THE STATE OF THE CALIFORNIA CURRENT, 1997–1998: TRANSITION TO EL NIÑO CONDITIONS

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ABSTRACT

This report, part of a continuing series of annual reports describing oceanographic conditions in the coastal waters of the Californias, emphasizes the 1997–98 period. The coastal waters of the Californias were strongly influenced by El Niño conditions beginning late in the summer of 1997 and continuing into the summer of 1998. Timely prediction of the onset of this event made it possible for several research programs to augment their observation programs. We review the pattern of atmospheric forcing and changes in the tropical ocean and note the initial impacts upon the California Current system. Sampling being done by the CalCOFI (California Cooperative Oceanic Fisheries Investigations) program is described, and recent data are summarized and interpreted. Data from several other programs including oceanographic sampling off Baja California and central California, and coastal data from buoys, shore stations, and diving programs in kelp forests are reported. There were large and rapid changes in atmospheric forcing and in the upper ocean temperature and salinity distribution and circulation pattern. The pelagic ecosystem was strongly influenced; cruise mean macrozooplankton abundance during the spring of 1998 was the lowest in the 50-year CalCOFI time series. Large changes in the range and abundance of plankton and fish populations were observed. El Niño–induced changes must also be considered in the context of changes on other space-time scales, and the relation of El Niño–related changes and secular trends seen since the mid-1970s regime shift will merit particular attention.

INTRODUCTION

This is the fifth in an annual series of reports (Hayward et al. 1994, 1995, 1996; Schwing et al. 1997) that describe and interpret oceanographic and related environmental data from the coastal region off the Californias. Physical data series are updated and intercompared to explain the prevailing forcing, and biological series and their anomalies are examined in relation to the physical structure. Our intent is to describe observational programs in the region and to provide a preliminary summary and interpretation of their results. The emphasis is on CalCOFI. We have, however, included information from several other programs in order to place the CalCOFI observations in a larger regional context and to provide a brief summary of other programs and a point of contact for additional information about them. The list of additional programs is by no means complete.

In an effort to consider the most timely information that is available, we have included preliminary data in this report; some values may change as the final steps of data processing are completed. We have also had to balance our goals of interpreting and summarizing observations for a timely report with the need to use preliminary data and the brief lead time for their analyses.

We have chosen to include some more speculative interpretation of the most recent data while recognizing that subsequent reevaluation may lead to revision of some of the ideas.

We start by examining the large-scale atmospheric and oceanic conditions that force much of the variability in the California Current. Last year's report (Schwing et al. 1997) described the initial development of strong El Niño conditions in the eastern tropical Pacific Ocean during the first five months of 1997 while in the same period the California Current system was affected by regional forcing. El Niño conditions became the dominant forcing process in the latter months of 1997. This report continues the description of the tropical El Niño and its subsequent effect on the California Current region. However, events on other space-time scales also strongly influence this system, and the effects of El Niño must be considered in the context of longer-term trends, particularly the secular trends of warming of the upper layers and decline in macrozooplankton biomass that have been evident since the mid-1970s regime shift (Roemmich and McGowan 1995). Our emphasis is upon oceanographic conditions and pelagic ecosystem structure, but trends in coastal kelp forest communities and pelagic seabirds are also described. A few fisheries issues are considered as well.

DATA SETS AND METHODS

Coastal data include temperature and salinity at shore stations (Walker et al. 1994). La Jolla (SIO Pier) and Pacific Grove daily temperatures and their anomalies from the long-term harmonic mean (1916–93 for La Jolla and 1919–93 for Pacific Grove) are shown as time series. Coastal sea-level data from San Diego and San Francisco are shown as monthly anomalies from the 1975–95 mean, corrected for atmospheric pressure. Monthly upwelling indices and their anomalies, relative to 1948–67, for the western North American coast are presented. From six representative buoys throughout the California Current region, time series of the daily alongshore wind component and sea-surface temperature (SST; data courtesy NOAA National Data Buoy Center) are plotted against the harmonic mean of each record; the location and base period of each buoy is given in table 1, and the position of all but the most northern one is plotted in figure 1.

Data from quarterly CalCOFI surveys in 1997 and 1998 are described. The CalCOFI monitoring program started in 1949. The present program consists of quarterly (normally January, April, July, October) cruises that occupy a grid of 66 stations off southern California (fig. 1). The core time-series data set now collected at each station includes a CTD/rosette cast with sensors for pressure, temperature, salinity, dissolved oxygen, photosynthetically active radiation, fluorescence, and transmissivity. Water samples are collected at 20–24 depths in

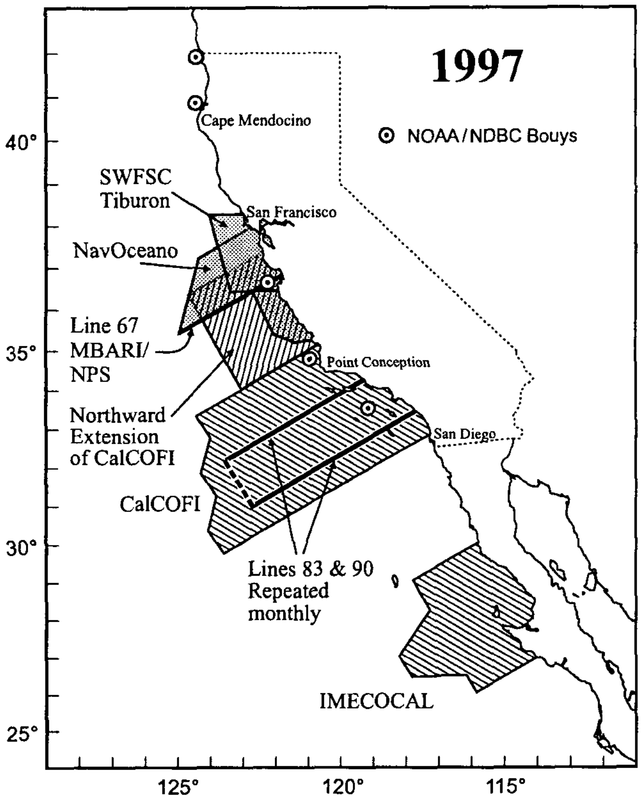

Figure 1. Positions and depiction of coverage for various sampling programs described in this report.

TABLE 1
Locations of SST and Alongshore Wind Time Series

Buoy	Name	Position	Base Period[a]	Alongshore angle[b]
46050	Stonewall Bank, Ore.	44.6°N 124.5°W	1991–98	0
46027	St. George, Calif.	41.8°N 124.4°W	1983–97	341
46022	Eel River, Calif.	40.8°N 124.5°W	1982–98	354
46042	Monterey Bay, Calif.	36.7°N 122.4°W	1987–97	328
46011	Santa Maria, Calif.	34.9°N 120.9°W	1980–98	326
46025	Catalina Ridge, Calif.	33.7°N 119.1°W	1982–98	294

[a] Period of harmonic mean.
[b] Determined from principal-component analysis.

the upper 500 m to determine salinity, dissolved oxygen, nutrients (NO_3, NO_2, PO_4, SiO_3), phytoplankton pigments (chlorophyll a and phaeophytin), and primary production (^{14}C uptake at one station per day). Oblique and surface (neuston) net tows (0.505 mm mesh) are taken at each station. Acoustic Doppler current profiler (ADCP) data are also recorded continuously, providing a measure of upper ocean currents as well as an estimate of zooplankton biomass based upon acoustic backscatter. Continuous near-surface measurements of temperature, salinity, and chlorophyll fluorescence are made from water pumped through the ship. In a separate pumping system, water from approximately 3 m depth is continuously filtered for fish eggs and larvae. Cruise 9604 was the first CalCOFI cruise on which this continuous underway fish egg sampler (CUFES) was used (Checkley et al. 1997). The CUFES has now become a standard CalCOFI sampling device. The most recent data presented here are preliminary, and some changes may be made after the final processing and quality control checks. More details on the methods, information about recent activities, and CalCOFI hydrographic data can be accessed via the World Wide Web (*http://www-mlrg.ucsd.edu/calcofi.html*).

Observations in regions off central California were made by various research groups including CalCOFI, the Monterey Bay Aquarium Research Institute (MBARI), the Naval Oceanographic Office (NAVOCEANO), the Naval Postgraduate School (NPS), the Southwest Fisheries Science Center (SWFSC) at Tiburon, and SWFSC at La Jolla (fig. 1) and are discussed below. A new monitoring program off Baja California by Mexican scientists, Investigaciones Mexicanas de la Corriente de California (IMECOCAL), coordinated by CISESE and UABC (see CalCOFI Committee Report, this issue), was initiated in 1997 and is also described in this report.

OBSERVATIONS

Large-Scale Oceanic and Atmospheric Climate Patterns

During 1997–98, a number of remarkable anomalies occurred in the large-scale distribution of atmospheric and oceanic patterns in the eastern North Pacific. Many of these represented the lingering effects of the 1995–97 La Niña (Schwing et al. 1997), while others were connected to the 1997–98 El Niño in the equatorial Pacific. In the early stages of the El Niño event (March–September 1997) the direct impacts of the event on the extratropical North Pacific appear to have been small. There is some evidence that during this period the extratropical North Pacific anomalies contributed to the development of El Niño anomalies in the equatorial Pacific. During the later stages of the event (November 1997–April 1998) there were major effects from the tropical Pacific on the extratropical North Pacific.

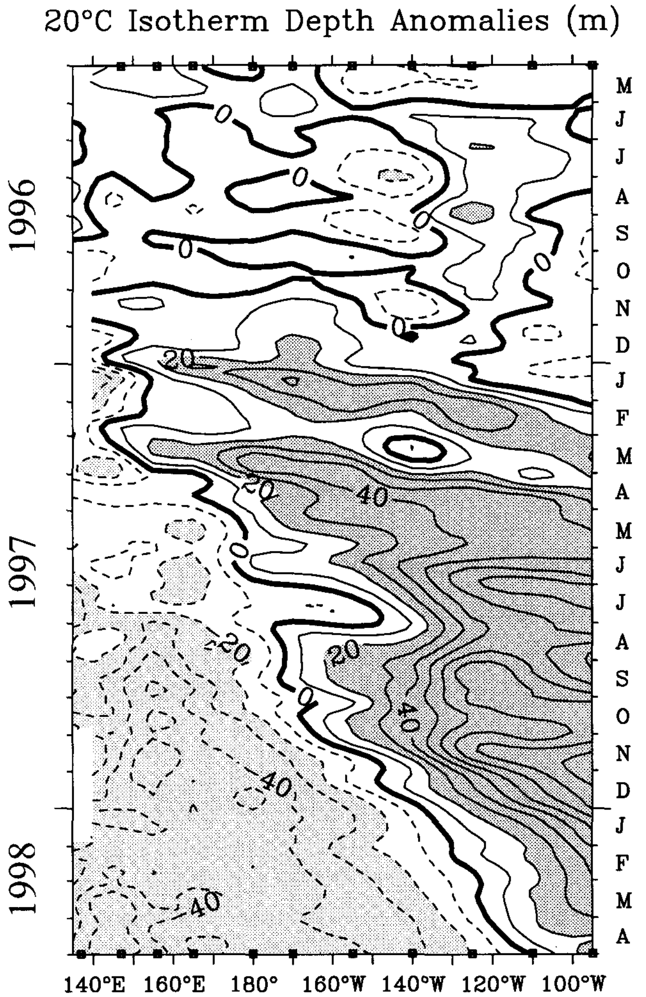

Figure 2. Depth of the 20°C isotherm between 2°N–2°S for May 1996–April 1998. Analysis based on the five-day averages of moored time-series data from the TAO array. Shading denotes isotherm depths more than 20 m deeper than the monthly climatology. The eastward-propagating deep and shallow anomalies indicate the passage of Kelvin waves across the equatorial Pacific (e.g., during December 1996–July 1997). The gradual eastward extension of the shallow anomaly from the western equatorial Pacific during July 1997–April 1998 shows the eastward extension of anomalously cool subsurface water. Adapted from NCEP (1998b).

During December 1996 and into the early months of 1997 the relaxation and reversal of westward winds in the western equatorial Pacific helped to initiate El Niño. Observations of equatorial subsurface temperatures reveal the propagation of a series of ocean Kelvin waves from the western equatorial Pacific to the South American coast during the first half of 1997 (fig. 2). During April–June 1997 El Niño grew very rapidly and reached an intensity rarely seen (fig. 3). By May, intensive and extensive anomalous warming had developed in the eastern equatorial Pacific, as evidenced by the sea-surface temperature anomalies (SSTAs; fig. 4b).

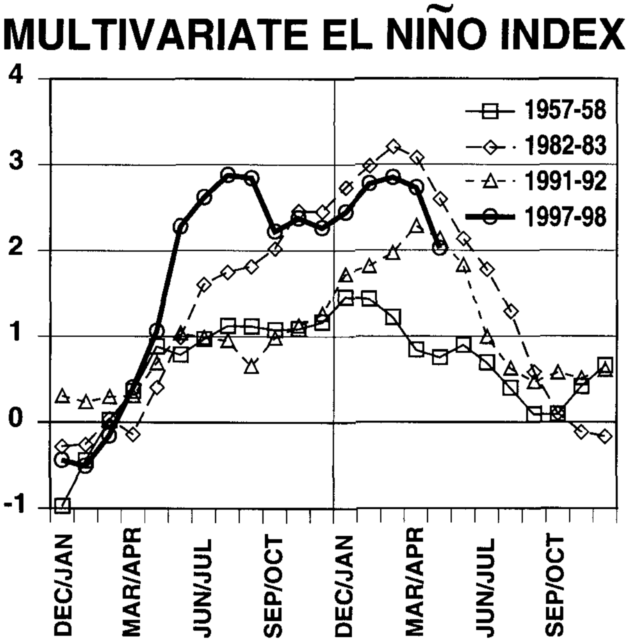

Figure 3. A multivariate El Niño index indicating the intensity of the 1997–1998 event relative to four strong historical El Niño events. Adapted from Wolter and Timlin (in press).

A basic pattern of above-average SST in a broad region off the North American coast and below average SSTs in the central North Pacific existed well before the initiation of El Niño and continued through the early months of 1997 (Schwing et al. 1997). In May 1997 there was a sharp intensification of SSTAs off the North American west coast coincident with the warming in the eastern equatorial Pacific (figs. 3 and 4b). However, the anomalous warming in the eastern North Pacific in spring–summer 1997 appears to have been primarily due to regional wind anomalies and not caused by equatorial Pacific El Niño processes. During April–June 1997, anomalously low sea-level pressure (SLP) in the eastern North Pacific led to a weak North Pacific High (NPH) and weak southwestward trade winds out of the NPH. For much of this period, the usual southward winds along the west coast were exceptionally weak, or even northeastward out of the subtropics. The positive SSTAs strengthened in a roughly triangular region of the northeast Pacific extending between Cabo San Lucas, Hawaii, and Vancouver Island (fig. 4b). This strengthening appears, to a large extent, to have been a response to anomalous surface Ekman transports resulting from the northeastward wind anomalies (fig. 4a; cf. Schwing et al. 1997). Atmospheric teleconnections from the equatorial Pacific to the North Pacific produce most of the significant effects of El Niño events, but these teleconnections are generally very weak in the northern summer and most pronounced during the northern winter. Thus, despite strong El Niño conditions in the equatorial Pacific during April–September 1997, the event appears to have had little direct effect via atmospheric teleconnections on the North Pacific at this time. Instead, the NPH and trade winds may have contributed to the intensification of the equatorial El Niño conditions, especially during April–June 1997 (figs. 3 and 4a, b).

During much of July–September 1997, anomalous atmospheric wave trains emanating from east Asia helped maintain weak SLPs in the eastern North Pacific and weak trade winds into the equatorial Pacific. The SLP anomaly (SLPA) pattern for August 1997 (fig. 4c) shows an example of the influence of this wave-train activity. The alternating positive and negative centers that gently arced across the North Pacific were part of a tropospheric wave train emanating from a region of intense tropical cyclone activity in east Asia (cf. Nitta 1987). This summer teleconnection pattern appears to have helped create anomalous surface Ekman transports and SSTAs across the North Pacific, including strongly positive SSTAs in the triangular region described earlier and along much of the West Coast (fig. 4d). July–September 1997 was also a period of large positive SSTAs in the central equatorial Pacific, and a period in which El Niño reached an initial peak in its intensity (fig. 3).

During November 1997–April 1998, the El Niño event reached a second peak in intensity (fig. 3), and the first clear effects on the North Pacific Ocean appeared. These effects were primarily the result of an atmospheric wave train that emanated from the central equatorial Pacific and produced a pattern similar to the Pacific–North American anomaly (cf. Murphree and Reynolds 1995). During much of this period, a similar but oppositely phased wave train emanated from near Indonesia and reinforced the first wave train over the northeast Pacific. Some of the clearest El Niño effects occurred during February 1998, when much of the northeast Pacific was dominated by a strong negative SLPA and strong wind anomalies out of the west-northwest (fig. 4e). The SSTAs in the central and eastern North Pacific were negative, while positive SSTAs were confined to a relatively narrow band next to the West Coast (fig. 4f). December 1997–February 1998 was a period of exceptionally intense winter storm activity along the West Coast, especially during February. These storms and their heavy precipitation represented the anomalous intensification and southward shift of the North Pacific jet stream caused by the impacts of El Niño on the upper tropospheric circulation.

From March through May 1998, El Niño conditions in the equatorial Pacific weakened considerably, with negative SSTAs developing in the central equatorial Pacific during May (NCEP 1998b). During this period, anomalously cool subsurface (50–300 m) temperatures extended along the equator from the western Pacific well into the eastern Pacific. This pattern resulted from the

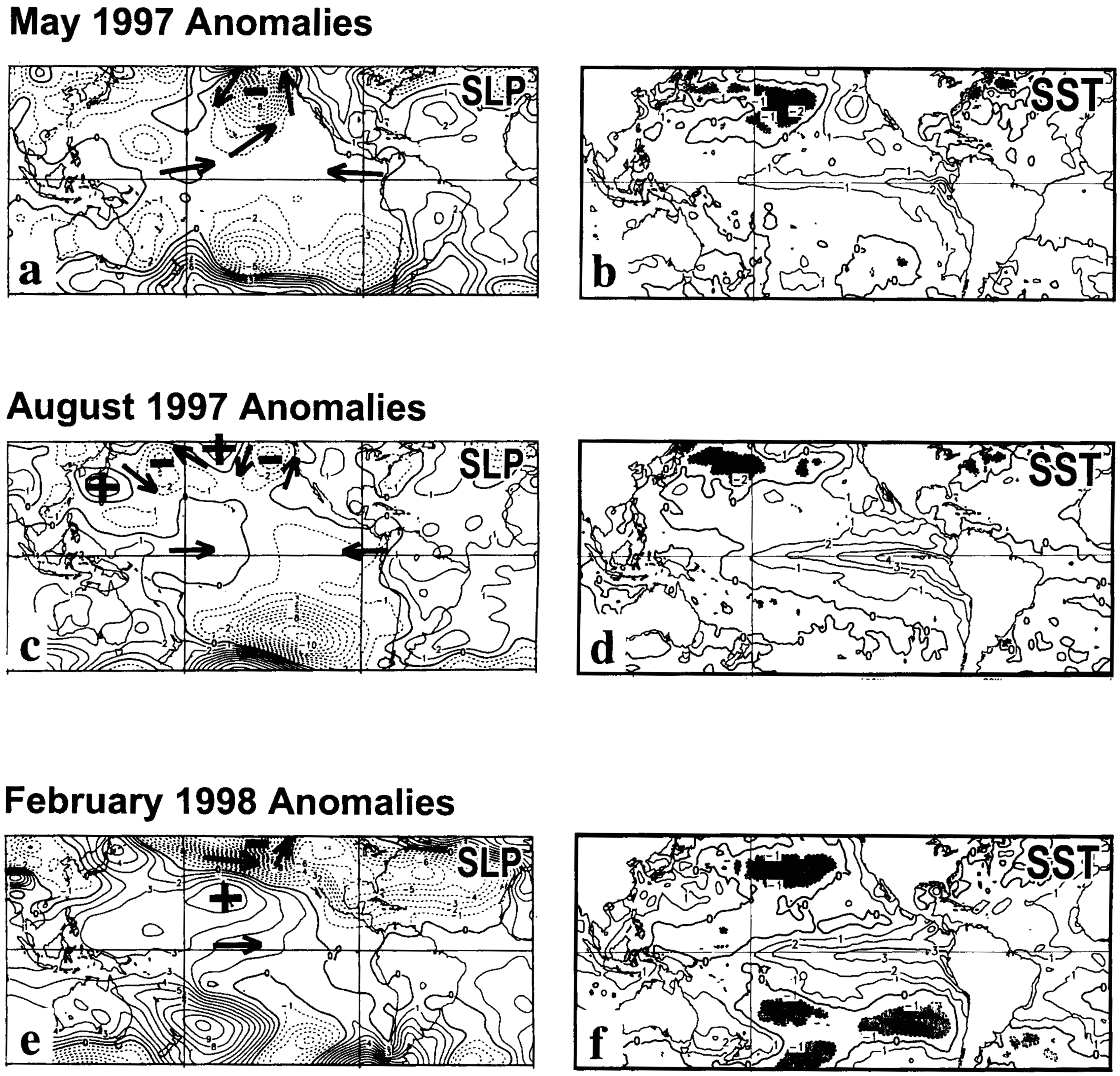

Figure 4. Sea-level pressure anomalies (SLPAs) with idealized surface wind anomalies, and sea-surface temperature anomalies (SSTAs) over the Pacific Ocean: *a*, SLPAs, May 1997; *b*, SSTAs, May 1997; *c*, SLPAs, August 1997; *d*, SSTAs, August 1997; *e*, SLPAs, February 1998; *f*, SSTAs, February 1998. Anomalies are departures of monthly-averaged fields from the 1979–95 base-period mean fields. Positive anomalies denote higher than average atmospheric pressure and warmer than average SST. Contour intervals are 1 mb for SLPA and 1°C for SSTA. The arrows indicate the direction and strength of the wind anomalies. Anomalous surface winds are approximately parallel with SLPA contours, and cyclonic (counterclockwise in Northern Hemisphere) around negative anomalies. Closer-spaced SLPA contours indicate faster anomalous winds. Adapted from NCEP (1997a, b, 1998a).

eastward expansion of a cool subsurface anomaly from the western Pacific beginning in July 1997 (fig. 3). This suggested a clear transition toward La Niña conditions, which several long-lead forecasts have predicted for late 1998 (COLA 1998). However, the equatorial Pacific trade winds were weak during March–May 1998, and some forecasts have predicted weak El Niño conditions extending into early 1999 (COLA 1998).

Coastal Conditions

The monthly upwelling indices (Bakun 1973; Schwing et al. 1996) along the U.S. West Coast during 1997 showed no remarkable long-term displacement from the annual signal (fig. 5). Indices were higher than normal (more upwelling) along southern California in early 1997 and along northern California in summer 1997. Extremely negative (downwelling-favorable) indices af-

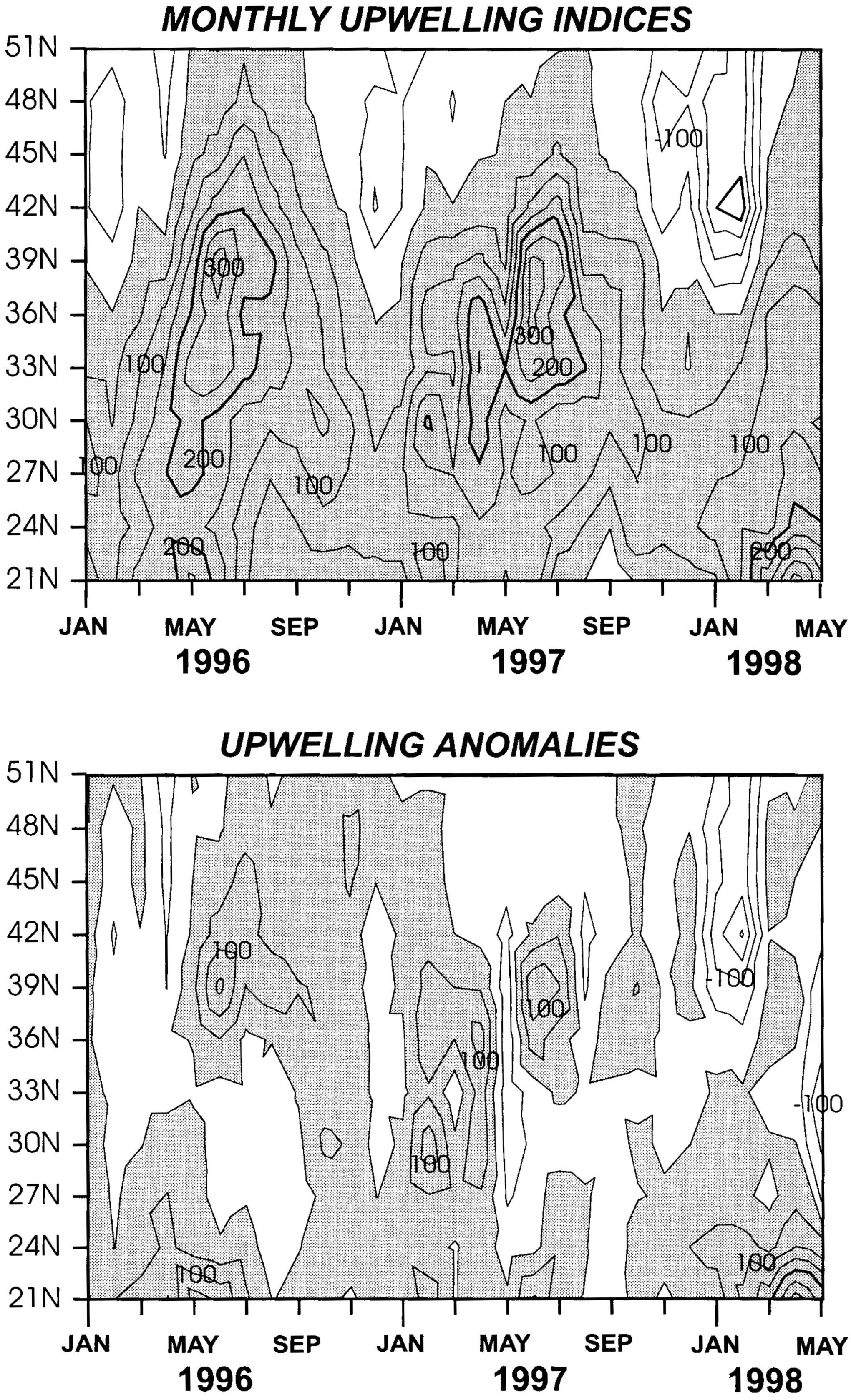

Figure 5. Monthly upwelling index and upwelling index anomaly during 1996–98. Positive values imply coastal upwelling. Shaded areas denote positive (upwelling-favorable) values in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1948–67 monthly means. Units are in m^3 sec^{-1} per 100 km of coastline.

fected the Washington, Oregon, and northern California coast in early 1998. Unusually weak upwelling developed in April–May 1998 off California and northern Baja California, similar to (but much greater than) the previous May. Southern Baja California experienced abnormally high upwelling during the first part of 1998. Since mid-1997, much of the West Coast has featured a three-month fluctuation in the upwelling anomaly (e.g., minima in May, August, November 1997, and February and May 1998). These fluctuations correspond to a cyclical pattern in the North Pacific High and associated buoy winds across much of the midlatitude and subtropical North Pacific. Conditions in 1996 were detailed in last year's report (Schwing et al. 1997).

NDBC buoy winds at selected available locations along the U.S. West Coast (fig. 6) display the short-term variability associated with synoptic atmospheric events, superimposed on the annual climatological cycle of strong southward winds in summer and northward or weak southward winds in winter. Wind vectors align strongly with the local coastline. Because of budget shortfalls, maintenance to the buoy network has been limited for the past few years, leading to very spotty data returns. Much of the 1996–97 winter featured generally greater than normal northward buoy winds (more downwelling-favorable), but February–March 1997 was a time of stronger than normal southward coastal winds. The following fall and winter (1997–98) exhibited numerous episodes of strong northward winds. This pattern is particularly evident off northern California, and coincides with very heavy winter storm activity and copious precipitation for much of the West Coast. Winds were very strong and oscillated in direction even in the Southern California Bight, where winds are normally relatively weak and variable. The upwelling index anomalies (fig. 5) correspond well with the tendencies of the buoy alongshore winds, with both indicating greater than normal upwelling in early 1997 and spring 1998, and anomalous downwelling in May and August 1997 and early 1998.

After several months of slightly cooler than normal surface conditions, SSTs at the West Coast buoys climbed rapidly beginning in the spring of 1997 (fig. 7). Two periods of particularly intense warming occurred in May and August 1997. These warming events coincided with times of weaker than usual southward buoy winds and negative upwelling anomalies. The absolute SST and its anomaly relative to the climatology peaked in early fall 1997, and remained well above normal through spring 1998. Since mid-1997, coastal SSTs have been 2°–3°C above average, and anomalies as much as +6°C were found in late summer. Since the buoy climatologies extend only to the early 1980s (table 1), the magnitude of the anomalies cannot be compared to those of the coastal shore stations because shore station base periods are much longer and the secular trend of warming has been well documented (Roemmich and McGowan 1995). The same caveats about base periods to determine "normal conditions" also apply to comparisons with the hydrographic data.

The temperature data from the coastal shore station at Pacific Grove (fig. 8) showed that SST fluctuated about its long-term mean from early 1997 through July, and conditions were anomalously warm from August 1997 to March 1998, except for a cold event in November 1997. In contrast to Pacific Grove, the shore station at La Jolla registered larger and more consistent positive SST anomalies. In the early months of 1997 the SST anomaly increased, to more than +4°C in May (fig. 8). From September 1997 through mid-March 1998 the SST anomaly was consistently in the range of +2° to +4°C.

Coastal sea level at San Francisco and San Diego showed similar fluctuations. There was a sharp rise in sea level at San Francisco in December 1996 and January 1997, which may have been partly caused by large inputs of fresh water from river runoff (fig. 9). After a drop to below-normal values, sea level began to rise in March 1997, generally increasing through February 1998. The largest anomalies occurred after September 1997. At San Diego sea level generally increased throughout 1997, starting from small negative anomalies and ending the year at high positive anomalies. In 1998 sea-level anomalies at San Diego declined in both January and February. A speculative interpretation is that the rise at San Diego after July and the rises at both stations after September are caused by strong increases in geostrophic adjustment to an unusually strong poleward coastal countercurrent/undercurrent, the oceanic response (coastally trapped Kelvin waves) to El Niño.

CalCOFI Survey Cruises

9704 (2–20 April 1997). The preliminary data from this cruise, included in last year's report (Schwing et al. 1997), used the 100 m temperature field as an estimate of the circulation pattern. The map of dynamic height (fig. 10), which gives the geostrophic flow pattern, differs from the earlier estimate only in the region very near the coast. Within the Southern California Bight the flow is generally weak with mixed direction. The main flow of the California Current has a very sharp meander that brought the relatively warm low-salinity core of the California Current close to Point Conception. There is a strong offshore sweep to the current core south of Point Conception, and the low-salinity jet which forms the core of the California Current is unusually far offshore in the southern part of the sample grid. (The long-term mean circulation patterns for the time periods coinciding with

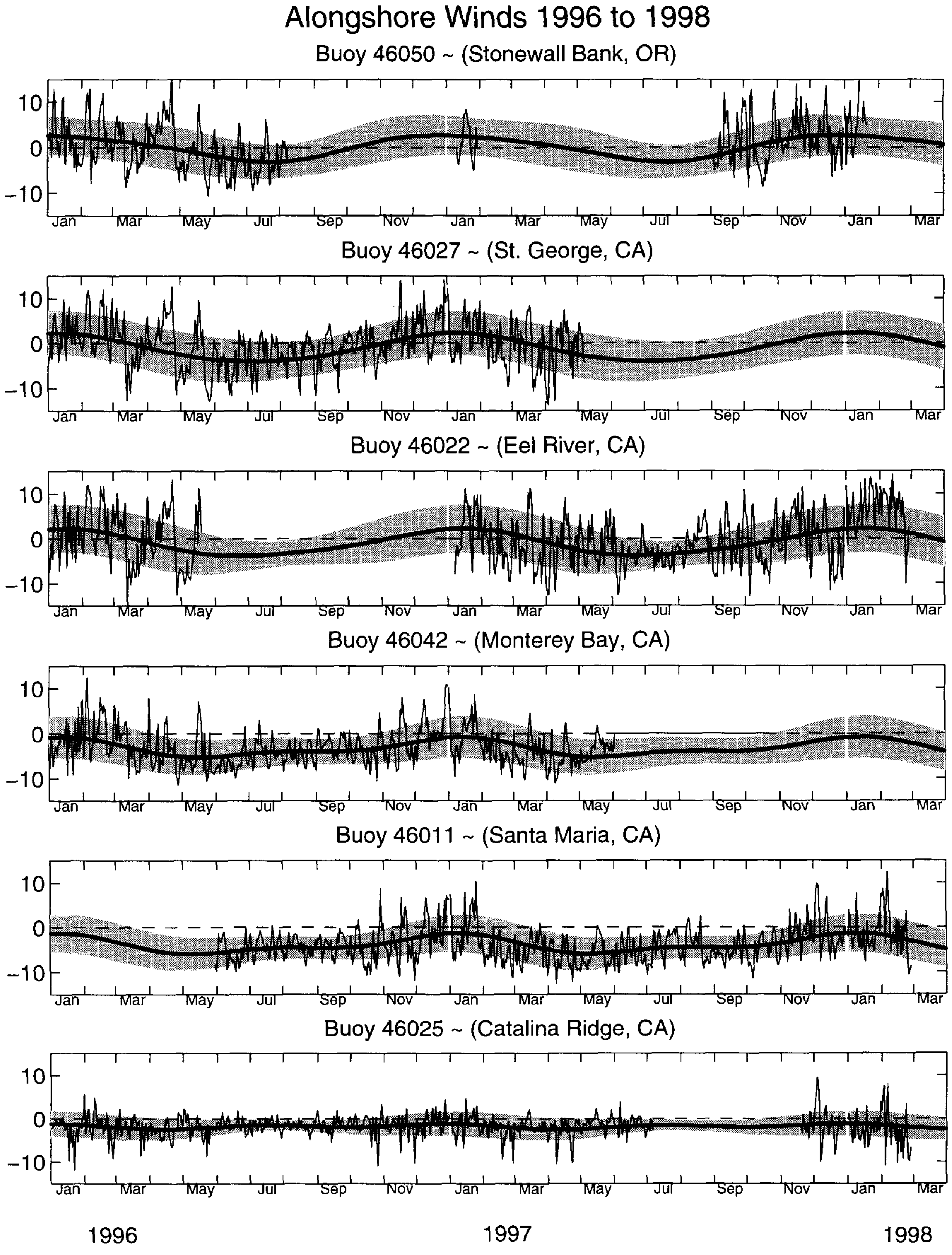

Figure 6. Time series of daily-averaged alongshore winds for 1996–98 at selected NDBC buoys. Bold lines are the harmonic mean annual cycle at each buoy. Shaded areas are the standard error for each Julian day. The period used for calculating the mean at each site and the alongshore angle are shown in table 1.

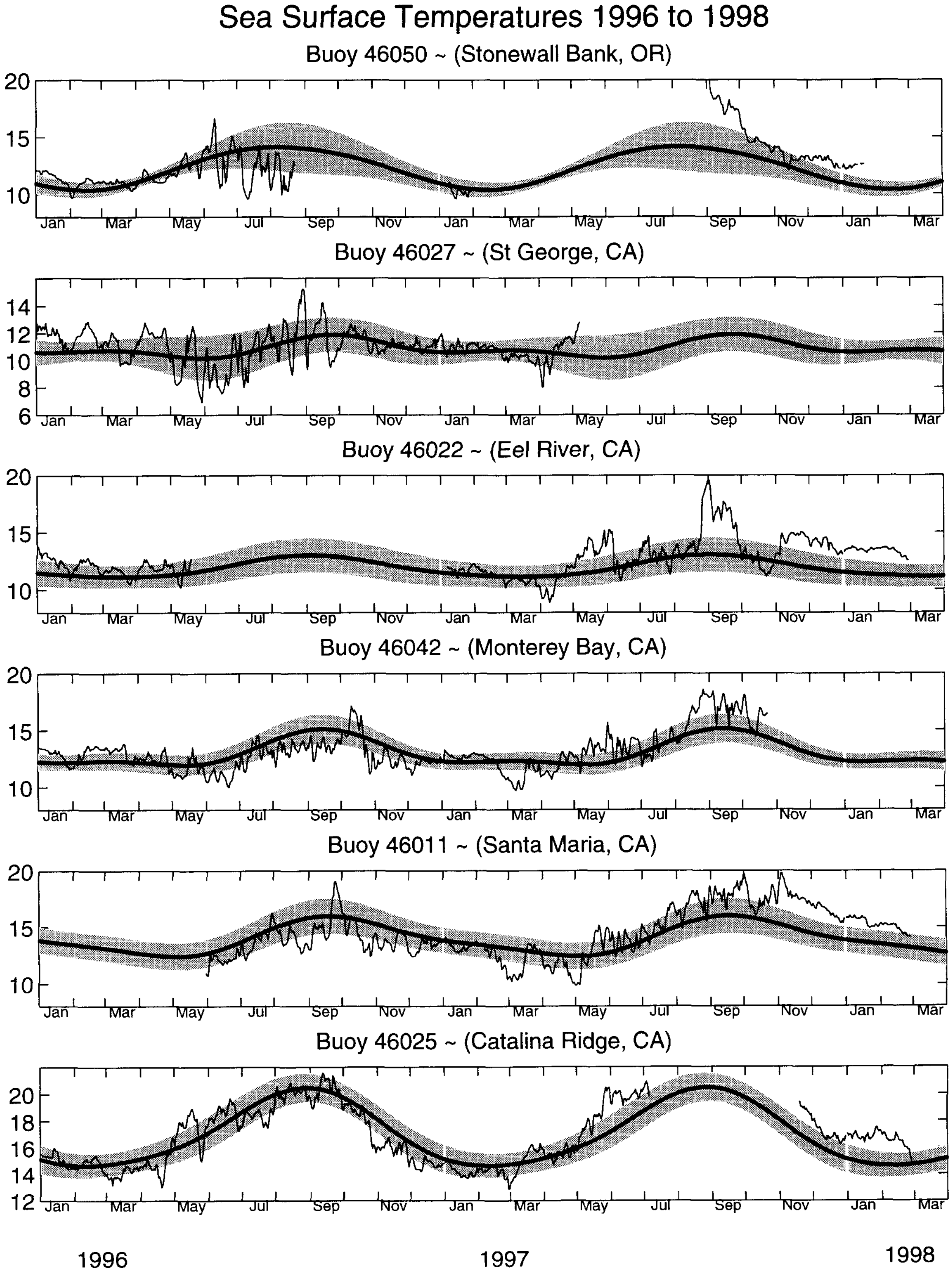

Figure 7. Time series of daily-averaged SST for 1996–98 at selected NDBC buoys. Bold lines are the harmonic mean annual cycle at each buoy. Shaded areas are the standard error for each Julian day. The period used for calculating the mean at each site is shown in table 1.

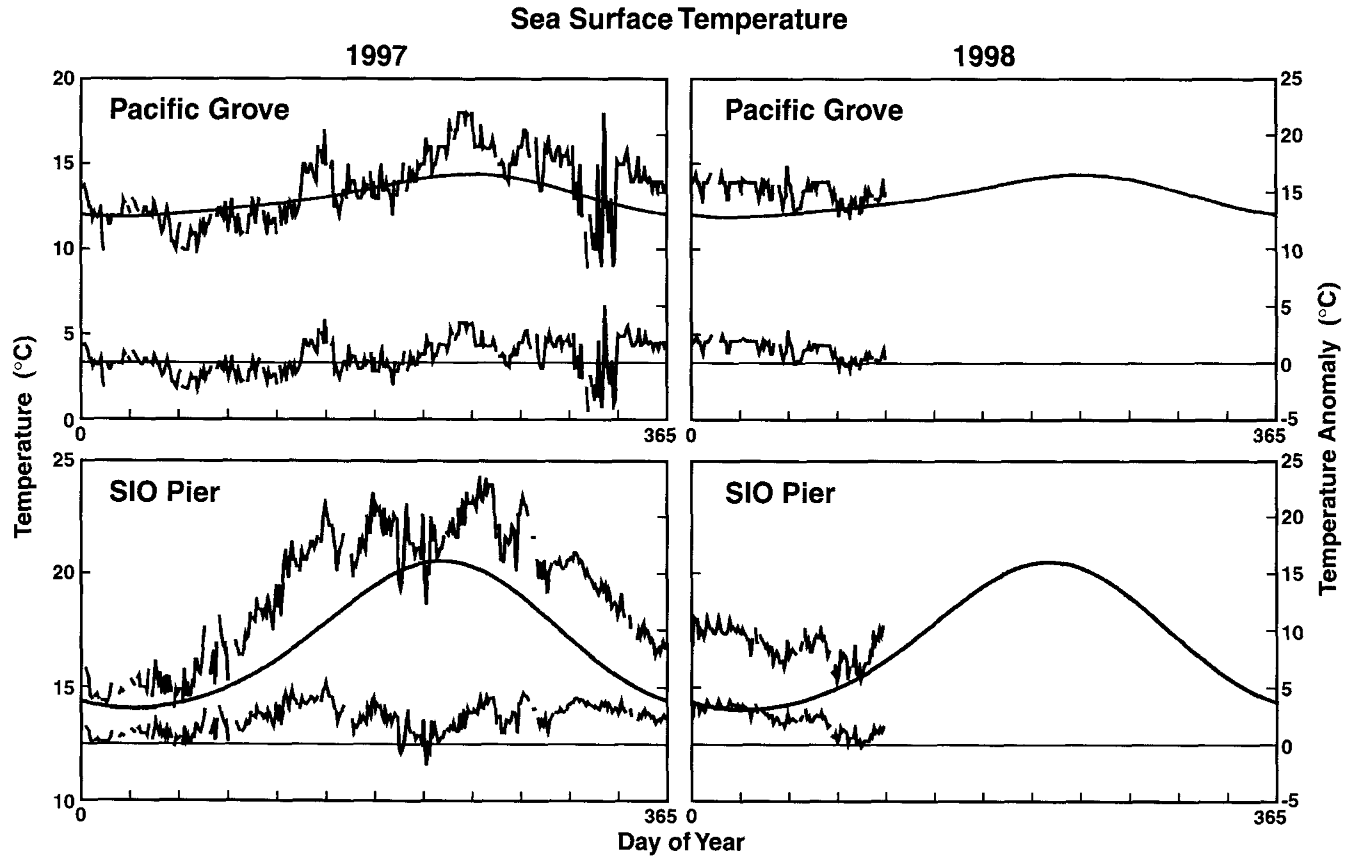

Figure 8. Sea-surface temperature at Pacific Grove and La Jolla (SIO Pier) for 1997 and 1998, and daily temperature and anomalies from the long-term harmonic mean (1919–93 for Pacific Grove and 1916–93 for La Jolla). The heavy line shows the annual cycle of the harmonic mean in SST.

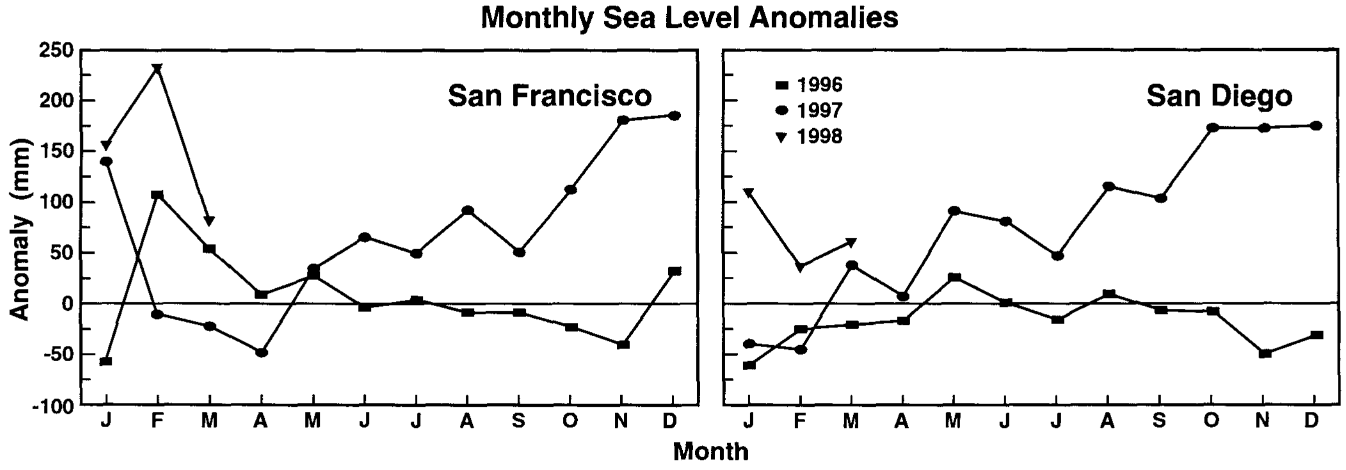

Figure 9. Monthly sea-level anomalies at San Francisco and San Diego for 1996, 1997, and 1998. The monthly anomalies are deviations from the period 1975–95, corrected for atmospheric pressure.

the CalCOFI cruises are shown in Hayward et al. 1994). Within the Southern California Bight, waters at 10 m were anomalously warm and saline. The chlorophyll distribution was typical of spring conditions, with elevated values in the vicinity of Point Conception and the Santa Barbara Channel. The concentration and spatial distribution of chlorophyll was similar to that seen in the springs of 1995 and 1996.

9707 (1–20 July 1997). Except for some minor features, the geostrophic flow field for 9707 (fig. 11) is typical of the normal pattern for summer. The well-defined core of the California Current is, however, slightly far-

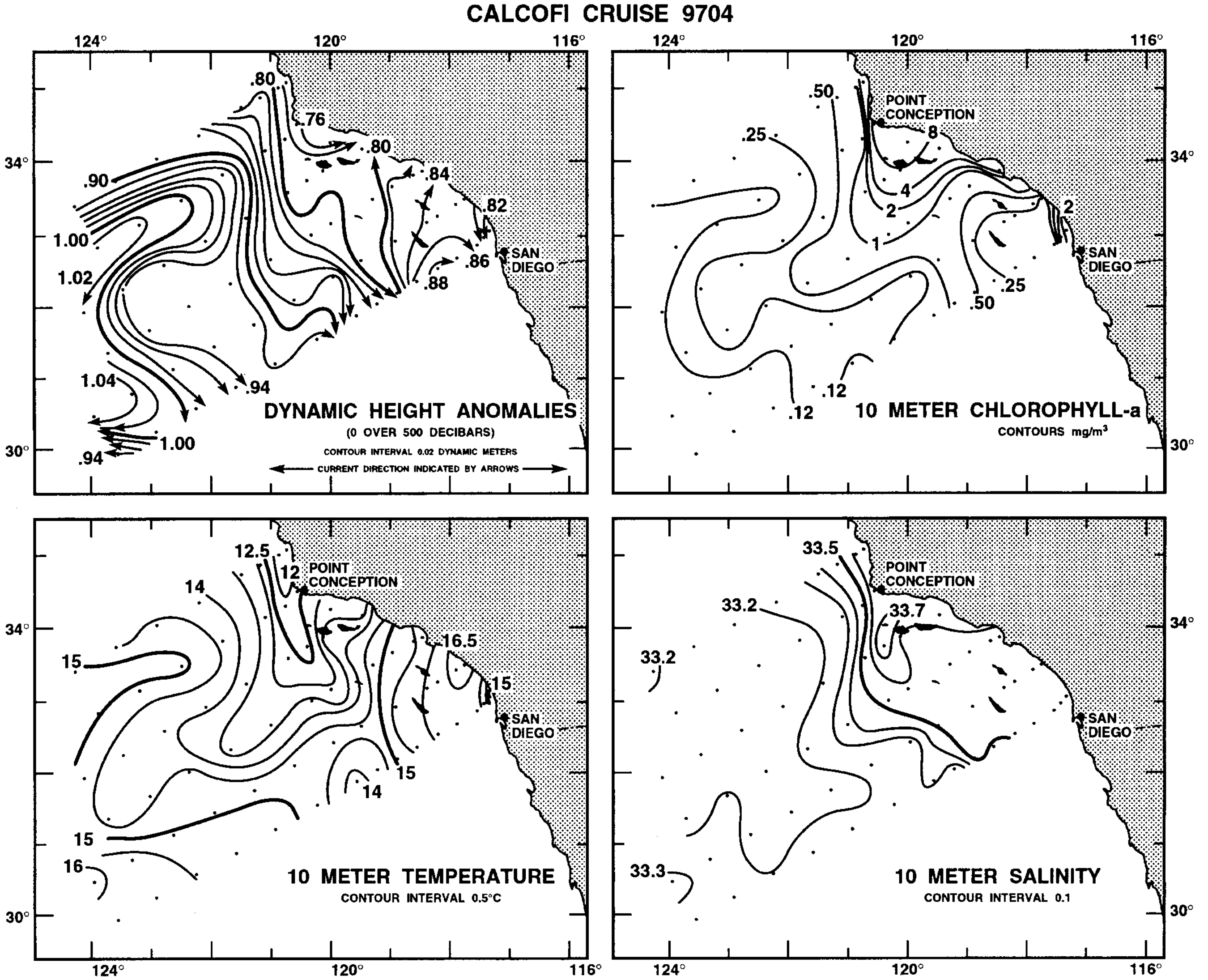

Figure 10. Spatial patterns for CalCOFI cruise 9704 (2–20 April 1997), including upper-ocean geostrophic flow estimated from 0 over 500 dbar dynamic height anomalies, 10 m chlorophyll, 10 m temperature, and 10 m salinity.

ther west than the long-term mean pattern (Lynn et al. 1982; Hayward et al. 1994). The inshore countercurrent is well developed, with greater than average velocities. The Southern California Eddy is small but intense enough to leave a strong signature in both the fields of SST and chlorophyll. With few exceptions the 10 m temperatures are above the long-term average; several areas exceed 1.5°C. Maps of SST anomalies from monitoring projects available on the World Wide Web (e.g., *NOAA/NWS/NCEP* and *NOAA/NESDIS/CoastWatch*) all showed a substantial increase between the months of April and May 1997. The core of low salinity at 10 m aligns with the outer half of the strong jet and is also displaced slightly westward of its long-term mean position. A comparison of cross-sections of salinity (line 93) for April and July shows a remarkable change in waters over or near the continental slope. In July there is a plug of water with salinity exceeding 34.4 where none had existed in April (fig. 12). The large change extends from 150 m to 450 m. Seen on a map of salinity at 300 m (fig. 11), this intrusion appears as a tongue of high-salinity water penetrating the bight from the south. The accompanying plot of ADCP vector flow confirms the southern source. The poleward California Undercurrent is very strong and continuous through the bight and around Point Conception. Waters with salinity exceeding 34.4 at this level are more typically found 550 km (300 nmi) to the south. This remarkable pattern may be part of the oceanic response (Kelvin wave) to the strong El Niño event in the tropics.

9709 (20 September–9 October 1997). The values of dynamic height calculated from this cruise are con-

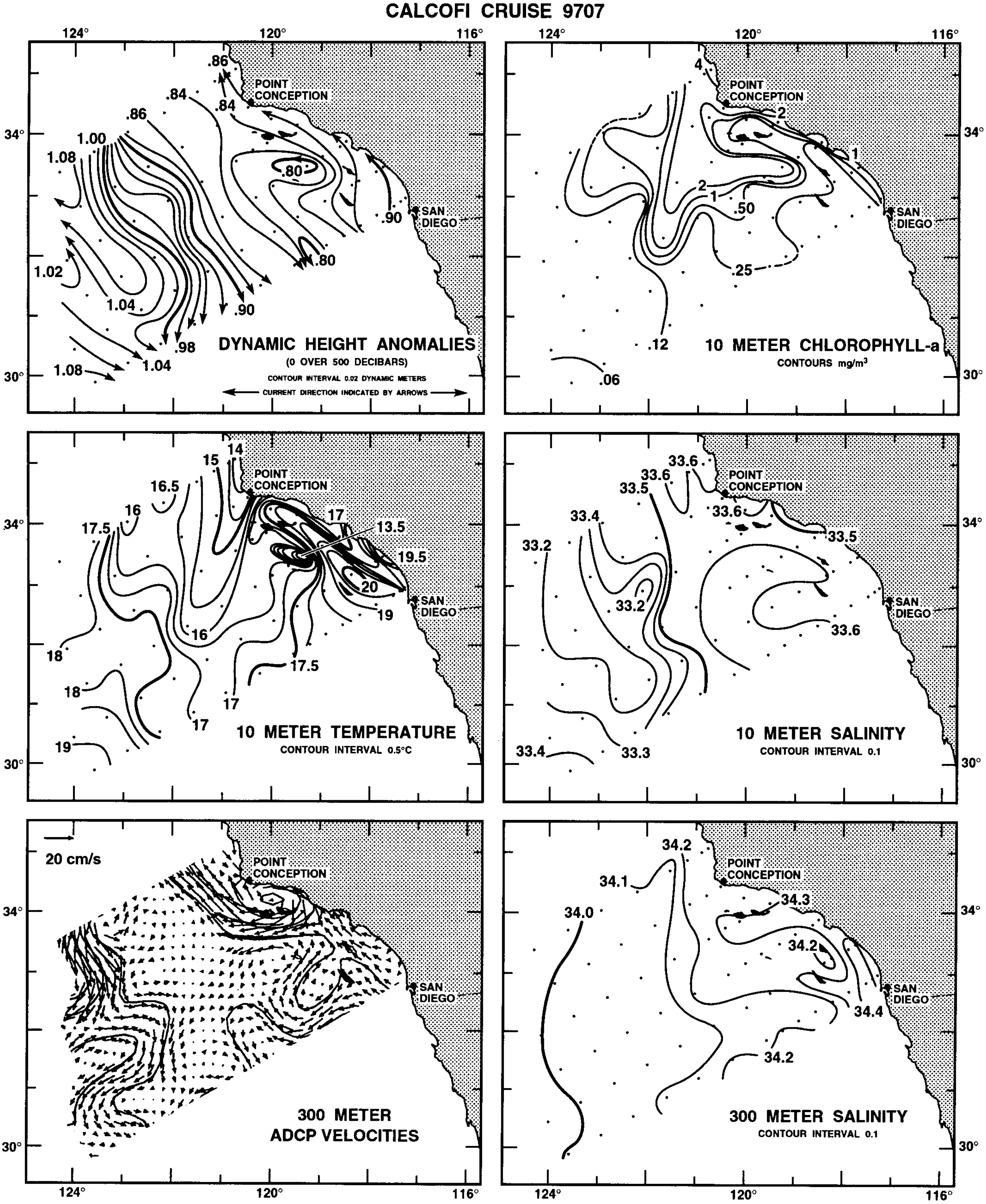

Figure 11. Spatial patterns for CalCOFI cruise 9707 (1–20 July 1997), including upper-ocean geostrophic flow estimated from 0 over 500 dbar dynamic height anomalies, 10 m chlorophyll, 10 m temperature, 10 m salinity, 275–325 dbar ADCP velocity vectors (courtesy of T. Chereskin), and 300 m salinity.

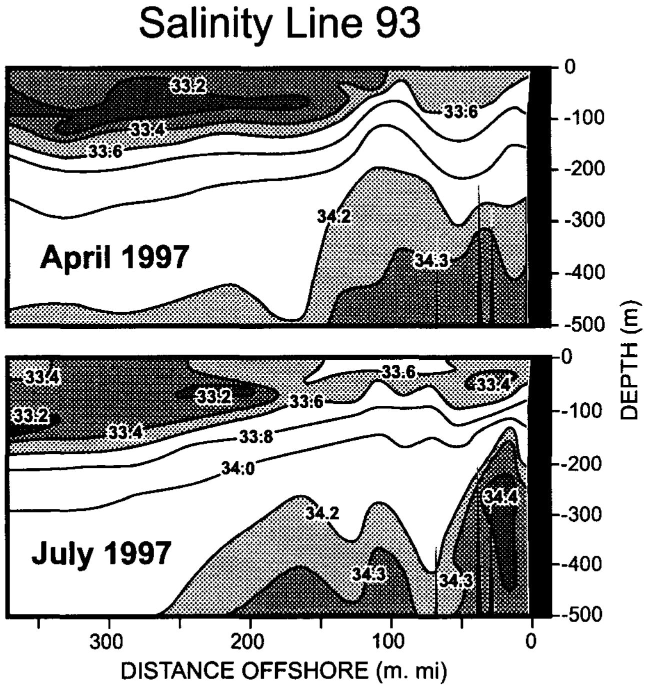

Figure 12. Vertical sections of salinity for line 93 from CalCOFI cruises 9704 and 9707. Salinity below 33.6 and above 34.2 is shaded.

siderably higher (mostly within the range of +0.04 to +0.15 dyn. m) than the long-term mean for October (fig. 13). Of the two strong cyclonic eddies, the one in the Southern California Bight is found in the mean field for October. The lowest temperature (17.15°C) and highest chlorophyll are found within this eddy. Positive 10 m temperature anomalies increased considerably from the previous cruise and are everywhere above normal, with the coastal band well exceeding 3.5°C. The inshore coastal countercurrent is continuous through the bight and around Point Conception, transporting very warm and saline water northward.

9802 (26 January–14 February 1998). Values of dynamic height for this cruise (fig. 14) are considerably higher than the long-term seasonal norm, reflecting both the anomalously higher surface temperatures and generally deeper thermocline; values range from 0.92 to 1.08 dyn. m. (10 J.kg^{-1}) compared to long-term mean values of 0.83 to 1.00 dyn. m. given by Lynn et al. (1982). Two cyclonic eddies characterize the circulation pattern during this cruise. The inshore limb of the shoreward eddy is the inshore countercurrent, and the flow is considerably stronger than normal. The surface water in this current has a salinity anomaly as much as +0.5 and a temperature anomaly greater than +3°C. The center of the California Current jet is displaced farther offshore and is characterized by the tongue of very low-salinity water. Between these two currents there is a large looping flow involving both eddies. A secondary lobe of cool, low-salinity water suggests that a new path may be developing for the main jet (just offshore of the Southern California Eddy), thus pinching off the offshore meander and the western eddy.

9804 (2–21 April 1998). The most dramatic seasonal change in conditions occurs between winter and spring. In April 1998 the California Current as estimated by the field of dynamic height appears as an exceptionaly strong coastal jet (fig. 15) replacing the poleward coastal countercurrent that had been found in February. The coastal jet is balanced by a strong upward tilt (shoreward) of the density structure, which upwells a narrow coastal band of water with very low temperature, high salinity, and high nutrients. The latter is evidenced by the high production of chlorophyll. The spatial pattern of chlorophyll is similar to that observed in the springs of 1997, 1996, and 1995. The California Current jet transports low-salinity waters from the north, appearing in this survey as a narrow tongue penetrating southward. The unusually high salinity in the southern and central portions of the Southern California Bight may be a product of upwelling of southerly waters that had been transported northward during the earlier period.

Additional El Niño Cruises

The timely predictions and early recognition of the El Niño event developing in the eastern tropical Pacific prompted West Coast marine research institutes and agencies to augment various observational programs. Funding has been made available to augment the quarterly CalCOFI cruises with additional abbreviated cruises that fill out a monthly sampling of lines 90 and 83 extending to station 100 for the period from October 1997 through December 1998. Time aboard the NOAA ship *MacArthur* was volunteered to start this new series 17–22 November 1997. The R/V *Robert Gordon Sproul* occupied these lines during 12–15 December 1997, 11–17 March 1998, and 16–21 May 1998. The data from these cruises show that the circulation patterns and plankton distributions can change very rapidly. Highlights (data not shown) include an abrupt deepening of the mixed layer along CalCOFI line 90 between November and December 1997, and a very abrupt change between March and April 1998. In February (CalCOFI) and March (mini-CalCOFI) an anomalously strong, coastal countercurrent was transporting warm, saline, low-nutrient water northward along the coast. One month later in April 1998 (fig. 15) strong southward flow of the low-salinity jet of the California Current was observed in the coastal region, especially in the Point Conception and Santa Barbara Channel region. Coastal SSTs in the Santa Barbara Channel region dropped from about 15° to 13°C, and 10 m surface chlorophyll increased from about 2 μg l^{-1} to greater than 7 μg l^{-1} (an adjacent station had a

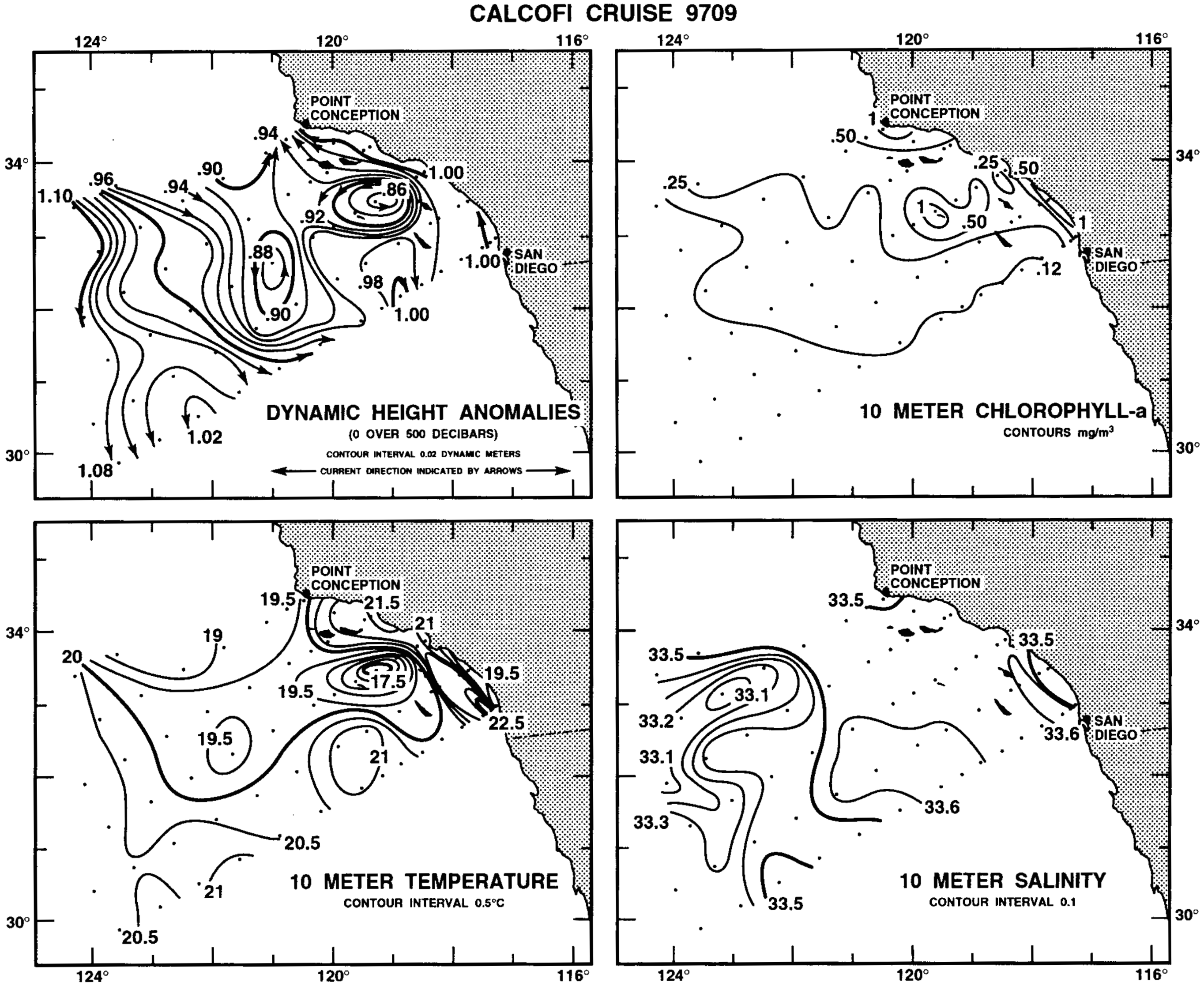

Figure 13. Spatial patterns for CalCOFI cruise 9709 (20 September–9 October 1997), including upper-ocean geostrophic flow estimated from 0 over 500 dbar dynamic height anomalies, 10 m chlorophyll, 10 m temperature, and 10 m salinity.

chlorophyll concentration greater than 14 μg l^{-1}) in this one-month period. The augmentation to monthly coverage will greatly help resolve the temporal pattern of physical forcing and the biological response, as well as the subsequent influences on higher trophic levels.

Central California Sampling Programs

A survey of spawning by small coastal pelagic fish was conducted from most of the CalCOFI station grid (since 1985) and additional northern grid lines (to line 67 off Monterey), 11 March–7 April 1997 (fig. 16). The observations from this survey precede those from CalCOFI cruise 9704 by approximately 3.5 weeks. Because CTD casts were limited to slightly over 200 m depth, the 100 m temperature is used to estimate the pattern of geostrophic flow. The fields of surface temperature, salinity, and estimated flow all indicate conditions prior to the "spring transition." Temperatures are higher and salinities lower than on the subsequent cruise. Coastal upwelling has not started. The California Current jet is in its offshore position typical of late winter. Shoreward of the jet is a broad region of negligible dynamic activity.

The SWFSC Tiburon Laboratory has conducted survey cruises annually since 1983 during May–June off San Francisco (fig. 1; Schwing et al. 1991; Sakuma et al. 1994). The rockfish surveys include a CTD cast with each trawl station. The CTD station grid was enhanced in 1987 and is occupied in three consecutive sweeps. CTD casts are made to 500 m, bottom depth permitting. During 1997 the grid was occupied as follows: sweep 1: 14–23 May; sweep 2: 23–31 May; and sweep 3: 7–18 June. This excellent spring time series will be

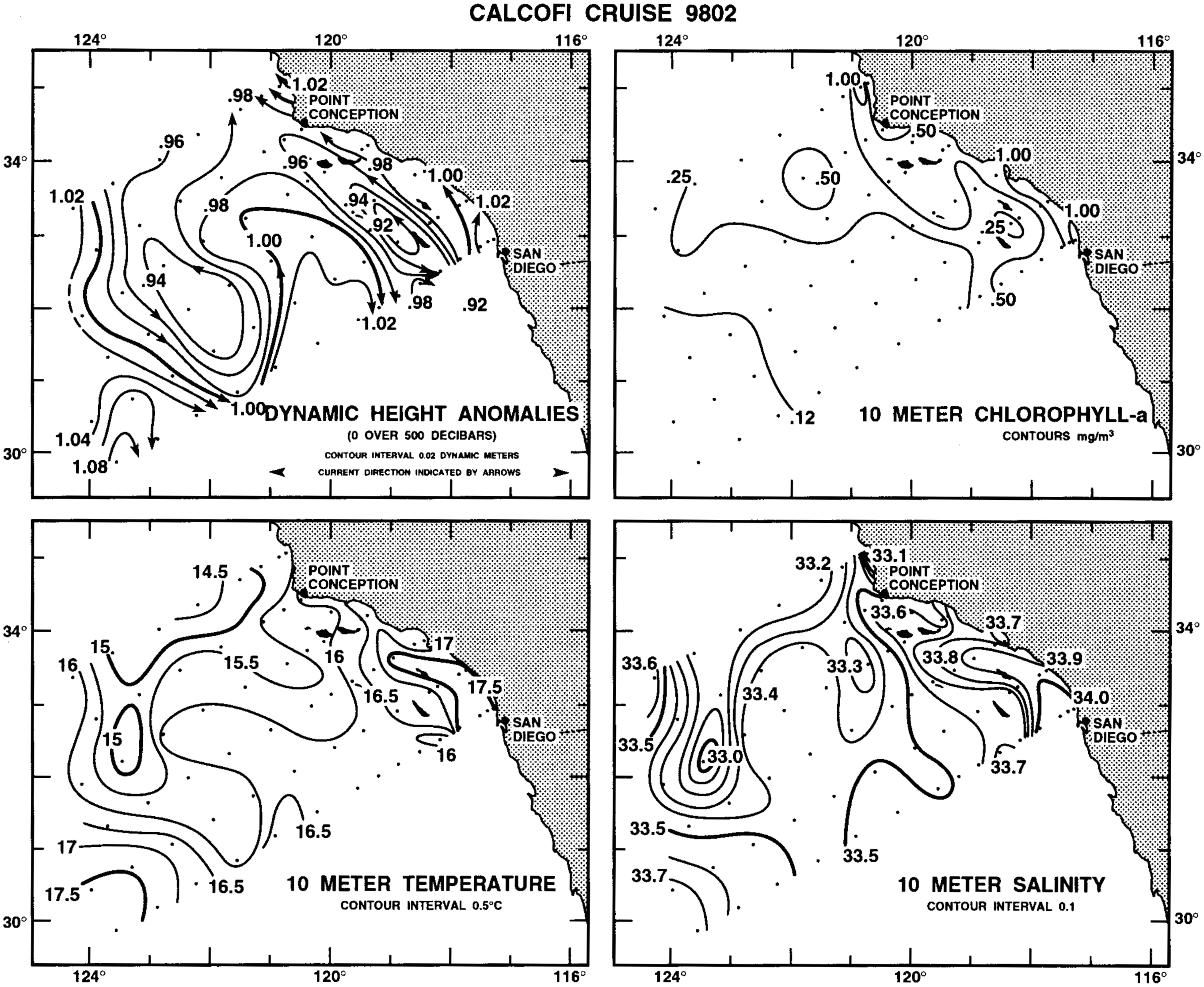

Figure 14. Spatial patterns for CalCOFI cruise 9802 (26 January–14 February 1998), including upper-ocean geostrophic flow estimated from 0 over 500 dbar dynamic height anomalies, 10 m chlorophyll, 10 m temperature, and 10 m salinity.

valuable for a comparative analysis of the 1997 coastal ocean dynamics.

MBARI, NPS, and NAVOCEANO cooperated in a series of cruises off central California. NAVOCEANO (D. Kronen and C. Szczechowski) conducted CTD/ADCP surveys 11–17 February 1997; 21–25 February 1997; and 5–14 March 1997 (NavOceano in fig. 1) which covered the coastal region from Morro Bay to Point Reyes. The surveys included CalCOFI line 67, which was occupied again in late July by the R/V *Point Sur* (MBARI and NPS). Results from this latter cruise revealed a strong poleward flow over the continental slope. At 200 meters poleward velocities reached 30 cm sec^{-1} (fig. 17). In the region immediately west of Monterey, a southward flow occurred to the east of the poleward flow, but this anticyclonic recirculation at the entrance to Monterey Bay is caused by the divergence of the strong poleward flow from the local bathymetry. Along line 67, a much larger anticyclonic feature was seen between 122.8°W and 123.8°W, resulting in poleward flows of 10–20 cm sec^{-1} between 123.8° and 124.2°. Farther offshore, weak equatorward flow associated with the California Current was observed.

Throughout the water column, temperatures were warmer in July 1997 than normal, with the greatest warming (greater than 1°C) found above the halocline and at a depth of 350 m over the continental slope (fig. 17). Within the halocline, the temperatures were slightly greater than normal: by 0.2°–0.4°C. Salinities were greater than normal almost everywhere along line

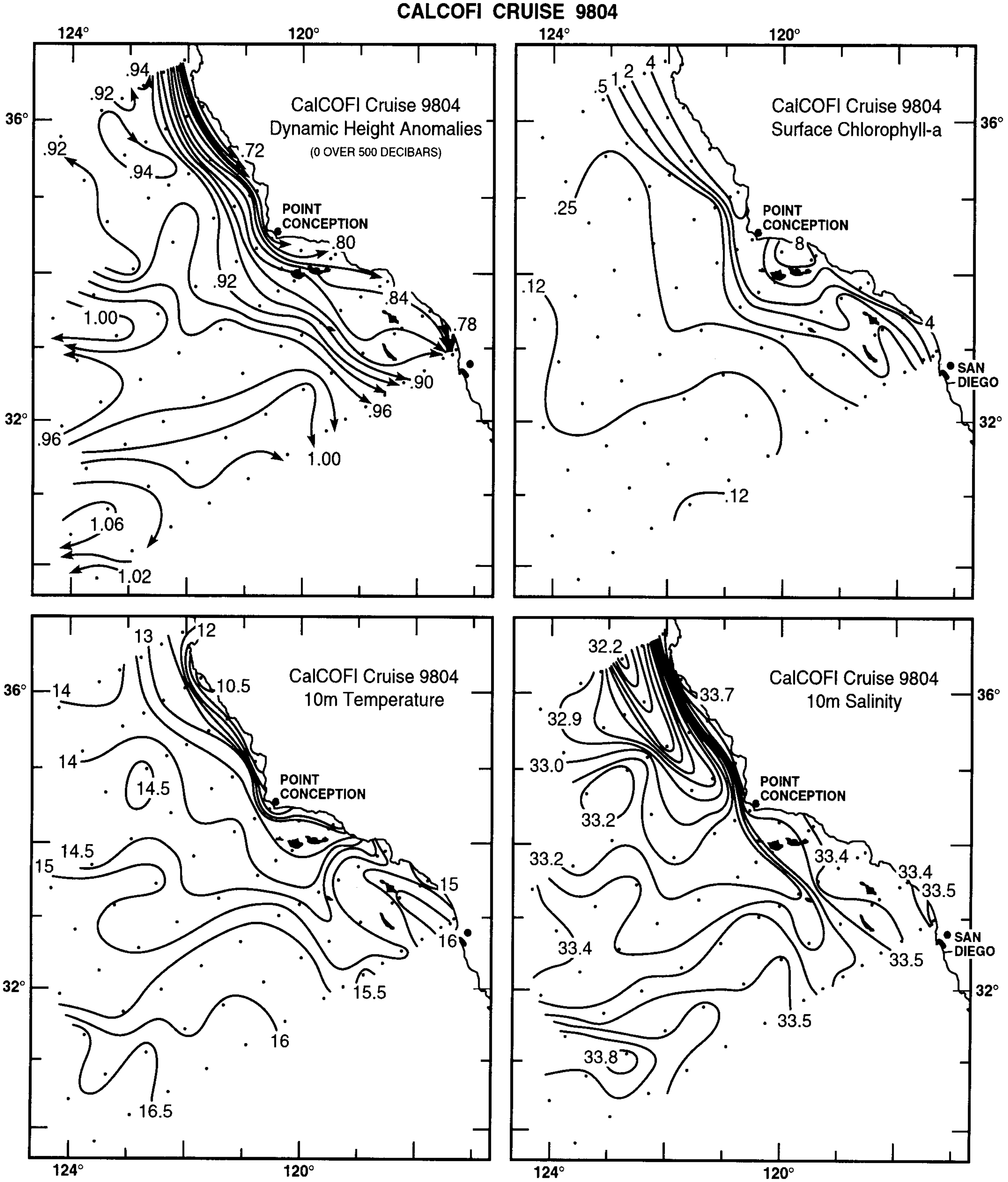

Figure 15. Spatial patterns for CalCOFI cruise 9804 (2–21 April 1998), including upper-ocean geostrophic flow estimated from 0 over 500 dbar dynamic height anomalies, 10 m chlorophyll, 10 m temperature, and 10 m salinity.

67 in July 1997, with the largest anomalies, 0.2, found above 150 m. Unlike the temperature anomaly field, the subsurface salinity field over the continental slope shows only a weak increase above normal.

These findings match in kind those described for CalCOFI cruise 9707 and thus further support the interpretation of a strong poleward countercurrent/undercurrent as an oceanic response to the equatorial ENSO events. The poleward flow was untypically strong and transported anomalously warm, generally higher-salinity waters to northern latitudes.

Baja California

A new program of ocean monitoring off Baja California by Mexican scientists, IMECOCAL (Investigaciones Mexicanas de la Corriente de California), seeks to reestablish sampling on a quarterly basis by using the CalCOFI station grid in the southern sector of the California Current. A brief description of the survey is given in the report of the CalCOFI Committee (this issue).

The initial IMECOCAL cruise, 9709/10 (24 September–5 October 1997) was carried out on the CICESE research vessel *Francisco Ulloa*, with R. Durazo and B. Lavaniegos as cruise leaders. This cruise occupied lines 110, 113, 117, 120, 123, and 127. The farthest offshore station occupied was 70, on lines 117 and 120; the remaining lines extended to station 55. CDT profiles were conducted to near-bottom depths, and surface water samples were collected to determine nutrients and chlorophyll. (Water samples were limited to the surface because of problems with operation of the CTD rosette.) Standard oblique bongo tows were made with 505 mm mesh, with one cod end dedicated to ichthyoplankton and the other to macrozooplankton. Continuous underway surface measurements were made of temperature, salinity, and fluorescence; the shipboard ADCP was used for continuous current profiling.

Temperature and salinity in the upper 500 m along line 120 (off Bahía Sebastián Vizcaíno) were, for the most part, above the seasonal norm (figs. 18 and 19). The anomalies are based on October values for the period 1950–78 from Lynn et al. (1982). In particular the surface layer was highly anomalous. Temperature exceeds 26°C and salinity exceeds 34.8 in the surface layer close to Punta Eugenia. The anomalies of temperature and salinity reach maximum values (8°C and 0.8) near 30–40 m depth at 30 nmi off Punta Eugenia. The core of positive anomalies penetrates offshore as a gradually thinning subsurface lens, particularly visible in the temperature

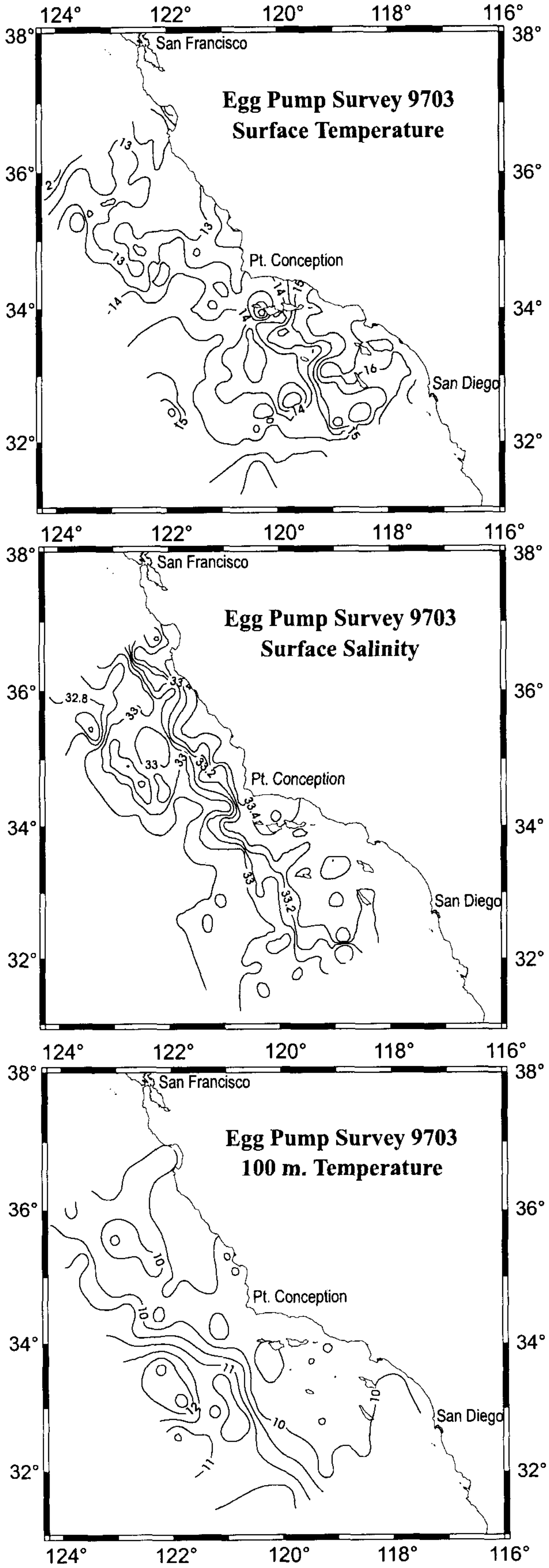

Figure 16. Spatial patterns for an NMFS/SWFSC pelagic fish egg and larvae survey (11 March–7 April 1997) including surface temperature and salinity, and 100 m temperature.

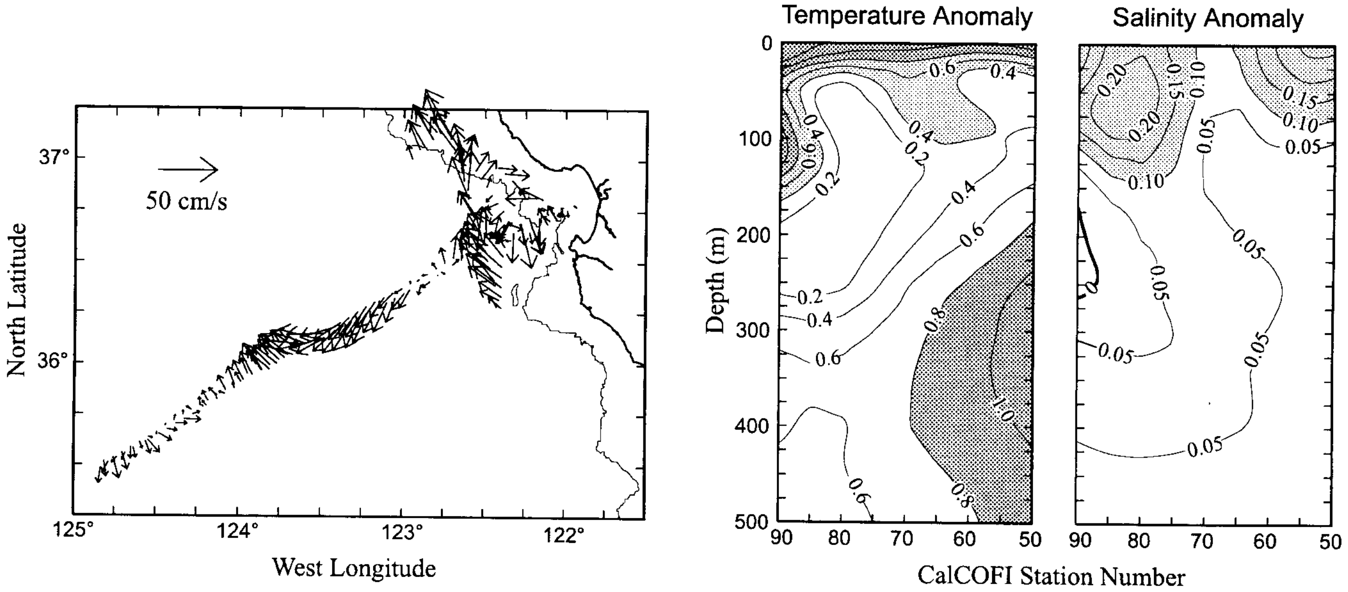

Figure 17. Left panel: ADCP current vectors at 200 m currents, 22–29 July 1997, and the 1,000 m isobath off Monterey Bay. Measurements were made with a vessel-mounted acoustic Doppler current profiler. Right panels: Vertical sections of anomalies of temperature and salinity for the offshore transect of the same cruise (CalCOFI line 67), 26–29 July 1997. Anomalies are based upon summer climatology for CalCOFI line 70 (Lynn et al. 1982).

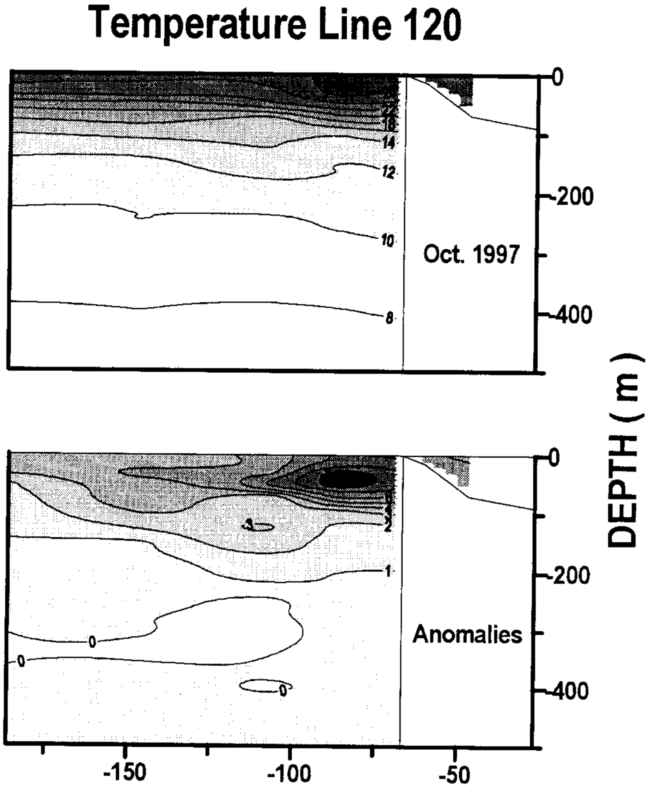

Figure 18. Top, Temperature from IMECOCAL cruise 9709/10 (24 September–5 October 1997) along CalCOFI line 120. Stations (35, 40, 45, 50, 55, 60, 65, 70) spaced at 20 nmi. Bottom, Temperature anomalies calculated from mean values given by Lynn et al. (1982) for the period 1950–78 for even-numbered stations plus nearshore stations 35 and 45.

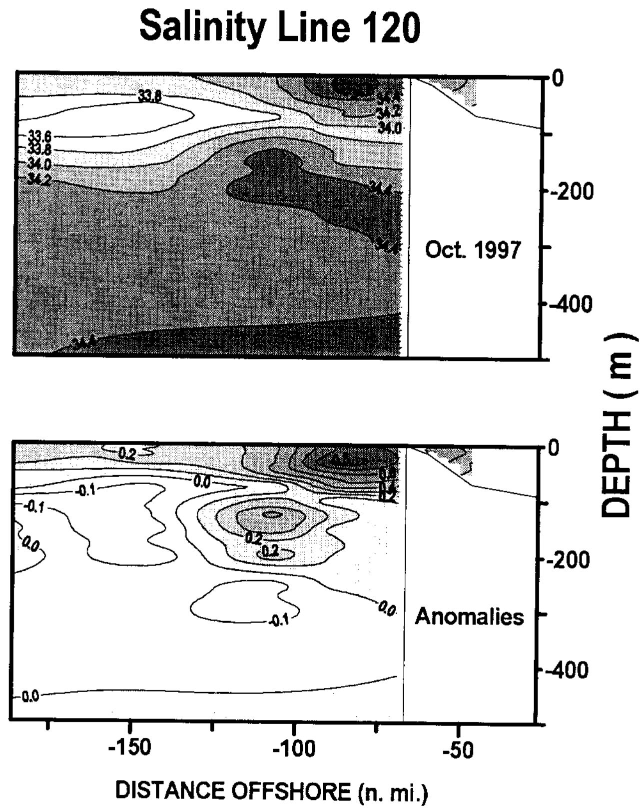

Figure 19. Top, Salinity values along line 120 for IMECOCAL cruise 9709/10. Bottom, Salinity anomalies calculated from mean values given by Lynn et al. (1982) for the period 1950–78 for even-numbered stations plus nearshore stations 35 and 45.

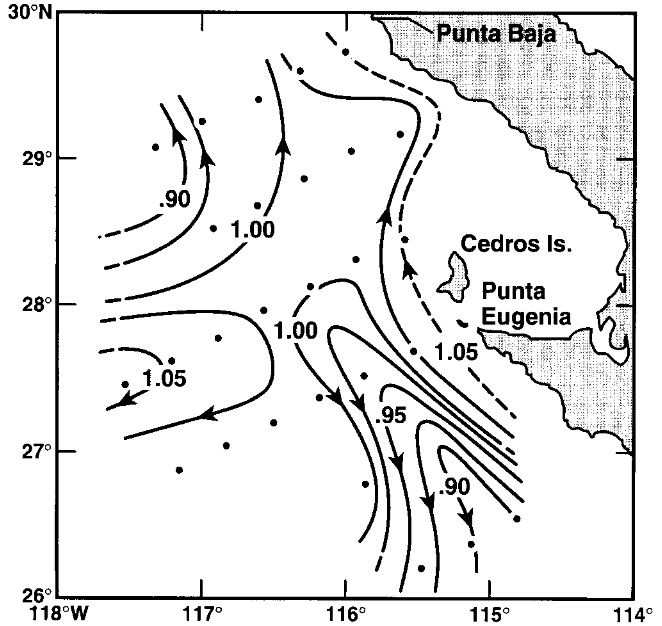

Figure 20. Dynamic height anomaly (10/500 dbar) for IMECOCAL cruise 9709/10. Contour interval is 0.025 dyn. m.

anomalies. The salinity section shows that this high-salinity lens was underlain by a wedge of low-salinity California Current water thinning toward the coast. At lesser extreme values, there is a second and deeper anomalous core lying farther offshore between 100 and 200 m depth. The T-S characteristics of this deeper core indicate subtropical subsurface water, as defined by Wyrtki (1967), mixed with California Current water, a composition expected for the poleward California Undercurrent with its high-salinity source to the south. The very high temperature and salinity anomalies of the near-surface core also indicate the anomalous penetration of coastal water normally found several hundred kilometers to the south (cf. alongshore sections for mean October salinity in Lynn et al. 1982).

Near-surface dynamic heights calculated as 10/500dbar (fig. 20) show a strong near-surface poleward coastal jet along the peninsula south of Punta Eugenia. The effects of this jet extend to depths greater than 100 m on the temperature and salinity sections and in dynamic heights of 125/500 dbar (not shown here). This jet splits into two branches at the latitude of Isla Cedros. A poleward branch follows along the contour of the shelf break, veering toward the coastline and finally leaving the survey area off Punta Baja. The other limb of the coastal jet bends around sharply to reverse its direction and flow equatorward with an offshore component near the southern edge of the survey area. An onshore flow enters the survey area at latitude 28°N from the west, also dividing into two branches. One branch turns north to join the flow along the shelf break, so that poleward flow prevails across the entire length of line 110 at the northern boundary of the survey area. The southern branch of onshore flow entering the survey area at 28°N converges with the offshore limb of the coastal jet and then recurves to flow back offshore.

The warm, high-salinity, near-surface core seen in figures 18 and 19 is located within the poleward coastal jet seen in the dynamic heights and can be followed from south to north across all the tracklines. The onshore flow at 28°N in figure 20 is associated with the low-salinity wedge of California Current water in figures 18 and 19. The dynamic topography for 125/500 dbar indicates that the California Current water is associated with generally southerly to southeasterly flow penetrating onshore as a broad meander forming the low-salinity wedge in figure 19. The presence of a slightly negative subsurface salinity anomaly on line 120 probably results from the onshore transport of California Current water.

BIOLOGICAL PATTERNS

Changes in biological structure over time are evaluated by comparing cruise means of individual cruises with the historical time series. The February and April 1998 CalCOFI cruises had the lowest macrozooplankton standing crops in the long-term (1951 to present) CalCOFI database (P. Smith, pers. comm.). The previous low plankton volume was in March of 1959, 23 months after the onset of the 1957–59 ENSO. The 1998 low was less than a year after the onset of the present ENSO. These patterns are evident in the cruise means of macrozooplankton biomass (fig. 21). It can also be seen that the secular trend of declining macrozooplankton biomass observed since the mid-1970s regime shift (Roemmich and McGowan 1995) is continuing, and the effects of the 1997–98 El Niño conditions are superimposed upon this.

The cruise means in integral chlorophyll also follow the pattern seen in recent years. Integral chlorophyll does not show a trend of declining values, at least since the mid-1980s; nor do the El Niño periods of 1992–93 (Hayward et al. 1994) or 1997–98 (fig. 21) stand out as being anomalous in the context of values measured over the entire 1984–98 time period. Understanding why strong decadal and El Niño trends are apparent in macrozooplankton biomass but not in vertically integrated chlorophyll concentration is an area of active research.

The coastal waters are often affected by red tide events. A phytoplankton bloom resulting in red tide conditions was not expected by many this spring because of the El Niño conditions present. Following the last major El Niño in 1982–83, phytoplankton concentrations were low, always less than $1 \times 105\ \mathrm{l}^{-1}$ (Reid et al. 1985). However, in 1998 a red tide began in San Diego in late May and lasted several weeks. The bloom was domi-

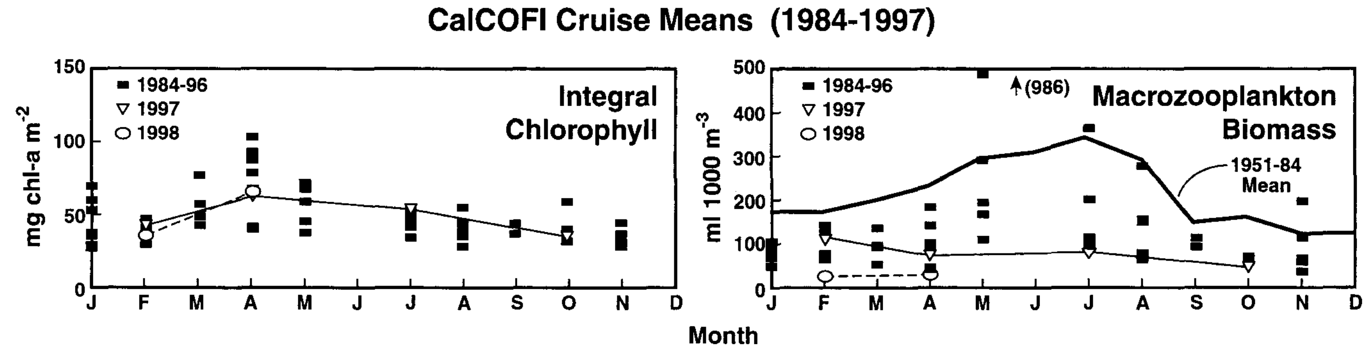

Figure 21. Cruise means of vertically integrated chlorophyll and macrozooplankton biomass plotted versus the month of CalCOFI cruises from 1984 to 1998. Each point represents the mean of all measurements on a cruise (normally 66). The solid squares show results from cruises conducted from 1984 to 1994. The open symbols are results from cruises in 1997 and 1998; cruises from individual years are connected with lines. The bold line in macrozooplankton biomass indicates the monthly means for 1951–84.

nated by the dinoflagellate *Prorocentrum micans*, which reached concentrations in surface waters of at least 5 × 10^5 cells l^{-1}. Blooms of *P. micans* do not appear to be a regular feature of El Niño. In the spring of 1983 *P. micans* was also present as a dominant member of the community (Reid et al. 1985) but was not observed during the 1957–58 El Niño (Balech 1960). The dinoflagellate species *Lingulodinium polyedrum*, the dominant constituent of the extremely large phytoplankton blooms that have occurred the last few years, was seen in only trace concentrations.

One of the exciting new components of the CalCOFI program is the improved ability to sample the distribution of fish eggs. The continuous underway fish egg sampler (CUFES), originally designed and used to sample menhaden eggs off the East Coast (Checkley et al. 1997), was first used in the California Current region in March 1996 (Checkley et al., in press). The large improvement in estimating the spatial extent of spawning habitat and egg production for sardines and anchovies has resulted in the use of the CUFES in fish egg and larval surveys, and its adoption as a standard observational tool in the CalCOFI quarterly cruises. In the CUFES water is pumped from a depth of 3 m at a rate of 640 L min^{-1}, then passed through a concentrator from which 30 L min^{-1} carrying the fish eggs passes to a sample collector. Samples are collected over periods typically ranging from 5 to 30 min (equivalent to 0.75 to 4.5 nmi at 9 knots).

The distribution of sardine eggs was greater off central California than off southern California during the spring surveys of 1997 and 1998 (fig. 22). The egg distributions differ sharply, however, in the broad, offshore extent in 1997 compared to the narrow, near-coastal pattern in 1998. The differences in egg distribution appear to relate to the large differences in the oceanographic patterns described earlier (figs. 15 and 16). The conditions in March 1997 were those of late winter, with

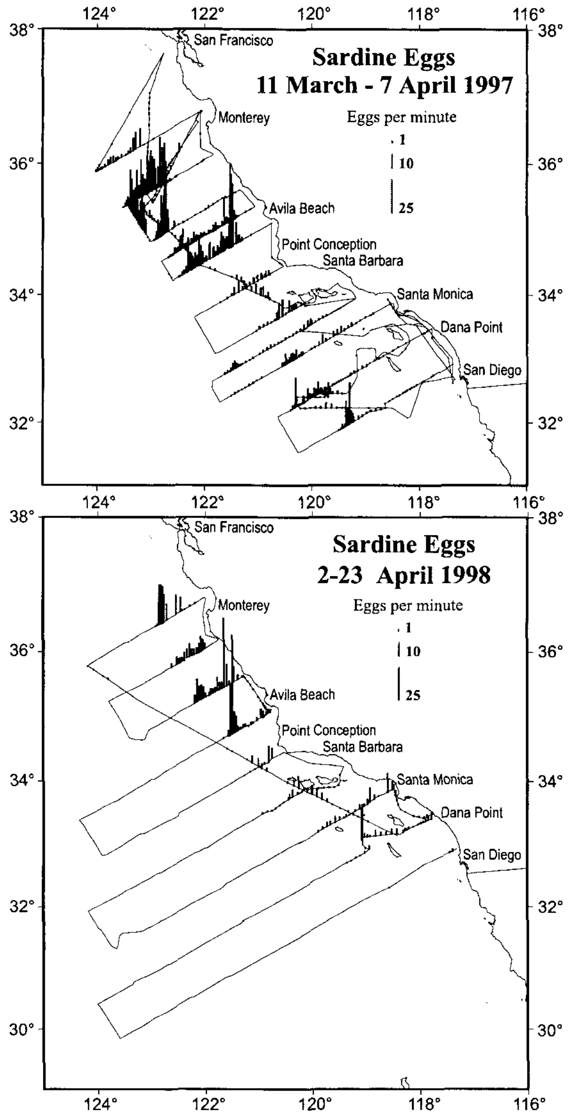

Figure 22. Upper panel, The distribution of sardine eggs as collected by the continuous underway fish egg sampler (CUFES) for an NMFS/SWFSC pelagic fish egg and larval survey (11 March–7 April 1997); and (lower panel) for CalCOFI survey 9804 (2–23 April 1998).

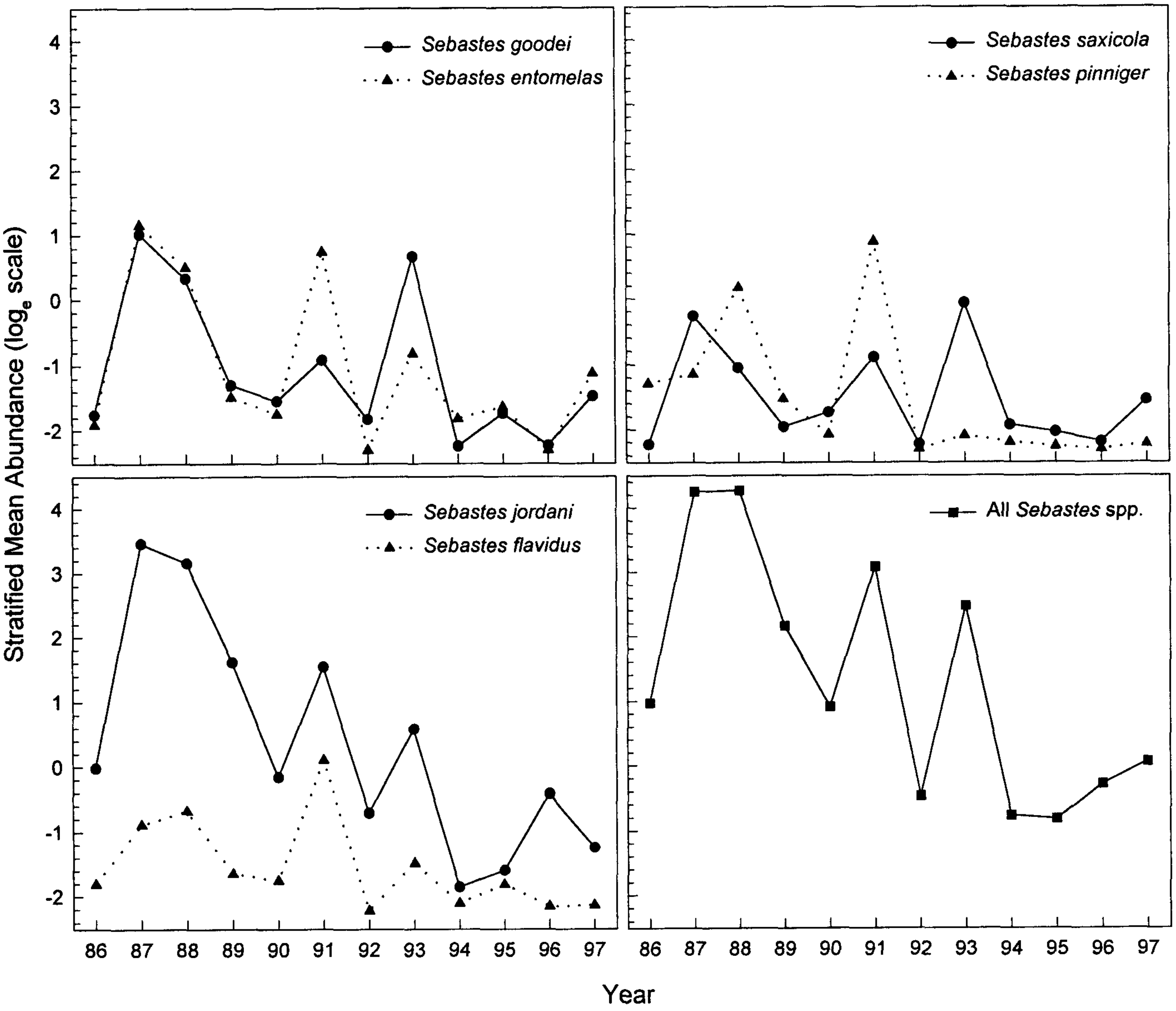

Figure 23. Annual abundance estimates of pelagic young-of-the-year rockfish, *Sebastes* spp., off central California for 1986–97. Abundances were adjusted according to Adams (1995) to account for interannual differences in size structure, and transformed by $\log_e(x + 0.1)$, where x is the length-adjusted catch.

an offshore California Current. In April 1998 the transition to spring conditions had taken place, and a narrow, exceptionally swift California Current was pressed against the coast.

Annual abundance indices of pelagic young-of-the-year rockfish (*Sebastes* spp.) off central California were estimated from midwater trawl collections by the NMFS SWFSC Tiburon Laboratory (see Adams 1995 for methods). Catch rates during May–June 1997 were higher than those observed in 1996, but still relatively low, as they have been since 1994 (fig. 23). The catch rate of *S. jordani* (the most common species collected) was slightly lower in 1997 than in 1996, but abundances of many of the remaining rockfishes showed a slight increase, leading to an overall increase in *Sebastes* spp. abundance. This increase in overall abundance was primarily due to moderate catches of large (>25 mm SL) *S. entomelas*, *S. goodei*, and *S. saxicola*, which occurred within the first week of the 1997 midwater trawl survey. However, as catches of these large specimens decreased substantially over the course of the survey, it appeared that the major recruitment pulse might have preceded the beginning of the survey. VenTresca (California Department of Fish and Game, Monterey, CA) observed that the recruitment of *S. mystinus* to the kelp bed areas of Monterey Bay was unusually early (pers. comm. reported by Schwing et al. 1997). The early transition to upwelling-favorable conditions in the beginning of 1997 may have been associ-

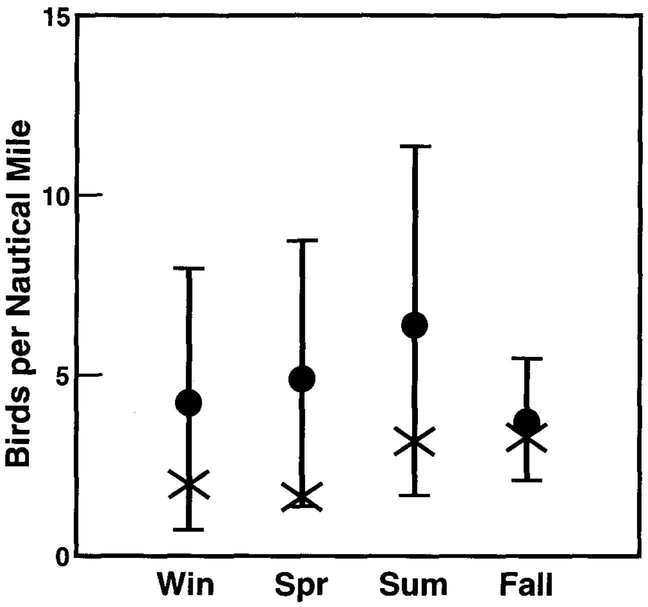

Figure 24. Mean and standard deviation (filled circles and error bars) of seasonal seabird abundance on CalCOFI cruises from May 1987 to April 1994, and abundance for cruises from July 1997 through April 1998 (depicted with an x). Figure modified from Hayward et al. (1996).

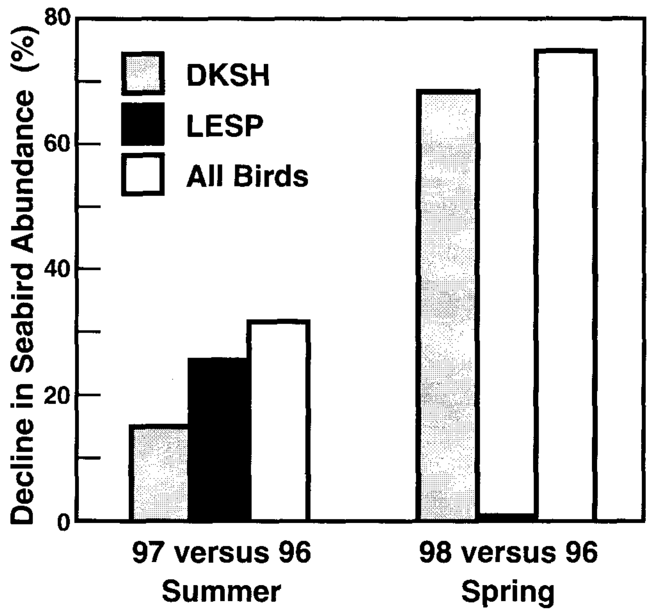

Figure 25. Short-term changes in abundance for numerically dominant offshore seabirds (LESP: Leach's storm-petrel); coastal seabirds (DKSH: sooty and short-tailed shearwater); and all bird species combined (All Birds).

ated with the observed early recruitment of *Sebastes* spp. In contrast, the ENSO conditions that developed later in 1997 (with the associated depression of upwelling) had a detrimental effect on the recruitment of *Sebastes* spp.; preliminary results from the May 1998 survey show that catch rates are the lowest in the history of the survey.

CalCOFI time-series cruises have provided the opportunity for systematic surveys of the distribution and abundance of seabirds, and studies of population trends in relation to oceanographic conditions. The abundance of seabirds in the CalCOFI region has declined steadily from 1987 to 1994 (Veit et al. 1996). Bird abundance during 1997–98 was consistently lower than the long-term mean, suggesting further declines during this period (fig. 24). In addition, the seasonal cycle of seabird abundance was disrupted in 1997–98. Instead of the usual summer peak, bird abundance was highest during fall 1997 and declined to a yearly minimum by spring 1998.

It is unclear to what degree these fluctuations are attributable to the 1997–98 El Niño. The decline in seabird abundance during summer 1997 affected both offshore and coastal species (fig. 25), and may have been related to anomalous physical conditions and low macrozooplankton biomass during the previous year (Schwing et al. 1997). It is likely that the onset of El Niño further affected bird distributions by compounding anomalous conditions in preceding months. For instance, the incursion of southern species during fall was probably related to enhanced poleward flow of the California Countercurrent and elevated sea-surface temperatures (Ainley et al. 1995). Veit and co-workers (1996) documented similar increases of black (*Oceanodroma melania*) and least (*O. microsoma*) storm-petrels during the 1992–93 El Niño. Finally, the decline in overall seabird abundance during spring 1998 was closely related to the failed immigration of shearwater species into coastal waters of the CalCOFI region (fig. 25). These are highly mobile predators capable of adjusting their distributions in response to large-scale changes in ocean productivity and prey biomass (Veit et al. 1997).

CalCOFI is also concerned with better understanding the influences of changes in oceanographic structure on nearshore communities. Kelp forest communities are diverse assemblages organized around the giant kelp, *Macrocystis pyrifera*, which is itself harvested for the production of alginates and whose biological structure and high productivity support numerous fisheries. Dependent on high levels of nutrient input to maintain growth rates and standing biomass, *Macrocystis* populations are very sensitive to interannual variability in sea-surface temperatures, measured as a surrogate for nutrient availability (Tegner et al. 1996). Because of the cascading effects of reductions in kelp on higher trophic levels, kelp forest communities are the temperate benthic community most strongly affected by El Niño events (Tegner and Dayton 1987; Dayton and Tegner 1990).

Anomalously warm sea-surface temperatures in 1997 decimated *Macrocystis* canopies bight-wide; by November the canopy of the Point Loma kelp forest near San Diego was about 10% of normal (D. Glantz, pers. comm.), and

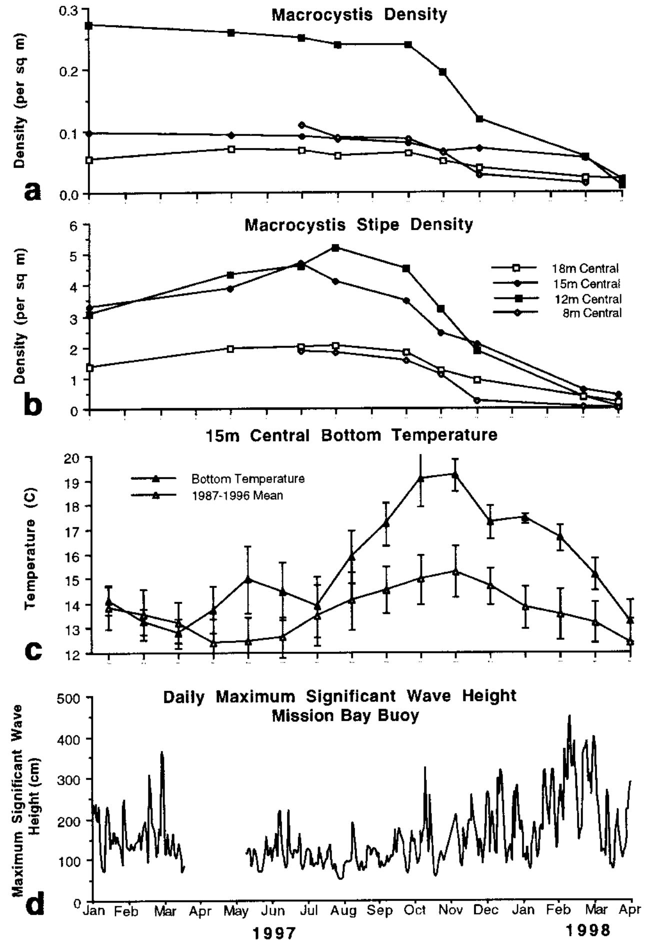

Figure 26. Changes in *Macrocystis* plant density (*a*) and stipe density (*b*) from permanent sites at 18, 15, and 12 m in the center of the Point Loma kelp forest during the 1997–98 El Niño. See Tegner et al. (1997) for sampling details. *c*, In situ temperature at 15 m for 1997–98 and the mean for 1987–96; error bars represent one standard deviation. *d*, Daily maximum significant wave height from the Mission Bay Buoy (Coastal Data Information Program).

it deteriorated further with the winter storms. Figure 26 compares subsurface changes in kelp populations across the depth gradient of this forest with benthic temperature and maximum significant wave height. *Macrocystis* stipe (analogous to branches of land plants) density, an index of carrying capacity for giant kelps, peaked after relatively cool bottom temperatures in July 1997 and then declined precipitously as bottom temperatures soared in fall 1997. Density of giant kelp plants also decreased, but is less sensitive than stipe density (Tegner et al. 1996, 1997). Both measures declined further as the extended period of large waves associated with El Niño conditions (e.g., Seymour 1996) affected the nearshore zone in fall 1997 and especially winter 1998. Note that the effects of warm, nutrient-depleted conditions as well as wave energy are most severe in shallow water and decrease with depth across the forest; the effect of these disturbances is to shift the forest into deeper water. Because canopy deterioration preceded the storm season, plants may have survived better than during the 1982–83 El Niño storm season. The combination of cool temperatures in April 1998 with the considerable open space cleared by the storms led to the onset of kelp recruitment and conditions for regrowth of surviving adults.

DISCUSSION

The period beginning in January 1997 and continuing to the present (May 1998) has been one of unusually large anomalies in physical and biological conditions in the coastal waters off the Californias. Observations show this to be one of the remarkable periods in the 50-year time series of CalCOFI. The coastal SSTs have been above seasonal norms throughout this period, and since May 1997 there have been large displacements in the distribution of many species of fish. Zooplankton levels are at their lowest recorded levels in the long-term CalCOFI time series. In the first half of 1997 the driving forces appear to have been of a local nature, a residual (and unusual) effect of the end of a La Niña period in the tropics. Conditions leading to an El Niño were initiated in the western equatorial Pacific at the beginning of this same period. The initial impact of El Niño upon California waters (July 1997) may have been an increase in the coastal undercurrent, which transported unusually warm and saline waters northward at depths below 100 m. The effects of El Niño on surface waters via the atmospheric teleconnection followed in November 1997. Important processes are taking place on other space-time scales as well. Some anomalies and trends in both physical and biological conditions are, at least in part, of long standing and have led to the recognition of decadal and multidecadal variations. The 1997–98 El Niño is as strong as that of the 1982–83 event, and it has had a strong effect on the California Current system.

The 1997 ENSO was predicted by various models well in advance of its inception (e.g., Barnett et al. 1996; Ji et al. 1996; and Kirtman et al. 1996). Although neither the swiftness of its onset nor its considerable strength of warming were predicted, research and monitoring groups were alerted, and lead time was allowed for preparation to intensify and augment observational programs. One augmentation is the additional observation of two of the standard CalCOFI lines (83 and 90) that, along with the quarterly cruises, will result in nearly monthly coverage for the period October 1997 to January 1999. Sampling is being done in the near-coastal region off San Diego to examine the coupling between offshore waters and kelp forests. The frequency and coverage of central California coastal waters was increased by a number of research groups including MBARI, NPS, NAVOCEANO, CalCOFI, and SWFSC. The initial IMECOCAL cruise was rescheduled to start earlier than originally planned in response to the developing El Niño. This ENSO event has been the most well observed to date. Despite the fact that it has yet to complete its course and will have residual effects on various marine populations for some months and perhaps years to come, analyses and reports are under way. The most dynamic effects occur in the eastern tropical Pacific, where the TAO buoy array has provided detailed temporal and spatial information at the equator since its installation in December 1994. The effects of the ENSO upon the North American Pacific coastal zone, whether through atmospheric or oceanic forcing, are even more complex; the observations to date involve numerous agencies and countries. The task that lies ahead for reasearch scientists is to assemble and analyze these observations (and others not herein reported) to provide a comprehensive understanding of the physical forcings and their effects on the marine biosphere.

The oceanic influences of El Niño became evident in deep California coastal waters by July 1997 as an enhancement of the undercurrent, seen as strong poleward flow in the coastal region at 200–300 meters, transporting water that was much warmer and more saline than normal. Although the surface waters were anomalously warm at this time, thermocline depth was near normal. In late fall the thermocline depth began to deepen, and it abruptly increased between November and December 1997. The data from regions off Baja California and central California will be of great value in determining whether events evolved at the same or differing times and in similar ways along the coast.

Changes in the upper ocean circulation pattern were also reflected in plankton populations. The strong association between the upper ocean physical structure and plankton distributions is well documented. However, it still remains to be determined what physical patterns constitute the presence of El Niño conditions in the California Current region and what aspects of a changing physical structure influence the pelagic ecosystem. The linkages between physical structure and ecosystem structure are now well known, but they may differ between El Niño events. Two important mechanisms are changes in range of populations due to changes in the pattern of circulation and hence transport, and direct trophic effects due to changes in nutrient inputs and primary production caused by changes in thermocline and nutricline depth. The data from Baja California and central California will also be of great value in looking at how advection affects changes in plankton abundance. The relative importance of changes due to advection and local changes in production may differ at different locations along the coast.

The 1997–98 period was also one of great changes in the near-coastal ocean. Kelp forest communities were strongly affected, and strong red tide events along the coast were a concern in early 1998. The causal role of El Niño and how these near-coastal populations are linked to the offshore circulation patterns will be an area of active research. It is important to learn to what extent offshore forcing processes influence the coastal region, and to what extent the higher-frequency measurements made at coastal observing programs can be used to understand changes in structure in the offshore region.

At publication time there are continuing new reports of highly unusual catches of commercial and sport fish. These include unseasonal catches or northward range extensions of yellowtail, bonito, barracuda, calico, sand bass, and albacore. Rockfish are at a historic low.

Seabird abundance during 1997–98 was consistently low, when compared to long-term averages and to surveys conducted in 1996. But it may be premature to ascribe fluctuations in seabird abundance during 1997–98 solely to El Niño. Short-term changes in avian abundance must be interpreted with care. Bird distributions do not reflect ocean conditions instantly, but respond after a time lag of several months. Furthermore, seabirds respond to oceanographic variability at multiple scales. Transient distributional changes in response to short-term forcing are embedded in long-term population trends related to ocean warming. El Niño can affect seabird populations at both short (distribution) and long (demography) temporal scales. Additional surveys will be necessary to elucidate the effects of the 1997–98 El Niño on the avifauna within the CalCOFI study region.

A review of the nine different forecast models published in the Experimental Long-Lead Forecast Bulletin (COLA 1998) suggests a near consensus in predicting a return to near normal conditions in the eastern tropical Pacific in 3 to 6 months and a high likelihood of lower than normal SSTs late in the year. The SST anomaly in Niño3 region reached +4°C during the month of December 1997. This SST anomaly has been declining since, although by May 1998 it was barely below +2°C. The experience of the apparent end of the 1992 ENSO and its surprising return in 1993 suggests some caution in relying on the predictions.

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LITERATURE CITED

Adams, P. B. 1995. Progress in rockfish recruitment studies. NMFS, SWFSC, Admin. Rep., Tiburon, T-95-01, 51 pp.

Ainley, D. G., R. R. Veit, S. G. Allen, L. B. Spear, and P. Pyle. 1995. Variations in marine bird communities of the California Current, 1986–1994. Calif. Coop. Oceanic Fish. Invest. Rep. 36:72–77.

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946–71. U.S. Dep. Commer., NOAA Tech. Rep., NMFS SSRF-671, 103 pp.

Balech, E. 1960. The changes in the phytoplankton population off the California coast. Calif. Coop. Oceanic Fish. Invest. Rep. 7:127–132.

Barnett, T., D. Pierce, N. Graham, and M. Latif. 1996. Dynamically based forecasts for tropical Pacific SST through winter 1997–98 using an improved hybid coupled ocean-atmospheric model. Experimental Long-lead Forecast Bull., Nat. Centers for Envir. Pred. 5:1–4.

Checkley, D. M., Jr., P. B. Ortner, L. R. Settle, and S. R. Cummings. 1997. A continuous, underway fish egg sampler. Fish. Oceanogr. 6:58–73.

Checkley, D. M., Jr., R. C. Dotson, and D. A. Griffith. In press. Continuous, underway sampling of eggs of northern anchovy (*Engraulis mordax*) and Pacific sardine (*Sardinops sagax*) in spring 1996 and 1997 off southern and central California. Deep Sea Res.

COLA. Center for Ocean-Land-Atmosphere Studies. 1998. Experimental long-lead forecast bulletin, B. Kirtman, ed. March 1998, vol. 7, no. 1. COLA, 4041 Powder Mill Road, Suite 302, Calverton, Md. 20705, 85 pp.

Dayton, P. K., and M. J. Tegner. 1990. Bottoms beneath troubled waters: benthic impacts of the 1982–84 El Niño in the temperate zone. *In* Global ecological consequences of the 1982–83 El Niño–Southern Oscillation, P. Glynn, ed. Amsterdam: Elsevier Oceanography Series No. 52, pp. 443–472.

Hayward, T. L., A. W. Mantyla, R. J. Lynn, P. E. Smith, and T. K. Chereskin. 1994. The state of the California Current in 1993–1994. Calif. Coop. Oceanic Fish. Invest. Rep. 35:19–35.

Hayward, T. L., D. R. Cayan, P. J. S. Franks, R. J. Lynn, A. W. Mantyla, J. A. McGowan, P. E. Smith, F. B. Schwing, and E. L. Venrick. 1995. The state of the California Current in 1994–1995; a period of transition. Calif. Coop. Oceanic Fish. Invest. Rep. 36:19–39.

Hayward, T. L., S. L. Cummings, D. R. Cayan, F. P Chavez, R. J. Lynn, A. W. Mantyla, P. P. Niiler, F. B. Schwing, R. R. Veit, and E. L. Venrick. 1996. The state of the California Current in 1995–1996; continuing declines in macrozooplankton biomass during a period of nearly normal circulation. Calif. Coop. Oceanic Fish. Invest. Rep. 37:22–37.

Ji, M., A. Kumar, and A. Leetma. 1996. Forecasts of tropical Pacific SST using a comprehensive coupled ocean-atmosphere dynamical model. Experimental Long-lead Forecast Bull., Nat. Centers for Envir. Pred. 5:10–14.

Kirtman, B., B. Huang, J. Shukla, and Z. Zhu. 1996. Tropical Pacific SST predictions with a coupled GCM. Experimental Long-lead Forecast Bull., Nat. Centers for Envir. Pred. 5:15–17.

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 30. La Jolla, Calif.: Scripps Institution of Oceanography, 513 pp.

Murphree, T., and C. Reynolds. 1995. El Niño and La Niña effects on the northeast Pacific: the 1991–1993 and 1988–1989 events. Calif. Coop. Oceanic Fish. Invest. Rep. 36:45–56.

NCEP. National Centers for Environmental Prediction. 1997a. Climate diagnostics bulletin, May 1997. Climate Prediction Center, NOAA/NWS/NCEP. No. 97/5. 80 pp.

———. 1997b. Climate diagnostics bulletin, August 1997. Climate Prediction Center, NOAA/NWS/NCEP. No. 97/8. 82 pp.

———. 1998a. Climate diagnostics bulletin, February 1998. Climate Prediction Center, NOAA/NWS/NCEP. No. 98/2. 80 pp.

———. 1998b. Climate Diagnostics Bulletin, April 1997. Climate Prediction Center, NOAA/NWS/NCEP. No. 98/4. 82 pp.

Nitta, T. 1987. Convective activities in the tropical western Pacific and their impact on the Northern Hemisphere summer circulation. J. Meteorol. Soc. Jpn. 65:373–390.

Reid, F. M. H., C. B. Lange, and M. M. White. 1985. Microplankton species assemblages at the Scripps Pier from March to November 1983 during the 1982–1984 El Niño event. Bot. Mar. 28:443–452.

Roemmich, D., and J. McGowan. 1995. Climatic warming and the decline of zooplankton in the California Current. Science 267:1324–1326.

Sakuma, K. M., H. A. Parker, S. Ralston, F. B. Schwing, D. M. Husby, and E. M. Armstrong. 1994. The physical oceanography off the central California coast during March and May–June 1993: a summary of CTD data from pelagic young-of-the-year rockfish surveys. U.S. Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-209.

Seymour, R. 1996. Wave climate variability in southern California. J. Waterway, Port, Coastal, Ocean Eng. July/August 1996, pp. 182–186.

Schwing, F. B., D. M. Husby, N. Garfield, and D. E. Tracy. 1991. Mesoscale oceanic response to wind events off central California in spring 1989: CTD surveys and AVHRR imagery. Calif. Coop. Oceanic Fish. Invest. Rep. 32:47–62.

Schwing, F. B., M. O'Farrell, J. M. Steger, and K. Baltz. 1996. Coastal upwelling indices, west coast of North America, 1946–95. U.S. Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-231, 207 pp.

Schwing, F. B., T. L. Hayward, K. M. Sakuma, T. Murphree, A. S. Mascarenas Jr., S. I. Larios Castillo, A. W. Mantyla, S. L. Cummings, F. P. Chavez, K. Baltz, and D. G. Ainley. 1997. The state of the California Current, 1996–1997: mixed signals from the tropics. Calif. Coop. Oceanic Fish. Invest Rep. 38:22–47.

Tegner, M. J., and P. K. Dayton. 1987. El Niño effects on southern California kelp forest communities. Adv. Ecol. Res. 17:243–279.

Tegner, M. J., P. K. Dayton, P. B. Edwards, and K. L. Riser. 1996. Is there evidence for long-term climatic change in southern California kelp forests? Calif. Coop. Oceanic Fish. Invest. Rep. 37:111–126.

Tegner, M. J., P. K. Dayton, P. B. Edwards, and K. L. Riser. 1997. Large-scale, low-frequency oceanographic effects on kelp forest succession: a tale of two cohorts. Mar. Ecol. Prog. Ser. 146:117–134.

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

Veit, R. R., J. A. McGowan, D. G. Ainley, T. R. Wahl, and P. Pyle. 1997. Apex marine predator declines ninety percent in association with changing oceanic climate. Global Change Biol. 3:23–28.

Walker, P. W., D. M. Newton, and A. W. Mantyla. 1994. Surface water temperatures, salinities, and densities at shore stations. United States west coast. SIO Ref. 94–9.

Wolter, K., and M. S. Timlin. In press. 1998. Measuring the strength of ENSO—how does 1997/98 rank? Weather 53.

Wyrtki, K., 1967. Circulation and water masses in the eastern equatorial Pacific Ocean. J. Oceanol. Limnol. 1:117–147.