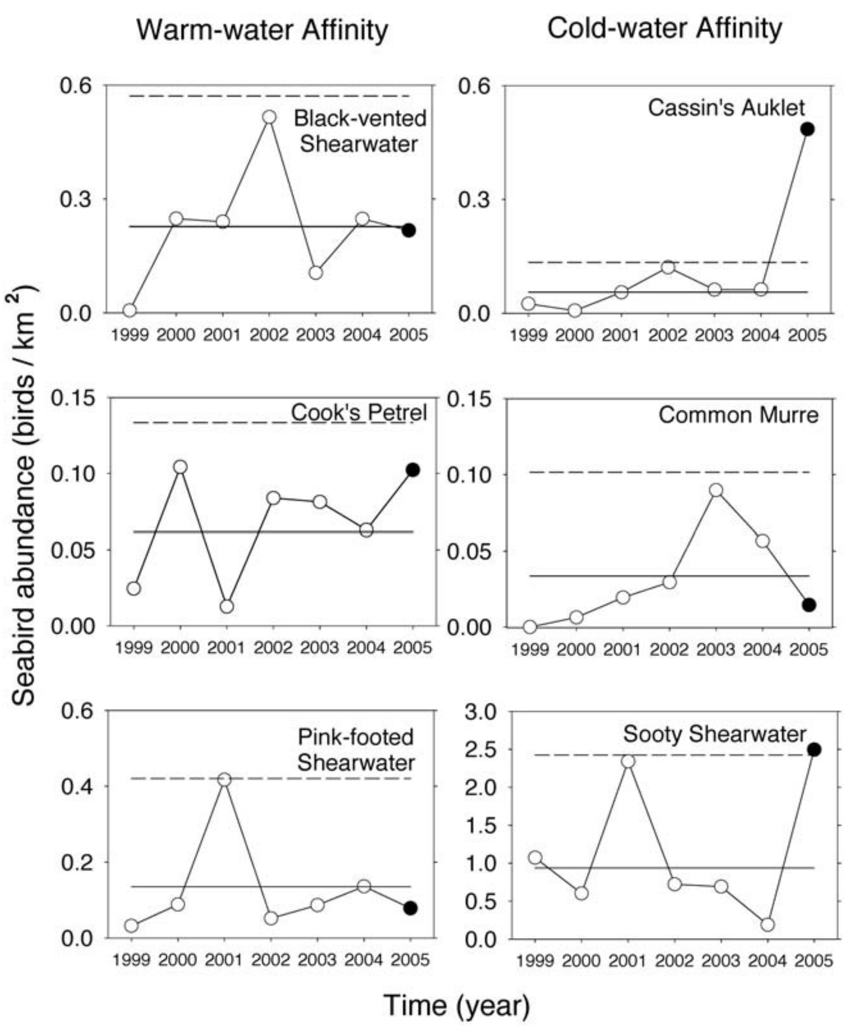


Figure 44. Anomalies of spring-time abundance for six seabird species indicative of warm-water and cold-water within the CalCOFI study area. The long-term averages (1999–2004) are depicted by the solid horizontal lines and the hatched lines illustrate the variability (mean +2 standard deviations). Filled circles highlight anomalies in 2005.

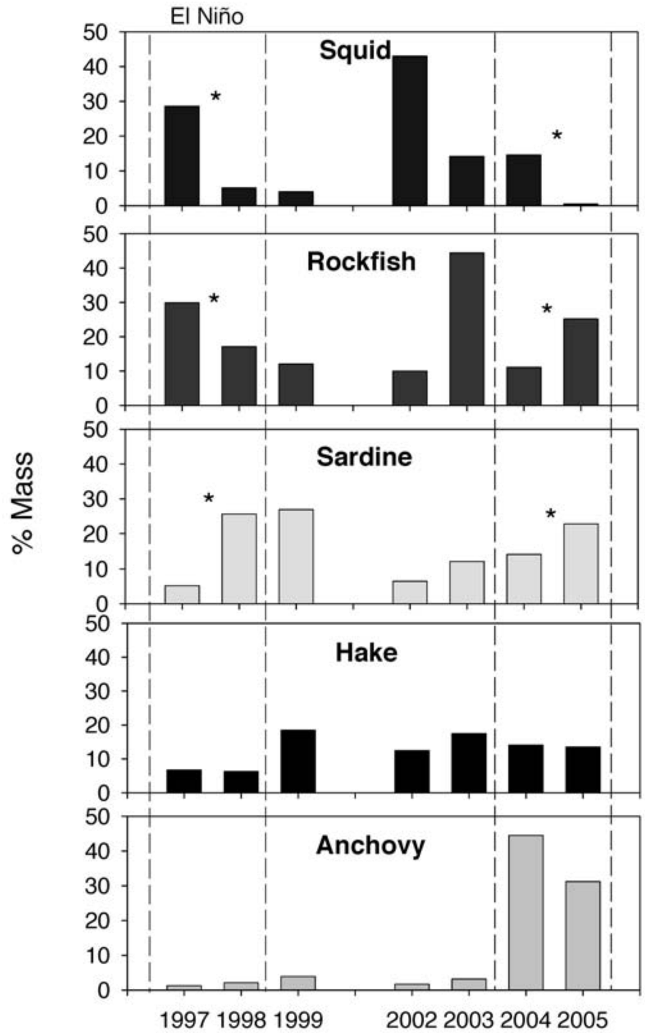


Figure 45. Percentage mass for market squid, rockfishes, sardine, anchovy, and hake identified and reconstructed from sea lion fecal samples collected on Año Nuevo Island from 2002 to 2005 (Weise 2006), and fecal samples collected by Weise (2000) and Weise and Harvey (in review) in the Monterey Bay from 1997 to 1999. Dashed lines highlight the 1997–98 El Niño event and similar changes during 2004–05. Asterisks indicate significant change in percentage mass between years ($P < 0.05$).

subtropical indicator species was comparable to the long-term average (1999–2004), and well within the observed pattern of variation (fig. 45). Conversely, the at-sea abundances of two cold-water indicators were anomalously high, with anomalies over two standard deviations above the long-term spring average (1999–2004). The sooty shearwater reached very high numbers (>2.5 birds km^{-2}), comparable to the densities observed in 2001. Most notably, the Cassin's auklet experienced an almost ten-fold (0.48 vs. 0.06 birds km^{-2}) increase in abundance over the recent spring-time average (1999–2004). Another locally-breeding species, the piscivorous common murre occurred at densities slightly below the average (fig. 45).

Marine Mammals

Central California: California Sea Lion (*Zalophus californianus*). Diet studies of California sea lion (*Zalophus californianus*) have been conducted at Año Nuevo Island (ANI; 37°6'N, 122°20'W), which is one of the largest haul-out sites for sea lions in central and northern California (Weise 2000, 2006; Lowry and Forney 2005). Annual variation in sea lion diet in central California was examined by identifying fish otoliths and cephalopod beaks found in fecal samples collected at ANI. Prey hard parts were measured and species-specific correction factors were used to estimate standard length and mass of prey consumed (Orr and Harvey 2001). The contribution of each prey species in the diet for each year was expressed as a percentage of the total estimated mass (%M) of prey ingested (Weise and Harvey In review).

During 2005, approximately 112 fecal samples were recovered containing 873 prey. Diet was dominated by schooling prey including northern anchovy (*Engraulis mordax*; 31.2%), rockfish (*Sebastes* spp.; 25.2%), Pacific sardine (*Sardinops sagax*; 22.8%), Pacific hake (*Merluccius productus*; 13.5%), and market squid (*Loligo opalescens*; 0.5%). Trends in the importance of prey species in the diet of California sea lions were apparent when comparing diet for multiple years (1997–99; Weise 2000; Weise and Harvey In review). The decreasing importance of market squid and the increasing importance of sardine in the diet from 2004 to 2005 during the anomalously warm waters were similar to trends observed during the 1997–98 El Niño (fig. 45). Sardines eaten by California sea lions were larger during the 1997–98 El Niño (Weise 2000), whereas during 2004–05 there was an increase in juvenile sardines (12–18 cm) in the diet, although adult sardines were still present (27–36 cm; fig. 46). Interestingly, during 2004 to 2005 there were increased numbers of rockfish species in the diet compared with the 1997–98 El Niño. These data indicated that the effects of climatic shifts during 2005 were not limited to the physical oceanography and lower trophic levels, but extended to an apex predator, providing insight into the level of plasticity in their diet and foraging strategies during environmental perturbations.

Southern California: California Sea Lion (*Zalophus californianus*). Pup production of California sea lions in the U.S. has been monitored annually since 1975. During this time period, decreases in pup production (fig. 47) were observed during the 1983, 1992–93, and 1998 El Niño events when above average water temperatures were present and when productivity levels were low due to decreased upwelling in the region. After pup counts peaked in 2000 and 2001, a decrease in the number of pups was observed in 2002 and 2003 when moderate El Niño conditions were seen in south-

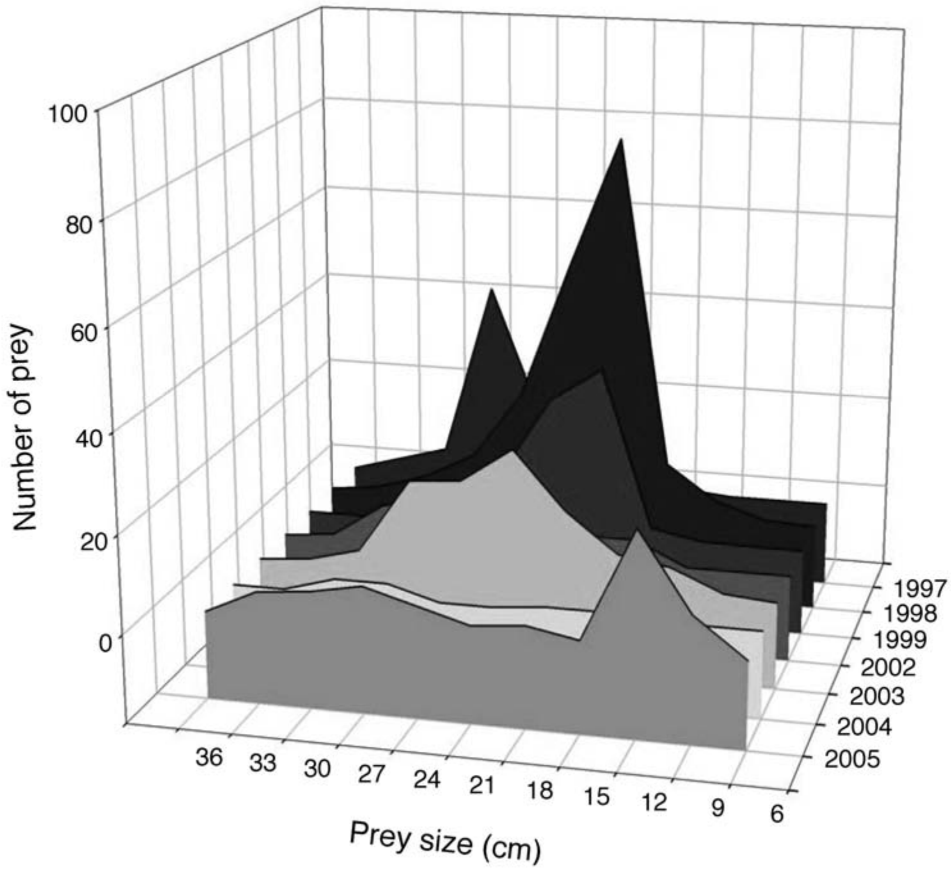


Figure 46. Reconstructed body length of sardines identified in fecal samples of California sea lions collected on Año Nuevo Island during 2002 to 2005, and sea lion fecal samples collected in Monterey Bay from 1997 to 1999.

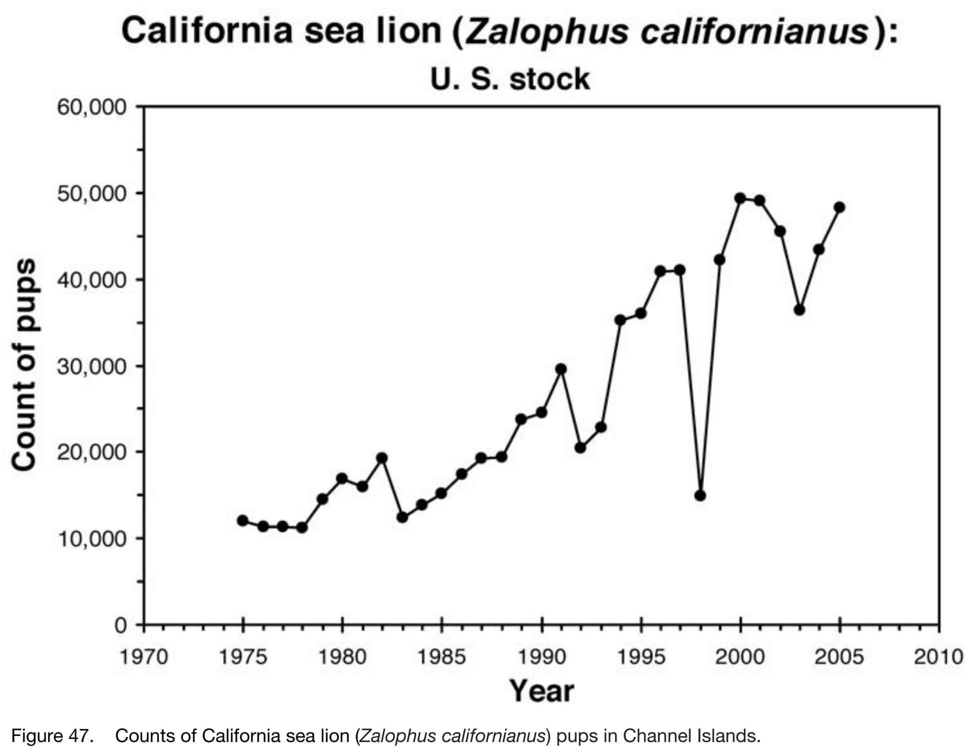


Figure 47. Counts of California sea lion (*Zalophus californianus*) pups in Channel Islands.

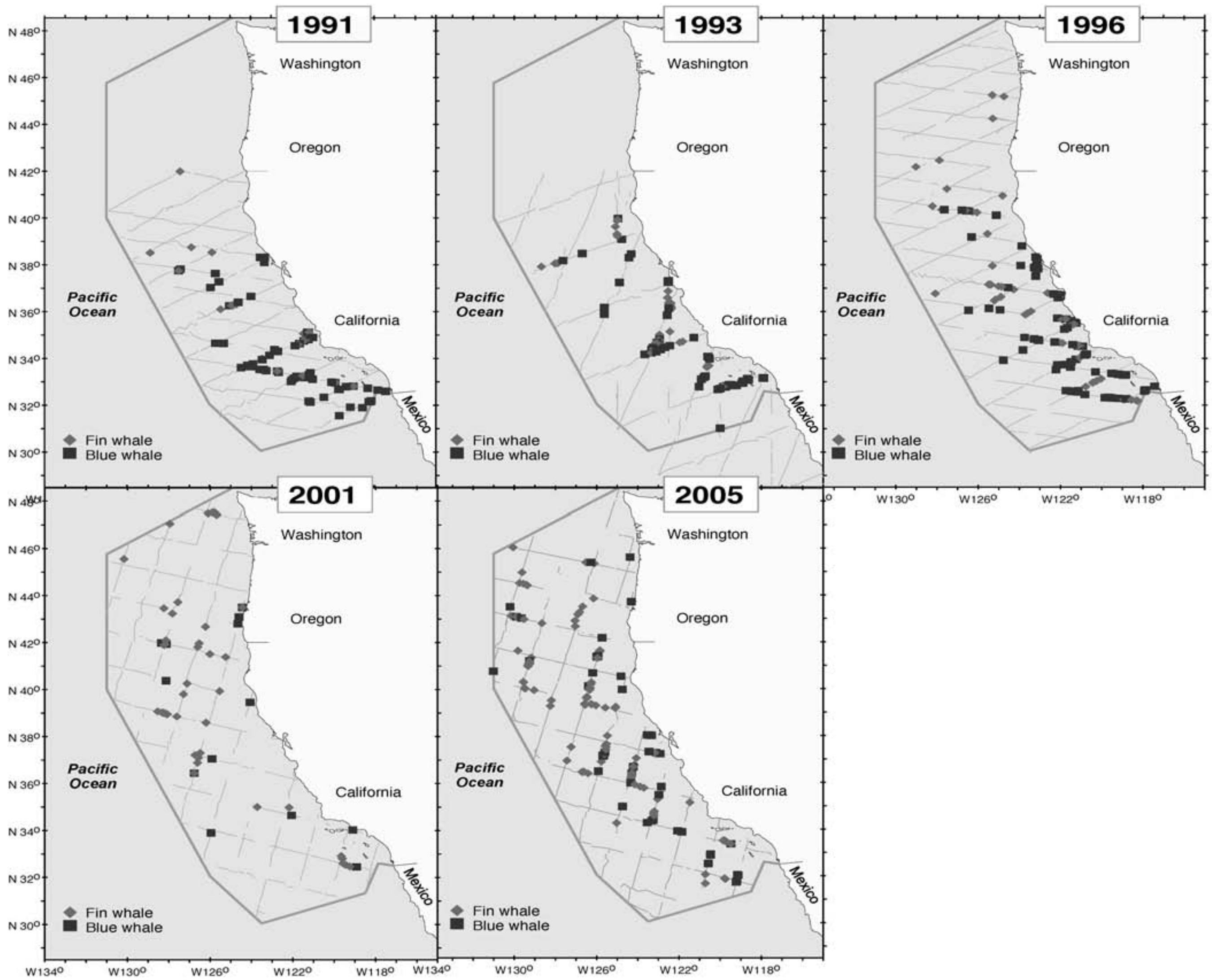


Figure 48. Survey transects and sightings of blue and fin whales during 1991, 1993, 1996, 2001, and 2005.

ern California (Venrick et al. 2003). In 2004, oceanographic conditions returned to normal in southern California (Goericke et al. 2004) and pup production increased, but at a level below the 2000 and 2001 peak. Pup counts from an aerial photographic survey conducted in July 2005 indicate an increase in pup production from that observed in 2004.

Diet studies of California sea lions—utilizing fecal samples collected at rookeries located at San Clemente and San Nicolas islands since 1981—show changes in the type of prey species consumed during El Niño events (M. Lowry, NMFS, SWFSC, unpublished data). During El Niño events, the diet becomes more diversified as the predators consume a greater proportion of non-primary prey species. The higher pup production in 2005 indicates sufficient prey was available for the California sea lion. Samples collected since early-2004 are archived in a freezer, but have not been processed due to funding constraints.

California Current System: Summer/Fall 2005. During CSCAPE surveys, a total of 12,954 km were surveyed systematically using standard line-transect protocols, resulting in 1,498 sightings of 21 cetacean and 5 pinniped species. The diversity of species was comparable to previous years; however the distribution of a few species differed notably. Northern fur seals (*Callorhinus ursinus*), which are commonly found at least 50 km from shore, were unusually abundant within 10 km of the central California coast during July. Fin whales (*Balaenoptera physalus*) were encountered more frequently than during previous years, and a greater number of fin whales were seen in northern offshore waters than during previous surveys, particularly compared to the 1990s

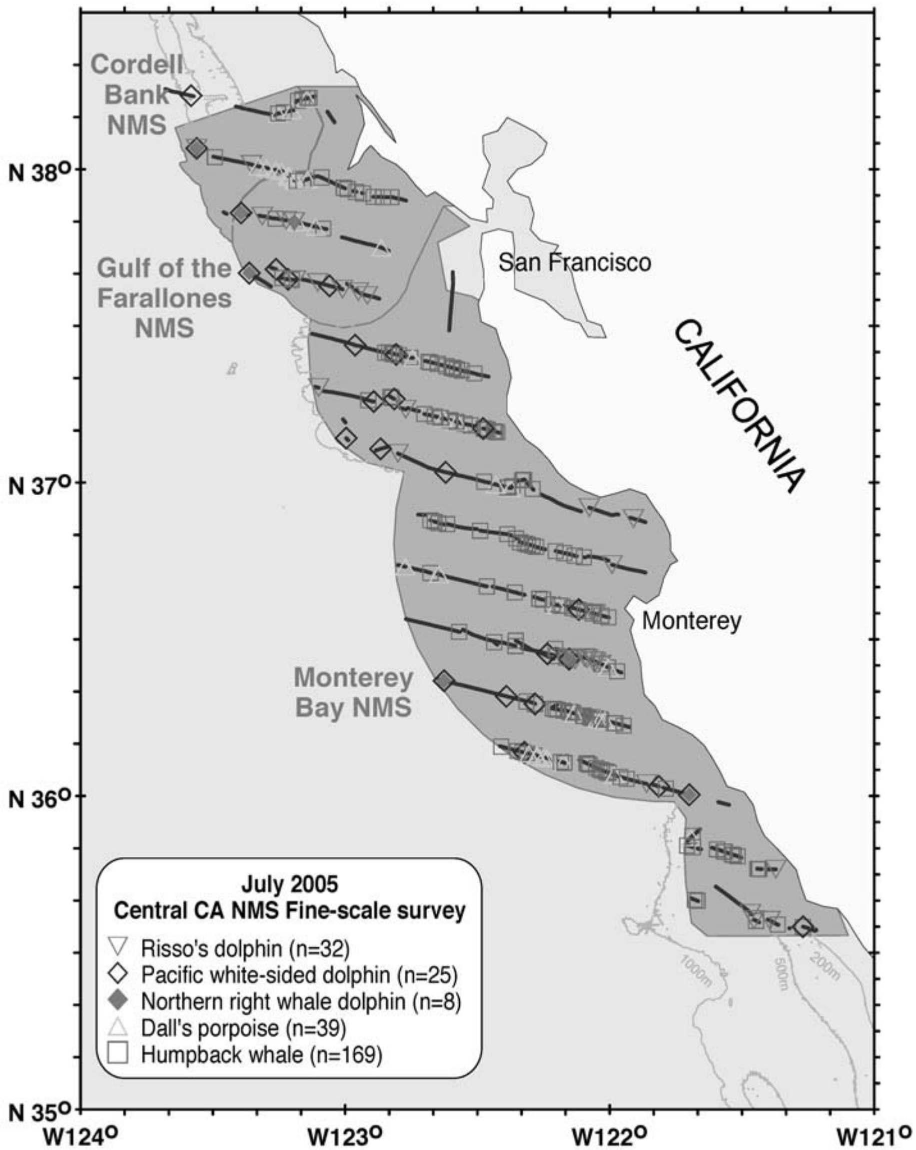


Figure 49. Sightings of marine mammals within the central California National Marine Sanctuaries.

(fig. 48). Blue whales (*B. musculus*) were also distributed more widely throughout the study area than in previous years (fig. 48). This may have been related to the poor recruitment of their euphausiid prey in nearshore foraging areas during 2005. As in previous years, humpback whales (*Megaptera novaeangliae*) were concentrated in nearshore waters off central California and Oregon-Washington. They were observed foraging primarily on dense aggregations of small pelagic schooling fish, particularly in nearshore regions where small cetaceans that feed on fish and cephalopods were also abundant, including Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), northern right whale dolphin (*Lissodelphis borealis*), Risso's dolphin (*Grampus griseus*), and Dall's porpoise (*Phocoenoides dalli*) (fig. 49).

Although the distributions of cetacean species have varied between surveys, species-environment relationships for some species have been remarkably consistent. For example, the offshore extent of Dall's porpoise off California appears directly linked to the offshore extent of upwelling-modified waters (fig. 50). During all survey years, this species was primarily found in cool, upwelling-modified waters less than about 17°C, while avoiding the coldest, most recently upwelled waters near shore. Further analyses of the CSCAPE results in the context of oceanographic processes are planned in the future, and, combined with the results of other studies in this report, will enhance our understanding of the dynamic nature of the California Current and the marine predators that inhabit this region.

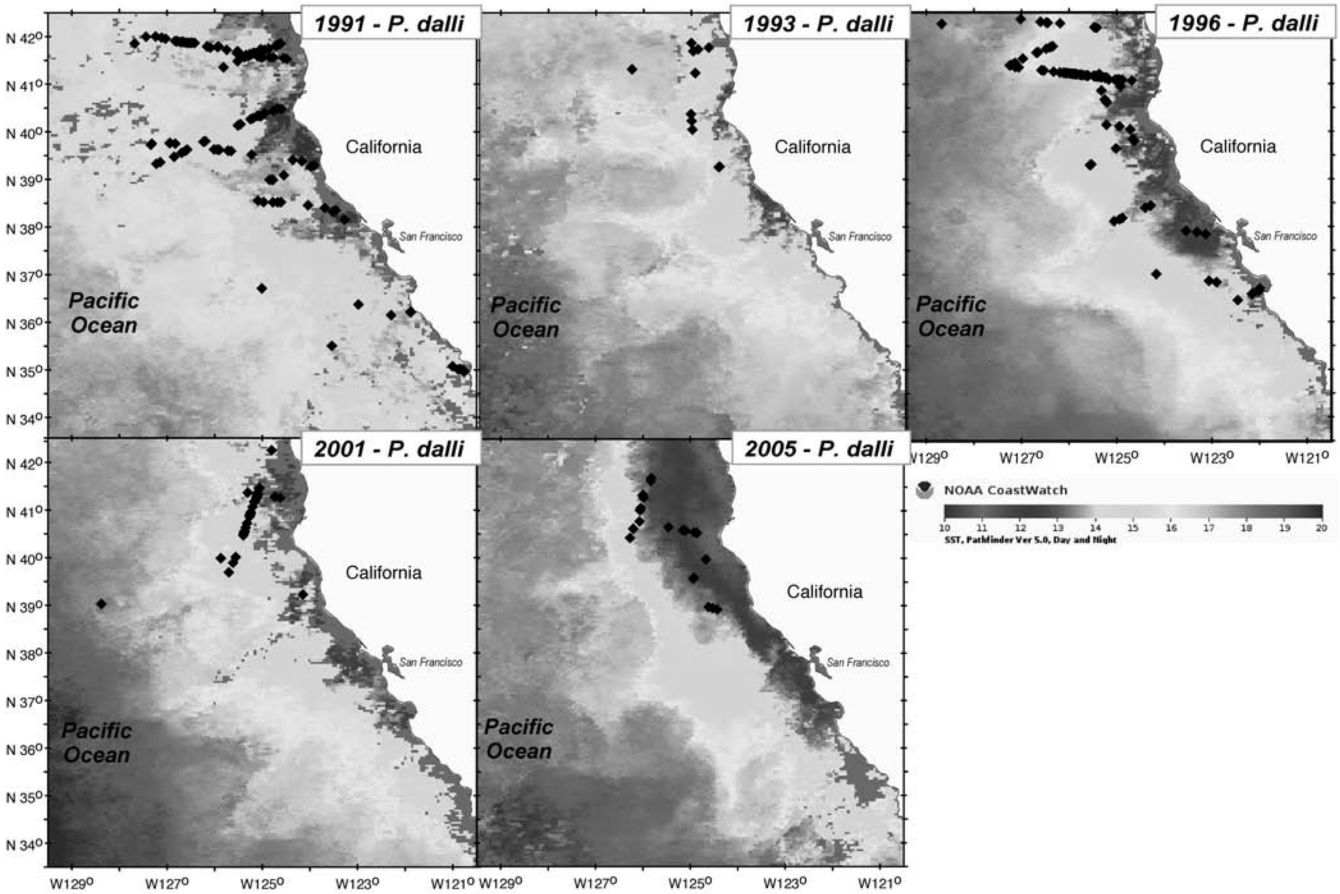


Figure 50. Mean satellite-derived August sea surface temperatures and July-September sightings of Dall's porpoise during surveys conducted in 1991, 1993, 1996, 2001, and 2005. (Satellite images courtesy of NOAA Coastwatch West Coast).

DISCUSSION

The overall conclusion of this "State of the California Current: 2005–2006" report is that the bulk of the Current was anomalously warm in 2005, but that the warming was not due to a tropical El Niño. Rather, the cause was failure of strong upwelling to become established until July, two months later than normal for the northern California Current. This delay in the initiation of upwelling disrupted normal seasonal cycles of plankton production with effects that cascaded through the entire food chain, from plankton to whales. For example, off Oregon euphausiids failed to reproduce in spring and copepods did not show any peak in abundance (whereas a strong peak is expected in July or August). Throughout most of the California Current, zooplankton biomass ended the season with anomalously low values. The results of either (or both) delayed upwelling and low zooplankton biomass were reduced catches of juvenile rockfish (lowest catches in 22 years occurred during summer 2005 off central California), poor recruitment of all forage fish off Oregon and Washington (sardines, anchovies, herring, and osmeriids), wide-spread recruitment failure and deaths of seabirds off central California and Oregon, and an apparent redistribution of leatherback turtles, fur seals, and fin and blue whales. Although most of the California Current was affected by the warming, conditions off Baja California were anomalously cool and both copepod and euphausiid biomass values had strongly positive anomalies. This was true both for coastal and offshore waters. Another factor that could have contributed to the dramatic ecosystem impacts is that the northern California Current has been warmer than normal for the past three years, thus this three-year warming event may have led to chronic stress on animals.

What is the prognosis for the future? Preliminary reports from 2006 suggest that this year will also be an unusual one. However, unlike 2005 with warm conditions in the north, average conditions off southern California, and cool conditions off Baja California, 2006 has been cool and moderately productive in the north (for copepods, euphausiids, sea birds, and juvenile salmon), but warm and unproductive in waters off central California. Cassin's auklets once again experienced reproductive failure (W. Sydeman, personal communication) and juvenile rockfish abundances were again at near-record low levels (S. Ralston, personal communication).

SUMMARY

- Sea surface temperatures (SST) throughout the central and northern California Current System in 2005 were typically 1°–2°C above normal (and up to 4°C above normal) and have been warmer than normal since the 2002–03 El Niño. Conditions were particularly warm in May and June 2005, months when upwelling is ordinarily expected to have its strongest impact. Upwelling became relatively strong commencing in June–July, resulting in a cooling of SST by August and a delayed pulse in seasonal productivity. Coastal upwelling continued later than expected into 2005, resulting in near-normal net upwelling for the year. Thus, the year 2005 will be a good example of a year in which the "seasonally averaged upwelling" will be a deceiving statistic.
- Average temperatures in southern and Baja California were nearly normal or slightly cooler than usual.
- The impact of the warm anomaly on the pelagic ecosystem in Washington, Oregon, and northern California were perhaps best described as devastating.
- Preliminary indications are that this pattern of delayed upwelling may repeat in 2006 in the central California region.
- Nutrient concentrations were lower than average off Newport and Monterey but slightly above average in the CalCOFI region, yet chlorophyll concentrations were average off Newport, above average off Monterey and CalCOFI, but below average off Mexico. Thus, nitrate and chlorophyll did not appear to be closely related.
- Zooplankton biomass was below normal off Newport, Monterey, and in the CalCOFI region, but above normal off Mexico. The normal pattern of an increase in zooplankton biomass in spring-summer also did not occur off British Columbia (Mackas et al. In review), Oregon, northern California, or central California
- The most noticeable signal off Newport was the presence of a "warm-water copepod community" throughout most of 2005, which resembled the community type seen during strong El Niño conditions. Warm-water copepod species also appeared to be more abundant off Monterey.
- Euphausiids off Oregon failed to spawn during spring; spawning was delayed in summer and did not commence until upwelling was initiated. The highest numbers of eggs occurred in September, rather than the usual July. Adult euphausiid biomass was below normal in central California but average in the CalCOFI region.
- The numbers of herring and white-bait smelt off Oregon fell to values that were 10% of the maxima observed during the cool-ocean conditions of 1999–2002, whereas sardine and anchovy numbers were little different from previous years. However, recruitment of all forage fish species appeared to be very low in 2005 since the surveys in 2006 are finding very low numbers, similar to numbers observed during the 1998 El Niño event. Thus, there will be a one-year lag between perturbation caused by "the warm ocean of 2005" and a measurable impact on biomass of forage fish in 2006.
- The abundances of juvenile rockfish off central California were the lowest ever measured from the 22-year time series. The near-absence of fish in the survey area was associated with a re-distribution of adult fishes, both to the north (for northern species) and to the south (for southern species), leaving a gap in the central portions of the current. Catches in 2006 were low as well.
- Sardine and Jack mackerel eggs in the CalCOFI surveys were not as abundant as in previous years but there was no evidence of anomalously low numbers, nor was there any evidence for warmer-than-usual conditions. Anchovy egg numbers were quite abundant, but again, nothing out of the ordinary.
- The abundances of the larvae of the mesopelagic lampfish and lanternfish suggest an ecosystem response to the warm conditions of 2005 that penetrated down several hundred meters in the water column. Northern lampfish (with a subarctic-transitional affinity) were found shoreward and northward during 2005, similar to observations made during years of warm phase PDO; during a cool phase these species are found seaward and southward. The tropical-subtropical mesopelagic species move in the opposite pattern of shoreward and northward during a warm phase of the PDO but seaward and southward during a negative phase.
- Cassin's auklets may be the most sensitive sentinel species in the California Current as a collapse in their breeding success was the first harbinger of the impacts of the 2005 warm event on any component of the ecosystem. Other seabirds in the Gulf of the Farallones showed a similar, but not as dramatic, response.
- For pelagic seabirds in the CalCOFI survey region, 2005 was unusual, but unlike other components of the ecosystem, they did not strongly resemble an "El Niño" assemblage. Interestingly, the Cassin's auklet, which is not usually very abundant in the CalCOFI region, became abundant there, suggesting a southward migration of the birds away from central California, perhaps similar to the southward migration suggested for rockfish.

- Studies of diets of California sea lions in the Monterey Bay region found a decreasing importance of market squid and increasing importance of sardines in 2005, similar to observations made during the 1998 El Niño event, and consistent with the reported decline of market squid in Monterey Bay.
- On the other hand, California sea lions in southern California showed no sign of being affected by warm-ocean conditions, indicated by a continued increase in production of pups in 2005. Pup production declined during past El Niño events (1983, 1992–93, 1998), but not during the 2005 warm event.
- Northern fur seals were found unusually close to shore in 2005; fin whales were more frequently encountered on coast-wide surveys and blue whales were dispersed and widely distributed, possibly in response to a scarcity of their primary prey, euphausiids.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Abraham, C. L. and W. J. Sydeman. 2004. Ocean climate, euphausiids, and auklet nesting: interannual trends and variation in phenology, diet, and growth of a planktivorous seabird, *Ptychoramphus aleuticus*. Mar. Ecol. Prog. Ser. 274:235–250.

Ainley, D. G., W. J. Sydeman, and J. Norton. 1995. Upper trophic level predators indicate interannual negative and positive anomalies in the California Current food web. Mar. Ecol. Prog. Ser. 118:79–89.

Bograd, S. J., P. M. DiGiacomo, R. Durazo, T. L. Hayward, K. D. Hyrenback, R. J. Lynn, A. W. Mantyla, F. B. Schwing, W. J. Sydeman, T. Baumgartner, B. Lavaniegos, and C. S. Moore. 2000. The state of the California Current, 1990–2000: forward to a new regime? Calif. Coop. Oceanic Fish. Invest. Rep. 41:26–52.

Bond, N. A., J. E. Overland, M. Spillane, and P. Stabeno. 2003. Recent shifts in the state of the North Pacific. Geophys. Res. Letters 30(23), 2183, doi:10.1029/2003GL)18597, 2003.

Brodeur, R. D., S. Ralston, R. L. Emmett, M. Trudel, T. D. Auth, and A. J. Phillips. 2006. Anomlous pelagic nekton abundance, distribution, and apparent recruitment in the northern California Current in 2004 and 2005. Geophys. Res. Letters. 33, L22SO8, doi:10.1029/2006GLO26614.

Chavez, F. P., J. T. Pennington, C. G. Castro, J. P. Ryan, R. P. Michisaki, B. Schlining, P. Walz, K. R. Buck, A. McFadyen, and C. A. Collins. 2002. Biological and chemical consequences of the 1997–98 El Niño in central California waters. Prog. Oceanogr. 54:205–232.

Climate Prediction Center. 2005. Climate Diagnostics Bulletin. 2005. online at: www.cpc.ncep.noaa.gov/products/analysis_monitoring/CDB_archive.html

Cushing, D. H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Adv. Mar. Biol. 26:249–293.

DiLorenzo, E., A. J. Miller, N. Schneider, and J. C. McWillliams. 2005. The warming of the California Current System: Dynamics and Ecosystem Implications. J. Phys. Oceanogr. 35:336–362.

Durazo, R., G. Gaxiola-Castro, B. Lavaniegos, R. Castro-Valdez, J. Gomez-Valdes, A. S. Mascarenhas Jr. 2005. Oceanographic conditions west of the Baja California coast, 2002-2003: A weak El Niño and subartic water enhancement. Cienc. Mar. 31:537–552.

Emmett, R. L., R. D. Brodeur, T. W. Miller, S. S. Pool, P. J. Bentley, G. K. Krutzikowsky, and J. McCrae. 2005. Pacific sardine (*Sardinops sagax*) abundance, distribution, and ecological relationships in the Pacific Northwest. Calif. Coop. Oceanic Fish. Invest. 46:122–143.

Goericke, R., S. J. Bograd, G. Gaxiola-Castro, J. Gomex-Valdes, R. Hooff, A. Huyer, K. D. Hyrenbach, B. E. Laveniegos, A. Mantyla, W. T. Peterson, F. B. Schwing, R. L. Smith, W. J. Sideman, E. Venrick, and P. A. Wheeler. 2004. The State of the California Current, 2003–2004: A rare "normal" year. Calif. Coop. Oceanic Fish. Invest. Rep. 45:27–60.

Goericke, R., E. Venrick, A. Mantyla, R. Hooff, C. Collins, G. Gaxiola-Castro, S. J. Bograd, F. B. Schwing, W. T. Peterson, B. Marinovic, A. Huyer, P. Wheeler, R. L. Smith, F. Chavez, N. Lo., K. D. Hyrenbach, and W. J. Sydeman. 2005. The state of the California Current, 2004–2005: still cool? Calif. Coop. Oceanic Fish. Invest. Rep. 46:32–71.

Hollowed, A. B. 1992. Spatial and temporal distribution of Pacific hake, *Merluccius productus*, larvae and estimates of survival during early life stages. Calif. Coop. Oceanic Fish. Invest. Rep. 33:100–123.

Hooff, R. C. and W. T. Peterson. 2006. Copepod biodiversity as an indicator of changes in ocean and climate conditions of the northern California current ecosystem. Limnol. Oceanogr. 51(6): 2042–2051.

Hyrenbach, K. D. and R. R. Veit. 2003. Ocean warming and seabird assemblages of the California Current System (1987–1998): response at multiple temporal scales. Deep-Sea Res. II. 50(14-16):2537–2565.

Jacobson, L. D. and A. D. MacCall. 1995. Stock-recruitment models for Pacific sardine (*Sardinops sagax*). Can. J. Fish. Aquat. Sci. 52:566–577.

Kister, R., and co-authors. 2001. The NCEP-NCAR 50-year reanalysis: Monthly means CD-ROM and documentation, Bull. Am. Meteorol. Soc. 82: 247–268.

Lo, N. C. H. and B. Macewicz. 2006. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2005. National Oceanic and Atmospheric administration, U.S. Dep. Commer. NOAA-TM-NMFS-SWFSC-387. 29pp.

Lo, N. C. H., B. Macewicz, and D. Griffith. 2005. The spawning biomass of Pacific sardine during 1994–2004 off California. Calif. Coop. Oceanic Fish. Invest. Rep. 46:93–112.

Lowry, M. S. and K. A. Forney. 2005. Abundance and distribution of California sea lions (*Zalophus californianus*) in central and northern California during 1998 and summer 1999. U.S. Fish. Bull. 103:331–343.

Lynn, R. J., K. A. Bliss, and L. E. Eber. 1982. Vertical and horizontal distributions of seasonal mean temperature, salinity, sigma-t, stability, dynamic height, oxygen, and oxygen saturation in the California Current, 1950–1978. Calif. Coop. Oceanic Fish. Invest. Atlas No. 30.

Lynn, R. J. and J. J. Simpson. 1987. The California Current System: the seasonal variability of its physical characteristics. J. Geophys. Res. 92:12947–12966.

Mackas, D. L., W. T. Peterson, M. D. Ohman, and B. E. Lavaniegos. In review. Zooplankton anomalies in the California Current system before and during the warm ocean conditions of 2005. Geophys. Res. Letters.

Mantua, N. J. and S. R. Hare. 2002. The Pacific Decadal Oscillation. J. Oceanogr. 58:35–44.

McGowan, J. A., D. R. Cayan, and L. C. Dorman. 1998. Climate-ocean variability and ecosystem response in the Northeast Pacific. Science 281:210–217.

Moser, H. G., R. L. Charter, P. E. Smith, D. A. Ambrose, S. R. Charter, C. A. Meyer, E. M. Sandknop, and W. Watson. 1993. Distributional Atlas of fish larvae and eggs in the California current region: Taxa with 1000 or more: total larvae, 1951 through 1984. Calif. Coop. Oceanic Fish. Invest. Atlas No. 31. 233 pp.

Orr, A. J. and J. T. Harvey. 2001. Quantifying errors associated with using fecal samples to determine the diet of the California sea lion (*Zalophus californianus*). Can. J. Zool. 79:1080–1087.

Pérez-Brunius, P., M. López, and J. Pineda. 2006. Hydrographic conditions near the coast of northwestern Baja California. Cont. Shelf Res. 26:885–901.

Peterson, W. T. and F. B. Schwing. 2003. A new climate regime in northeast Pacific ecosystems. Geophys. Res. Letters 30(17), 1896, doi:10.1029/2003GL)17528, 2003.

Pierce, S. D., J. A. Barth, R. E. Thomas, and G. W. Fleischer. In press. Anomalously warm July 2005 in the northern California Current: historical context and the significance of cumulative wind stress. Geophys. Res. Letters.

Ramírez-Manguilar, A. M. 2005. Variabilidad estacional e interanual en el Sistema de la Corriente de California frente a la costa de Baja California, México. M. S. Thesis, Facultad de Ciencias Marinas, Univ. Autón. Baja Calif., Mexico, 107 pp.

Schwing, F. B., C. S. Moore, S. Ralston, and K. M. Sakuma. 2000. Record coastal upwelling in the California Current in 1999. Coop. Oceanic Fish. Invest. Rep. 41:148–160.

Smith, R. L., A. Huyer, and J. Fleischbein. 2001. The coastal ocean off Oregon from 1961 to 2000: is there evidence of climate change or only Los Niños? Prog. Oceanogr. 49:63–93.

Sydeman, W. J., R. W. Bradley, P. Warzybok, J. Jahncke, K. D. Hyrenbach, V. Kousky, M. A. Hipfner, and M. D. Ohman. 2006. Krill and Krill Predators: Responses of Planktivorous Auklets (*Ptychoramphus aleuticus*) to the Anomaly of 2005. Geophys. Res. Lett.

Sydeman, W. J., M. M. Hester, J. A. Thayer, F. Gress, P. Martin, and J. Buffa. 2001. Climate change, reproductive performance, and diet composition of marine birds in the southern California Current system, 1969–1997. Prog. Oeanogr. 49:309–329.

Thomas, R. E., G. W. Fleischer, K. D. Cooke, I. A. Holmes, P. H. Ressler, and S. D. Pierce. 2006. Distribution of Pacific hake in relation to ocean conditions: implications for documenting climate change. Published Abstract, p. 120, American Society of Limnology and Oceanography, Summer Meeting, Victoria, BC, Canada.

Veit, R. R., P. Pyle, and J. A. McGowan. 1996. Ocean warming and long-term change of pelagic bird abundance within the California Current System. Mar. Ecol. Prog. Ser. 139:11–18.

Venrick, E., S. J. Bograd, D. Checkley, R. Durazo, G. Gaxiola-Castro, J. Hunter, A. Huyer, K. D. Hyrenbach, B. E. Laveniegos, A. Mantyla, F. B. Schwing, R. L. Smith, W. J. Sideman, and P. A. Wheeler. 2003. The state of the California Current, 2002–2003. Calif. Coop. Oceanic Fish. Invest. Rep. 44:28–60.

Weise, M. J. 2000. Abundance, food habits, and annual fish consumption of California sea lion (*Zalophus californianus*) and its impact on salmonid fisheries in Monterey Bay, California. M.S. Thesis, San Jose State University.

Weise, M. J. 2006. Foraging ecology of male California sea lion (*Zalophus californianus*): movement, diving and foraging behavior, and diving capacity. Ph.D. Dissertation, University of California, Santa Cruz.

Weise, M. J. and J. T. Harvey. In review. Effects of El Niño and La Niña on Seasonal and Annual Variability in Abundance, Diet, and Consumption of California Sea Lion (*Zalophus californianus*). Mar. Ecol. Progr.

Wolter, K. and M. S. Timlin. 1998. Measuring the strength of ENSO—how does 1997–1998 rank? Weather 53:315–324.