State of the California Current 2012–13: No Such Thing as an "Average" Year

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STATE OF THE CALIFORNIA CURRENT 2012–13: NO SUCH THING AS AN "AVERAGE" YEAR

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ABSTRACT

This report reviews the state of the California Current System (CCS) between winter 2012 and spring 2013, and includes observations from Washington State to Baja California. During 2012, large-scale climate modes indicated the CCS remained in a cool, productive phase present since 2007. The upwelling season was delayed north of 42°N, but regions to the south, especially 33° to 36°N, experienced average to above average upwelling that persisted throughout the summer. Contrary to the indication of high production suggested by

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[1] The first four authors represent members of the SWFSC California Current Integrated Ecosystem Assessment group and worked in equal collaboration on preparation of this report.

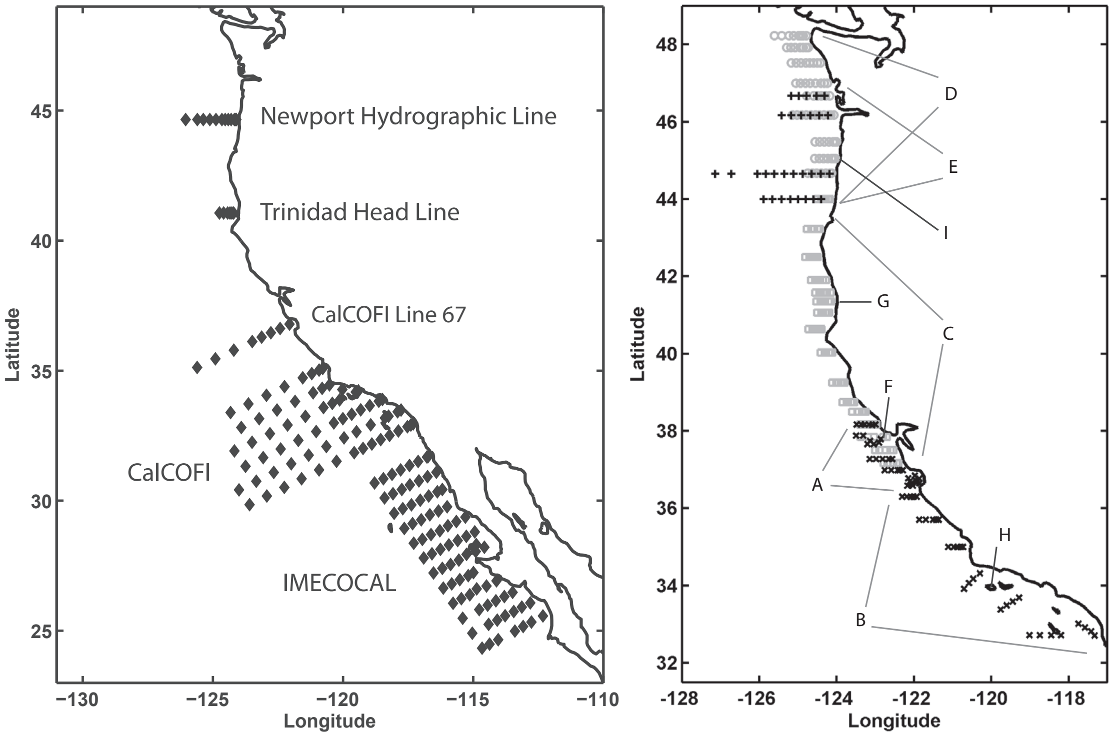

Figure 1. Left: Station maps for surveys that were conducted multiple times per year during different seasons to provide year-round observations in the California Current System. The CalCOFI survey (including CalCOFI Line 67) were occupied quarterly; the spring CalCOFI survey grid extends just north of San Francisco. The IMECOCAL survey is conducted quarterly or semiannually. The Newport Hydrographic Line was occupied biweekly. The Trinidad Head Line was occupied at biweekly to monthly intervals. Right: Location of annual or seasonal surveys, including locations of studies on higher trophic levels, from which data was included in this report. Different symbols are used to help differentiate the extent of overlapping surveys. A. SWFSC FED midwater trawl survey core region (May–June) B. SWFSC FED midwater trawl survey south region (May–June). C. SWFSC FED salmon survey (June and September) (grey squares). D. NWFSC salmon survey (May, June, and September). E. NOAA/BPA pelagic rope trawl survey (May through September). F. Southeast Farallon Island. G. Castle Rock. H. San Miguel Island. I. Yaquina Head Outstanding Natural Area.

the climate indices, chlorophyll observed from surveys and remote sensing was below average along much of the coast. As well, some members of the forage assemblages along the coast experienced low abundances in 2012 surveys. Specifically, the concentrations of all life-stages observed directly or from egg densities of Pacific sardine, *Sardinops sagax*, and northern anchovy, *Engraulis mordax*, were less than previous years' survey estimates. However, 2013 surveys and observations indicate an increase in abundance of northern anchovy. During winter 2011/2012, the increased presence of northern copepod species off northern California was consistent with stronger southward transport. Krill and small-fraction zooplankton abundances, where examined, were generally above average. North of 42°N, salps returned to typical abundances in 2012 after greater observed concentrations in 2010 and 2011. In contrast, salp abundance off central and southern California increased after a period of southward transport during winter 2011/2012. Reproductive success of piscivorous Brandt's cormorant, *Phalacrocorax penicillatus*, was reduced while planktivorous Cassin's auklet, *Ptychoramphus aleuticus* was elevated. Differences between the productivity of these two seabirds may be related to the available forage assemblage observed in the surveys. California sea lion pups from San Miguel Island were undernourished resulting in a pup mortality event perhaps in response to changes in forage availability. Limited biological data were available for spring 2013, but strong winter upwelling coastwide indicated an early spring transition, with the strong upwelling persisting into early summer.

INTRODUCTION

This report reviews the oceanographic and ecosystem responses of the California Current System (CCS) between winter 2012 and spring of 2013. Biological and hydrographic data from a number of academic, private, and government institutions have been consolidated and described in the context of historical data (fig. 1). The various institutions have provided data and explanation of the data after an open solicitation for contributions; these contributions are acknowledged in the author list. These data are synthesized here, in the spirit of providing a broader description of the present condition of the CCS. All data are distilled from complex sampling programs covering multiple spatial and temporal scales into a simple figure(s) that might not convey the full complexity of the region being studied. As a consequence, we

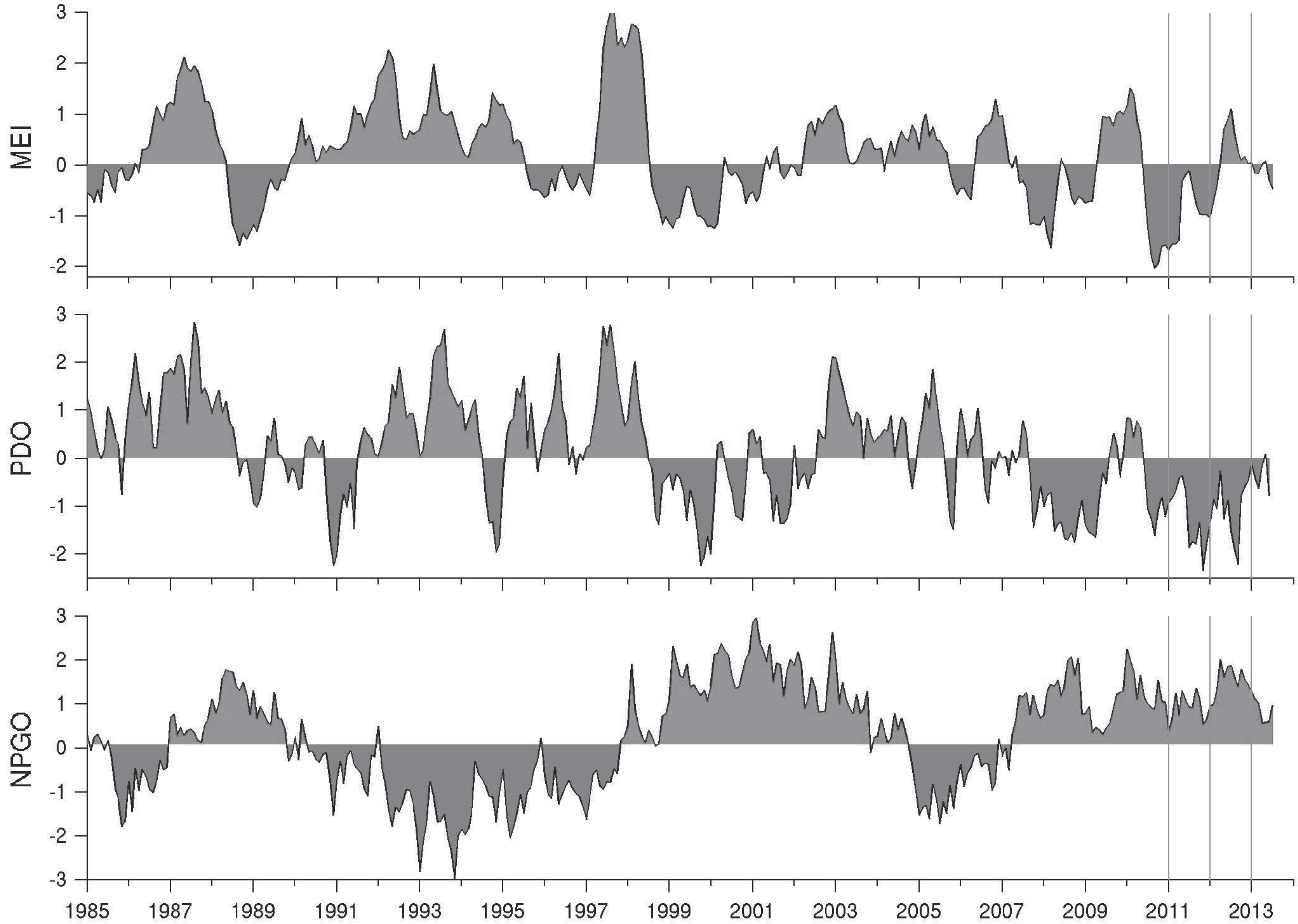

Figure 2. Time series of monthly mean values for three ocean climate indices especially relevant to the California Current: the multivariate ENSO index (MEI), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO) for January 1985–June 2013. Vertical lines mark January 2011, 2012, and 2013.

focus on the findings of the data and limit our descriptions of the methodology to only that which is required for interpretation. More complete descriptions of the data and methodologies can be found in the supplement. Can be found in the supplement (http://calcofi.org/publications/ccreports/568-vol-54-2013.html)

In 1949, the California Cooperative Oceanic Fisheries Investigations program (CalCOFI) was formed to study the environmental causes and ecological consequences of Pacific sardine, *Sardinops sagax*, variability. Consideration of the broader forage communities has been invigorated by recent fluctuations in the abundance of sardine and another important forage fish, the northern anchovy, *Engraulis mordax* (Cury et al. 2011; Pikitch et al. 2012). Specifically, there has been a decline in the observed catches of larval, juvenile, and adult northern anchovy reported by the various sampling programs along the CCS (Bjorkstedt et al. 2012). While not unprecedented, with two similar examples since 1993, the estimated Pacific sardine biomass declined from 1,370,000 MT in 2006 to 659,539 MT in July 2012 (http://www.pcouncil.org/wp-content/uploads/MAIN_DOC_G3b_ASSMNT_RPT2_WEB_ONLY_NOV2012BB.pdf). Here, we return to an initial focus of the CalCOFI program and consider physical and biological signals related to coastal pelagic species. Importantly, the survey designs that we examine are dissimilar and each has unique limitations restricting a common interpretation along the CCLME. Therefore, this report should be considered a first examination for instigating more focused exploration of potential drivers of the forage community's dynamics.

This report will focus on data highlighting variability in the forage community with additional (supporting) data provided in the supplement. Some information in the supplement are data that have been presented in previous reports and are included as a reference to an aspect of the "state of the CCS," which might be of interest beyond the focus here. As in past reports, we begin with an analysis of large-scale climate modes and upwelling conditions in the California Current. Following, the various observational data sampling programs are reviewed to highlight the links between ecosystem structure, processes, and climate.

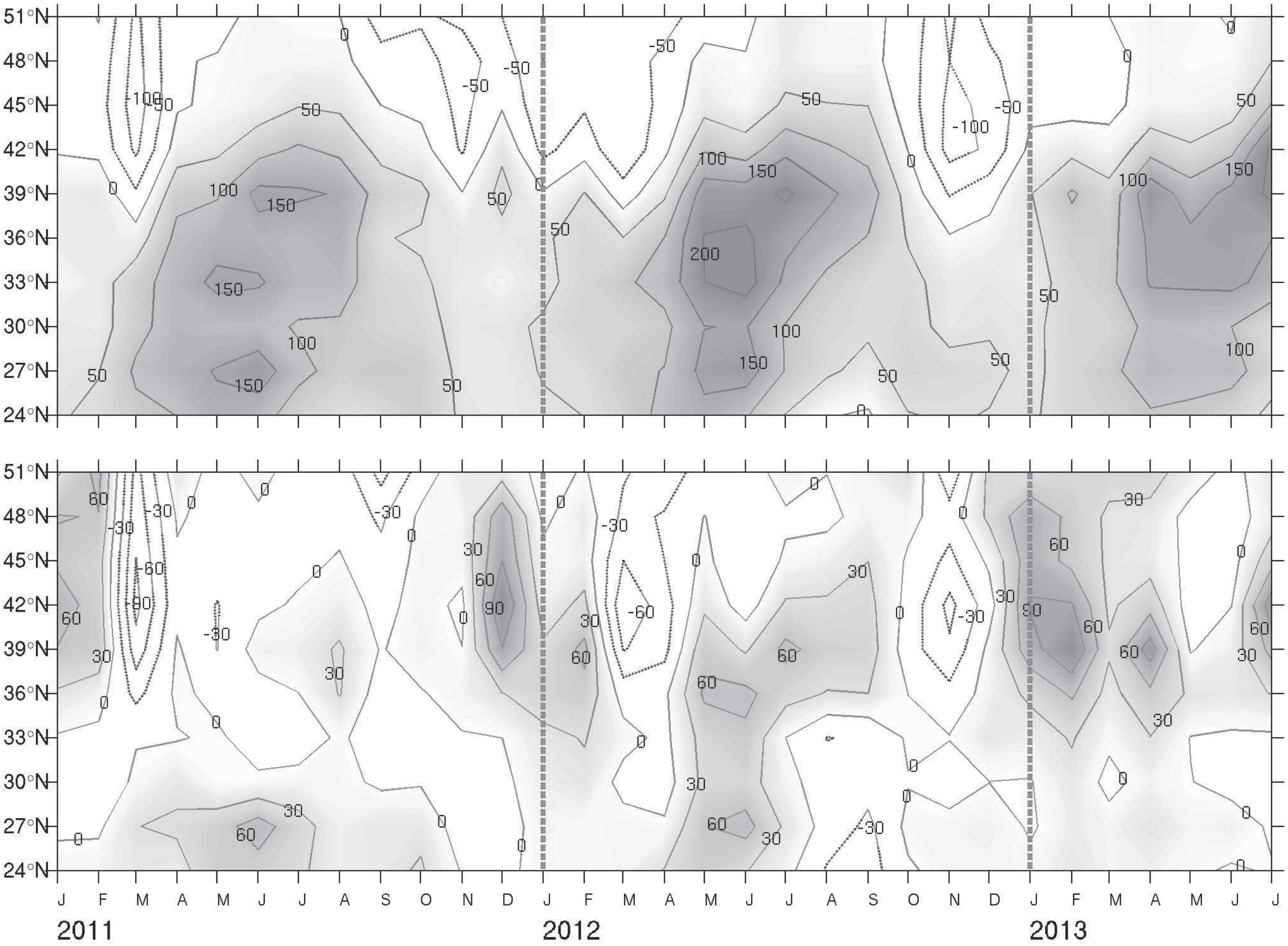

Figure 3. Monthly upwelling index (top) and upwelling index anomaly (bottom) for January 2011–May 2013. Shaded areas denote positive (upwelling-favorable) values in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1967–2013 monthly means. Units are in m³ s–1 per 100 km of coastline.

NORTH PACIFIC CLIMATE INDICES

The multivariate El Niño Southern Oscillation (ENSO) index (MEI) (Wolter and Timlin 1998) transitioned from La Niña conditions in summer of 2010 through January 2012 (fig. 2). In the summer of 2012, MEI increased but the values were too low and short-lived to be classified as an ENSO event; the values returned to neutral conditions in the spring of 2013. The Pacific Decadal Oscillation index (PDO) (Mantua and Hare 2002) has been negative (cool in the CCS) coinciding with the start of the La Niña in the summer of 2010 (fig. 2). The PDO continued in a negative phase through the summer of 2012, with a minimum in August. After October 2012, the PDO increased to slightly negative values in the winter and spring of 2013. The May 2013 value of the PDO was +0.08 but dropped to a value of –0.78 in June. The North Pacific Gyre Oscillation index (NPGO) (Di Lorenzo et al. 2008) was positive from the summer of 2007 to the spring 2013 with a peak value in July 2012 (fig. 2).

NORTH PACIFIC CLIMATE PATTERNS

A basin-scale examination of SST allows for the interpretation of the spatial evolution of climate patterns and wind forcing over the North Pacific related to trends in the basin-scale indices (fig. 2). In the summer of 2012, predominately negative SST anomalies over the western Pacific coincided with anticyclonic wind anomalies. Warmer than normal SST (+1.0°C) in the central and eastern north Pacific occurred during a period of anomalous eastward winds in October of 2012. For 2013 the northeast Pacific experienced winter SST anomalies that were slightly cooler than normal (< –0.5°C), followed by slightly warmer anomalies (< +0.5°C) in the spring. SST anomalies across the North Pacific in 2013 (January to June) were positive and were simultaneous with a rise in PDO values from the extreme negative values experienced in 2012. However, SST anomalies along the CCS remained slightly negative (< –0.5°C) forced by equatorward meridional wind anomalies (fig. S1).

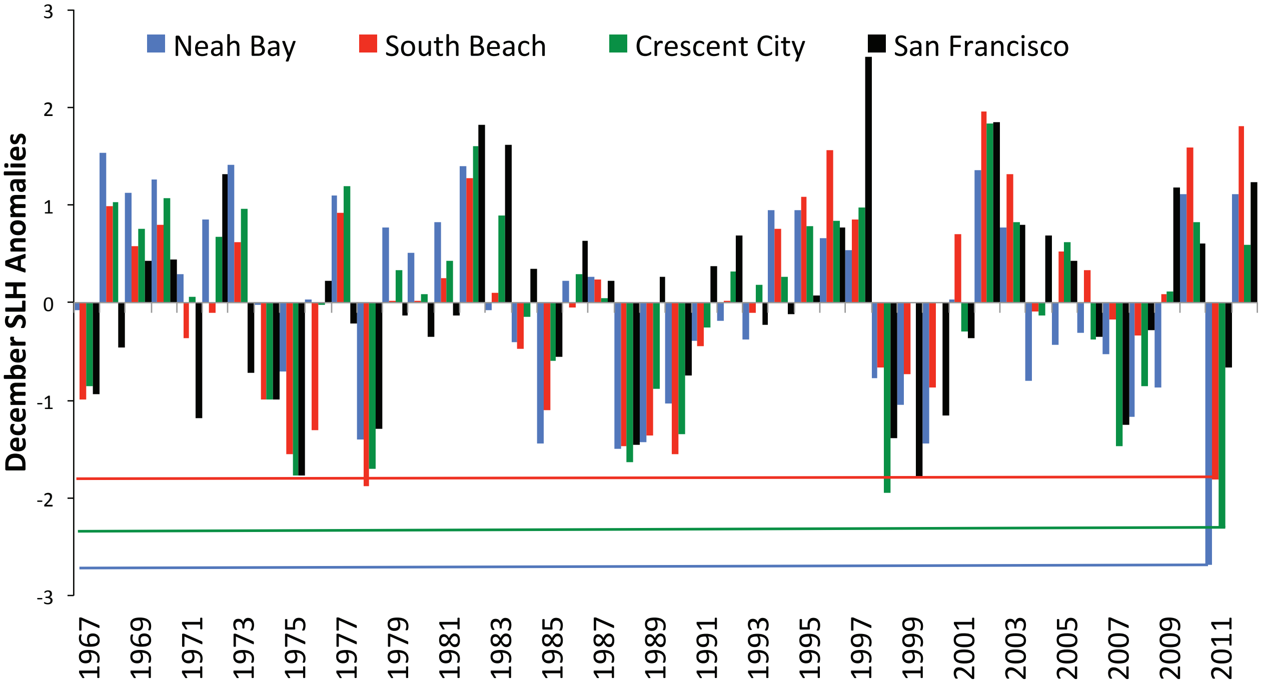

Figure 4. Sea level height anomalies measured by tidal gauges during December for the following four locations along the CCS: Neah Bay, WA, South Beach, OR, Crescent City, CA and San Francisco, CA. Horizontal lines mark the values observed in December 2011.

Upwelling in the California Current

December 2011 was marked by anomalously strong upwelling between 36°N and 45°N and substantially weaker downwelling north of 45°N (fig. 3). This resulted in anomalously low coastal sea levels, as measured by tidal gauges, in December at Neah Bay, WA, South Beach, OR, and Crescent City, CA (fig. 4). Such low coastal sea levels suggests southward transport in winter 2011/2012.

By March 2012, upwelling winds north of 39°N were anomalously low while winds south of 39°N remained near the climatological mean. Upwelling north of 39°N did not resume again until May and for summer and fall remained at close to climatological values. In contrast, south of 39°N average upwelling prevailed from winter 2011 to April 2012, after which it intensified. Strong upwelling continued off central California until fall. North of 36°N, high upwelling persisted through winter 2012 and into January–February 2013 (fig. 3).

The cumulative upwelling index (CUI) gives an indication of how upwelling influences ecosystem structure and productivity over the course of the year (Bograd et al. 2009). In the north from 42° to 48°N, the upwelling season in 2012 began early (fig. S2) resulting in average CUI values from January 1 to the beginning of March, but dropped to below long-term average over the spring and summer. The upwelling season also began early in southern and central California (33°–36°N) during 2012, with highest levels of the CUI at the end of February since record highs experienced in 2007. Strong upwelling continued into the summer off southern California (33°N) with CUI estimates at the end of July being the highest since 1999. At 36°N, the 2012 CUI values at the end of the year were the second highest on record, falling just below the high in 1999. Through mid-2013, CUI values are greater than previously observed records throughout the CCS. While there were significant regional differences in upwelling in 2012, strong upwelling occurred more widely in the CCS in winter and spring of 2013.

Coastal Sea Surface Temperature

In 2011, the daily December values of SST were below average especially at the northern California and Oregon buoys (fig. S3). This is due to upwelling at the start of December; these winds were especially long in duration for the Oregon buoy, with the event lasting over half of the month. Anomalously cool SST values in December 2011 extended into spring of 2012 as measured by all of the buoys. There was very little temperature variation between winter of 2011/2012 through spring of 2012. Periods of northerly winds occurred in January and February for the northern buoys with these winds switching directions to southerly in March and April. SST increased for the northern two buoys but the southern buoys showed average temperatures. Only one buoy (St. George, CA) had a complete record of winds in the summer (June–August) of 2012, and the winds

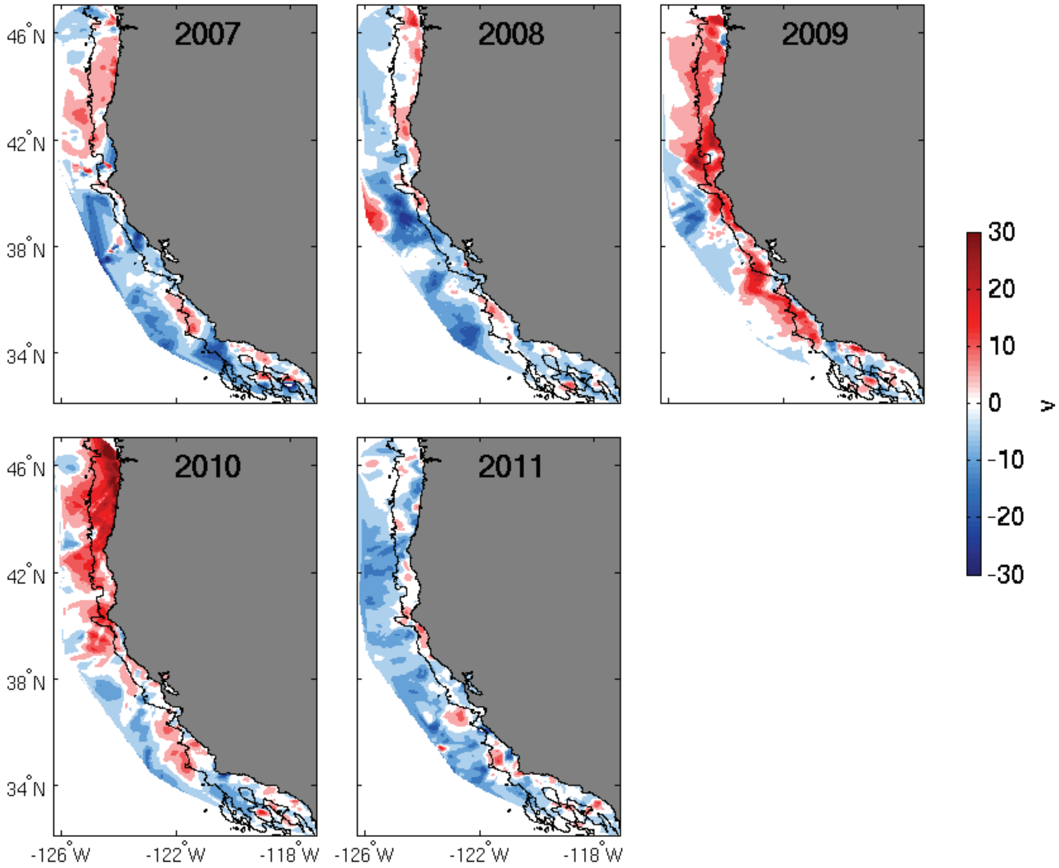

Figure 5. Maps of mean HF radar meridional surface currents observed December 2011 throughout the CCS 2007–11 (December 2012 was not available for this report). Meridional current speed is indicated by color bar (blue shading indicates southward flow) with units of cm/s.

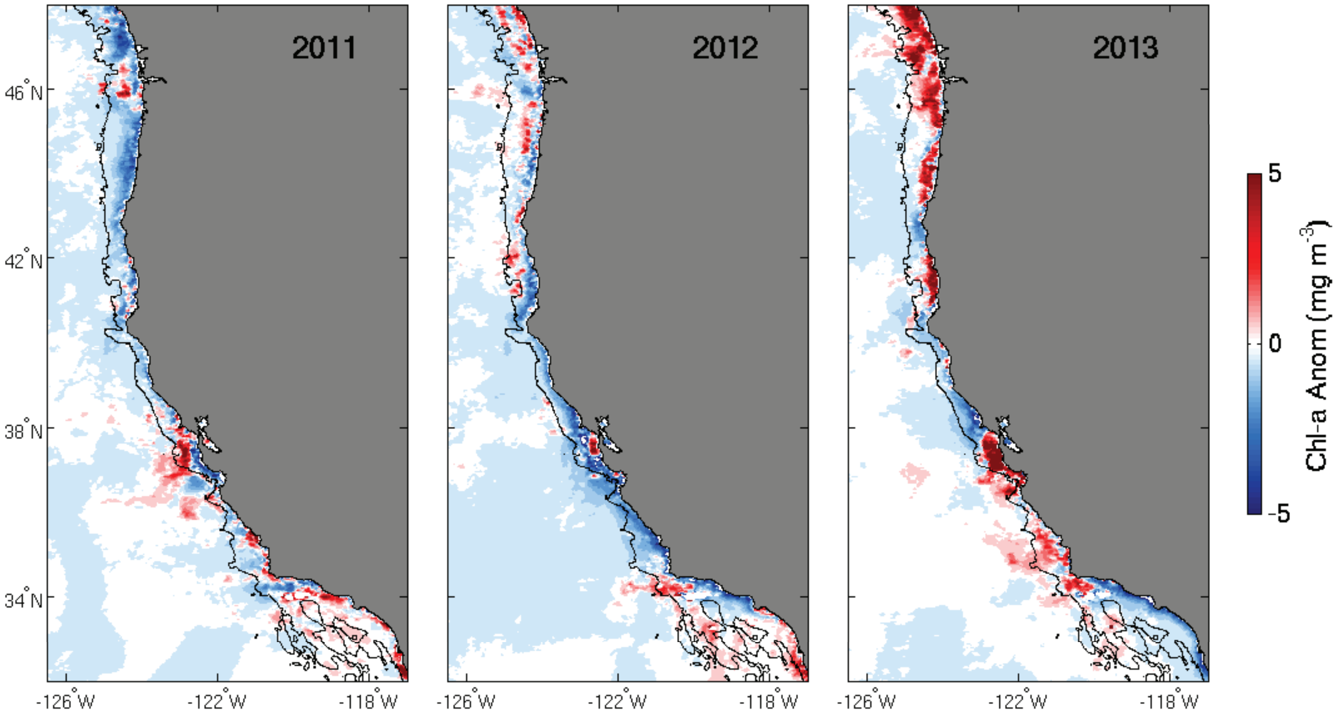

Figure 6. Aqua MODIS satellite measured chlorophyll *a* anomalies for March–May averages. The climatology was based on data for the years 2003–13. The black line is the 1000 m isobath.

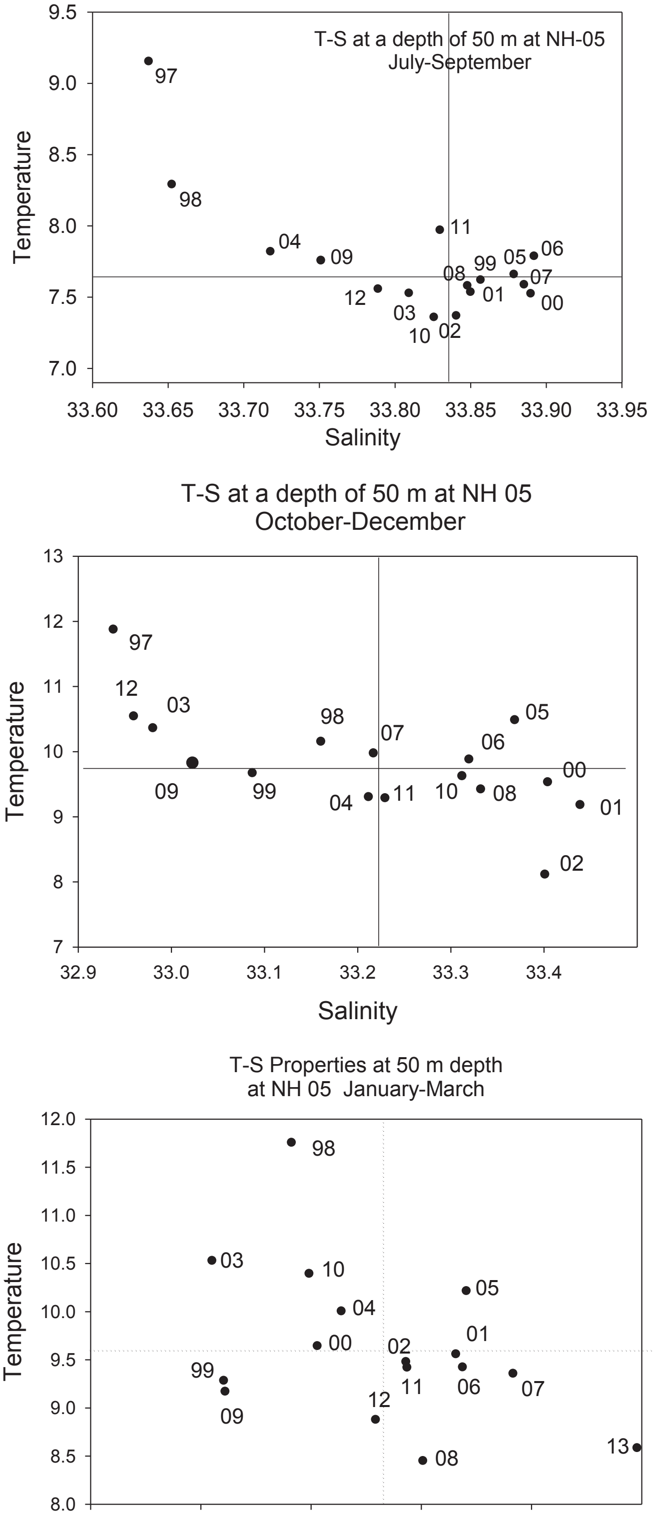

Figure 7. Seasonal mean temperature and salinity at 50 m depth at NH-5 along the Newport Hydrographic Line averaged for summer, fall and winter 2012. Cruises are made biweekly. Numbers adjacent to each data indicate "year."

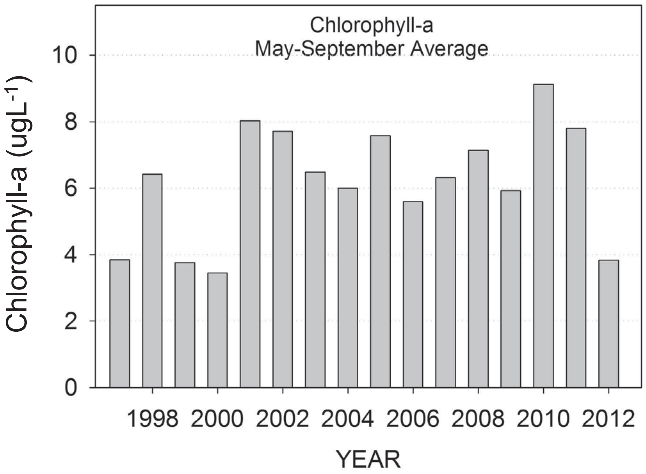

Figure 8. Chlorophyll *a* time series off Newport Oregon at station NH5 showing that chlorophyll *a* averaged over the May–September upwelling season, was unusually low in the year 2012, similar to values not seen since 1999 and 2000.

were predominately downwelling in direction with only a few days of upwelling winds in June. Towards the end of fall (October–November of 2012) above average SSTs occurred for all of the buoys for which we had data. The winds during this time were downwelling-favorable except for a strong upwelling event in the beginning of December. Cool temperatures were evident in early 2013 and persisted until April for all of the buoys. In late April, SSTs dipped due to a strong upwelling event. The winds in January through June of 2013 have mostly been upwelling-favorable except off Oregon where there have been short periods of downwelling.

High Frequency Radar
Surface Current Observations

Surface transport was southward in the northern CCS during December 2011, as observed by high frequency (HF) radar (fig. 5) in support of the upwelling (fig. 3) and sea level (fig. 4) data. For the spring of 2012 surface currents observed with HF radar revealed southward currents, developing into marked offshore flow in summer with a general weakening in the fall and a tendency for weak northward flow in winter (see supplement for additional results, fig. S4).

Coast-wide Analysis of Chlorophyll

We used Aqua MODIS satellite measurements to evaluate spring chlorophyll (anomalies; climatology based on 2003–13) in the surface waters of the CCS for 2011–13 (details in supplement). Surface chlorophyll anomalies were generally below average north of San Francisco, CA during the spring of 2011, while the spring values of chlorophyll in 2012 were below average south of Cape Mendocino except for increased production in the Gulf of the Farallones and throughout

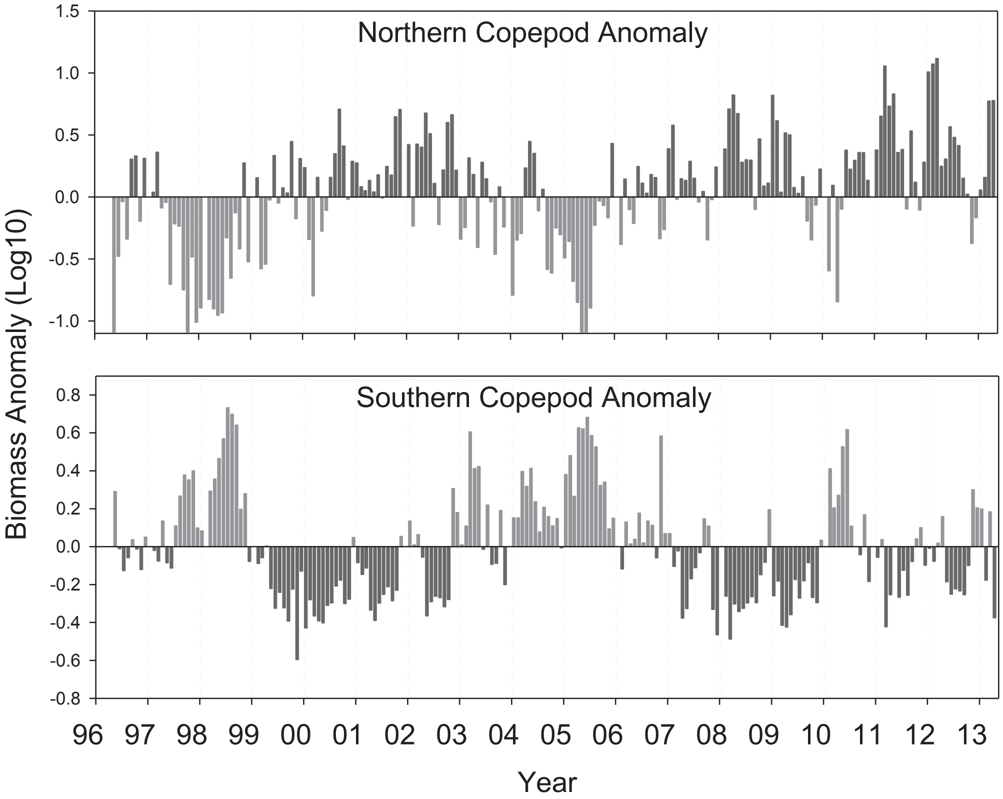

Figure 9. Time series of monthly values of the Northern Copepod Anomaly and Southern Copepod Anomaly. The copepod data are from biweekly sampling at station NH-5 along the Newport Hydrographic Line.

much of the offshore regions south of Point Conception (fig. 6). In spring 2013, chlorophyll was elevated along most of the coast north of Point Conception; south of Point Conception chlorophyll was below average.

REGIONAL SUMMARIES OF HYDROGRAPHIC AND PLANKTONIC DATA

Several ongoing surveys provide year-round hydrographic and planktonic observations across the CCS but vary in terms of spatial extent, temporal resolution survey design, and limitations (fig. 1). In the following section we review recent observations from these surveys from north to south.

Northern California Current: Newport Hydrographic Line

Daily values of SST from the Newport Hydrographic Line showed warm temperature anomalies in June and July 2012, with daily values of temperature anomalies around +3˚C in mid-July. The monthly average anomaly was +1.7˚C for July. SST at hydrographic station NH5 (five miles offshore of Newport) was also above-average over the May–September period with a peak in SST (15.9˚C) observed on 25 June, a value which was the 12th warmest of 450 sampling dates since 1997.

The April–June 2012 data were among the fresher and warmer years; July–September was cool and fresh. By contrast, during the January to March period of 2013, deep water was the most saline of the time series. Concomitant with that, the temperature was also one of the two lowest, 2008 being the lowest (fig. 7). Chlorophyll values at five miles off shore (NH5) averaged over May–September were the lowest they have been since 1999 and 2000 (fig. 8).

Examination of the copepod community can help to determine source waters and provide insights into the productivity of the system (Peterson and Keister 2003). Copepods that arrive from the north are cold-water species that originate from the coastal Gulf of Alaska and include three cold-water species: *Calanus marshallae*, *Pseudocalanus mimus*, and *Acartia longiremis*. Copepods that reside in offshore and southern waters (warm-water species) include *Paracalanus parvus*, *Ctenocalanus vanus*, *Calanus pacificus*, and *Clausocalanus* spp. among others. Copepods are transported to the Oregon coast, either from the north/northwest (northern species) or from the west/south (southern species). The Northern Copepod Index (Peterson and Keister 2003) was positive from autumn 2010 through summer 2012. The January and February 2012 values were the highest ever for the index and occurred after the southern transport anomaly observed in the winter of 2011 (figs. 9 and 4). The

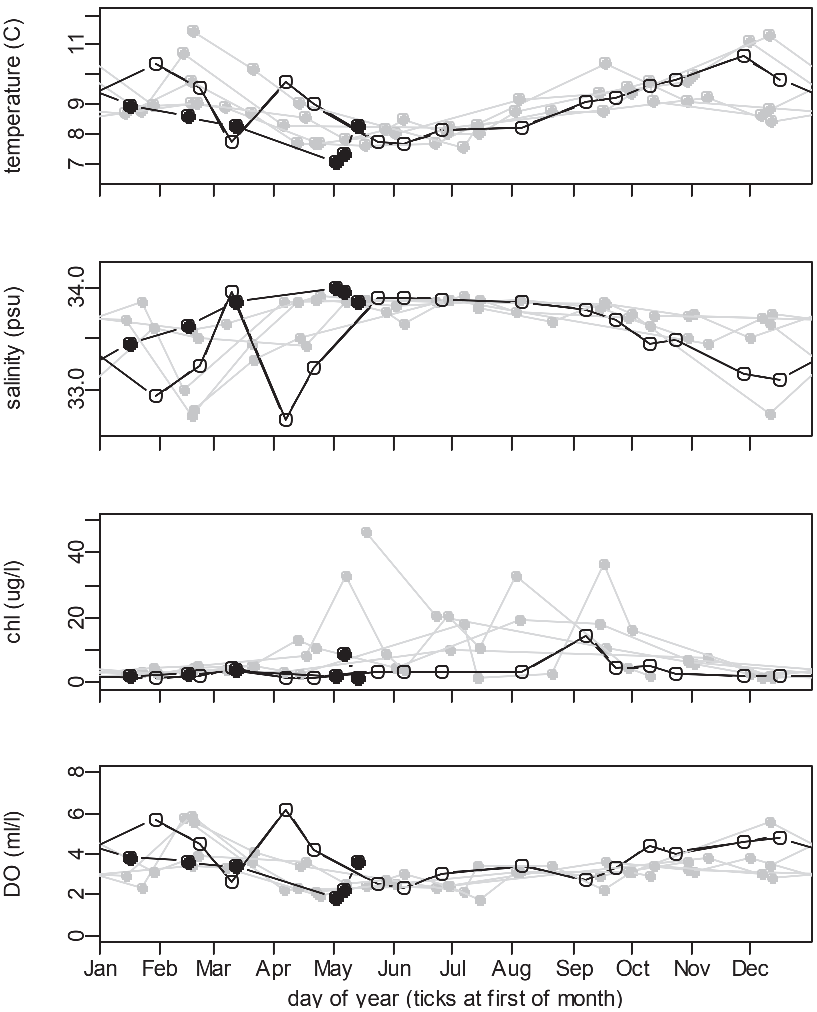

Figure 10. Hydrographic and ecosystem indicators at mid-shelf along the Trinidad Head Line (station TH02, 75 m depth). Panels from top to bottom show near-bottom (60 m) temperature, near-bottom (60 m) salinity, mean chl *a* concentration over the upper 30 meters of the water column, and near-bottom (60 m) dissolved oxygen concentrations. Grey symbols indicate historical observations (2006–11), open circles indicate observations during 2012, and closed symbols indicate observations in 2013.

Southern Copepod Index was predominately negative throughout much of the 2011 to 2013 period (fig. 9).

Northern California Current: Trinidad Head Line

Consistent with the Newport Hydrographic Line, observations along the Trinidad Head Line indicated that coastal waters off northern California were affected by strong downwelling and freshening during a series of storms in spring 2012 (fig. 10). Storm activity continued to affect waters off northern California through the spring and into summer, with northward wind and rain events occurring into July. Chlorophyll concentrations in the upper water column remained very low over the shelf throughout 2012 (figs. 6 and 10), save for a modest bloom that developed in early fall (fig. 10). This trend was apparent along the entire line, out to approximately 50 km offshore. Low chlorophyll concentrations in spring and summer 2012 do not appear to have been a result of low nutrient availability as nutrient concentrations were average.

In contrast to the stormy conditions observed in early 2012, ocean conditions in early 2013 along Trinidad Head Line reflect the effects of a relatively dry winter marked by unusually consistent, extended periods of upwelling favorable winds, and relatively infrequent storms of short duration. Intense upwelling throughout April resulted in the coldest, saltiest water observed on the shelf during the time series; conditions over the shelf remained cold and salty relative to spring 2012 (fig. 10). Since the onset of intense upwelling, average chlorophyll concentrations in the upper water column have remained relatively low (fig. 6).

In 2012 the copepod assemblage over the northern California shelf included relatively few northern neritic species, and high species diversity reflecting the preva-

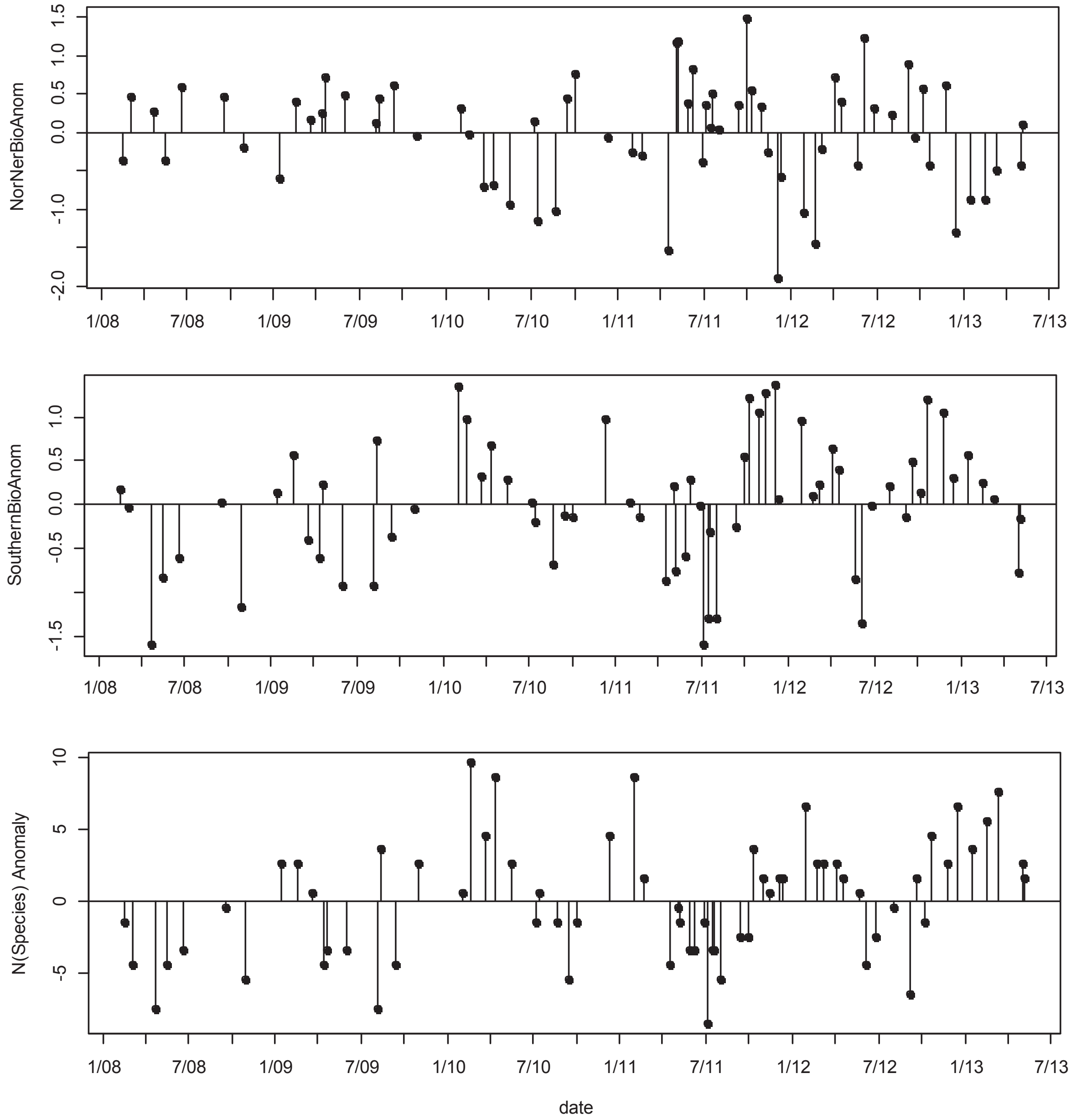

Figure 11. Anomalies (from the 2008–13 mean) in biomass and species richness of the copepod assemblage at mid-shelf on the Trinidad Head Line (station TH02, 75 m depth). Top: Biomass anomaly of dominant northern neritic copepods (dominated by *Pseudocalanus mimus*, *Calanus marshallae*, and *Acartia longiremis*). Middle: Biomass anomaly of southern copepods (neritic and oceanic taxa combined; dominated by *Acartia tonsa*, *Acartia danae*, *Calanus pacificus*, *Ctenocalanus vanus*, *Paracalanus parvus*, *Clausocalanus* spp., and *Calocalanus* spp.). Bottom: species richness anomaly.

lence of "southern" and "offshore" taxa over the shelf (fig. 11). Northern neritic taxa were modestly more abundant in late spring and summer, but southern taxa were displaced from the shelf only for a brief period in summer 2012. Coupled trends in the copepod assemblage (declining biomass of southern and oceanic taxa and increasing biomass of northern neritic species) in early 2013 were consistent with expected effects of physical forcing and patterns observed to the north (Newport Hydrographic Line).

Central California[2]

In January 2012 surface values were colder and saltier due to upwelling winds in late 2011. However, salinity values returned to average by June (fig. 12). Surface temperatures remained lower than average until fall. At 100 m anomalous high salinity and low temperature values persisted from January to May, after which they became average to above average for the remainder of

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See supplement for HF radar data and description of surface current patterns in the Central California region.

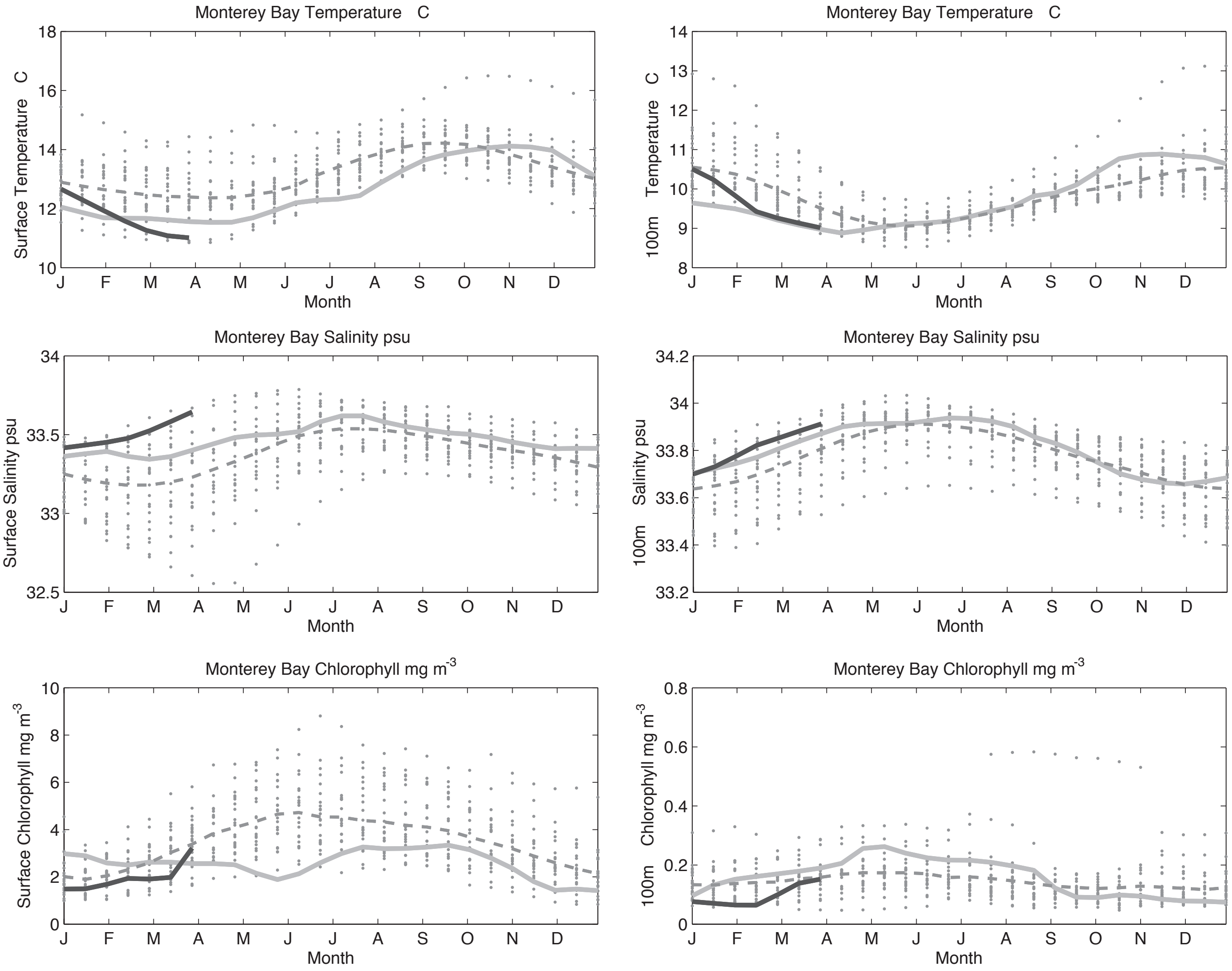

Figure 12. Temperature (top panels), salinity (middle panels) and chlorophyll concentration (bottom panels) at the surface (left hand column) and at 100 m (right hand column) observed at the M1 mooring.

the year. Surface chlorophyll was above average during January–February but was below average in the spring and continued to decrease to the lowest values on record by June (fig. 12). At 100 m chlorophyll was average to above average from January to August.

In early 2013, upwelling was significantly stronger than 2012, with the surface salinity and temperature near their maximum and minimum values respectively by April (fig. 12). Surface chlorophyll values increased from below average values in January to mean values by April. At depth, the relationships were similar to those at the surface (fig. 12).

Southern California

The 2012 mixed-layer temperatures continued to be mostly below long-term averages in southern California (fig. 13), consistent with the trends across much of the northeast Pacific (PDO, fig. 2). Mixed-layer temperatures since the 1998/99 ENSO have been decreasing but not significantly. Mixed-layer salinities have been increasing over the last two years; this increase reflected a similar increase of the NPGO (fig. 2). Areas of the CalCOFI study domain within the California Current and coastal areas affected by it saw the increase in salinity values. The increase in salinity is primarily observed in those areas of the CalCOFI study domain that are affected by the California Current. The salinity signal was not observed in the offshore areas of the CalCOFI domain that represent the edge of the North Pacific Gyre (fig. S6).

Concentrations of nitrate were close to long-term averages, except for above average spring 2013 values (fig. 13). The distinctive increase of nitrate at the σ_t 26.4 kg/m^3 isopycnal from 2009 to 2012 noted in Bjorkstedt et al. 2012 has returned to near-mean values over the last

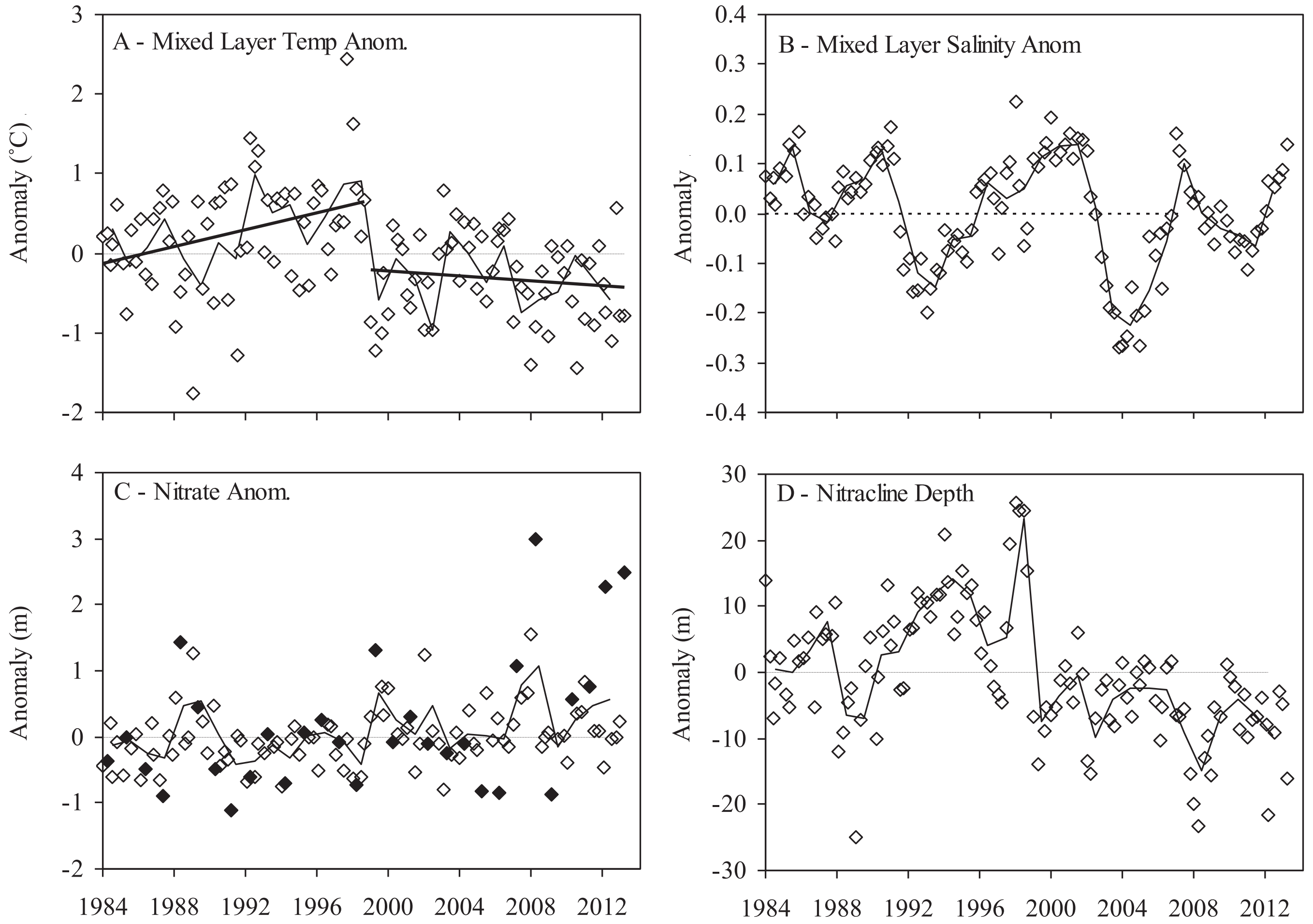

Figure 13. Property anomalies for the mixed layer (ML) of the CalCOFI standard grid: A – ML temperature anomaly, B – ML salinity anomaly, C – ML nitrate concentration anomaly and D – nitracline depth anomalies which are negative when the nitracline is closer than expected to the surface and positive when deeper than long-term averages. Data from individual CalCOFI cruise data are plotted as open diamonds. The thin solid lines represent the annual averages, the dotted lines the climatological mean, which in the case of anomalies is zero and the straight solid lines, when present, long-term linear trends. In panel C, nitrate, solid symbols are spring values.

12 months. Nitrate anomalies at the isopycnal were 1.8 µM during July 2012, the highest value observed over the last 29 years, but dropped to 0.9 µM in the spring of 2013 (data not shown).

In the CalCOFI region (fig. 1) concentrations of chlorophyll were similar to long-term averages (fig. 14) for all four cruises covered by this report. At the edge of the North Pacific Central Gyre, concentrations of chlorophyll were still above long-term averages while the depth of the subsurface chlorophyll maximum dropped from 50 m to 75 m (fig. S7). Similar patterns were observed in the southern California Current region (fig. S7). Concentrations of chlorophyll, however, were at or below long-term averages in the northern California Current region and in the coastal areas (figs. 6 and S7). Values of primary production were below or at long-term averages during the summer and fall of 2012 but substantially above long-term averages during the first half of 2013.

Anomalies of zooplankton displacement volume, a proxy for zooplankton biomass, are only available up to the fall of 2012 (fig. 14, lower panel). Values during 2012 were significantly greater than long-term averages, comparable to values observed during the 1980s and the 1999 La Niña period. These patterns were largely driven by very high abundance of salps and pyrosomes during 2012.

Baja California (Investigaciones Mexicanas de la Corriente de California, IMECOCAL)

Consistent with the observations from 2011–12 (Bjorkstedt et al. 2012), temperatures remained cooler than average in 2012–13. In fact, the three coolest SST values since 1998 occurred in 2011, 2012, and 2013. As well, surface waters continued to be fresher through spring of 2013 but were slightly more saline than that of 2011 (fig. 15). Chlorophyll off Baja California was near average throughout 2011–13, with the exception

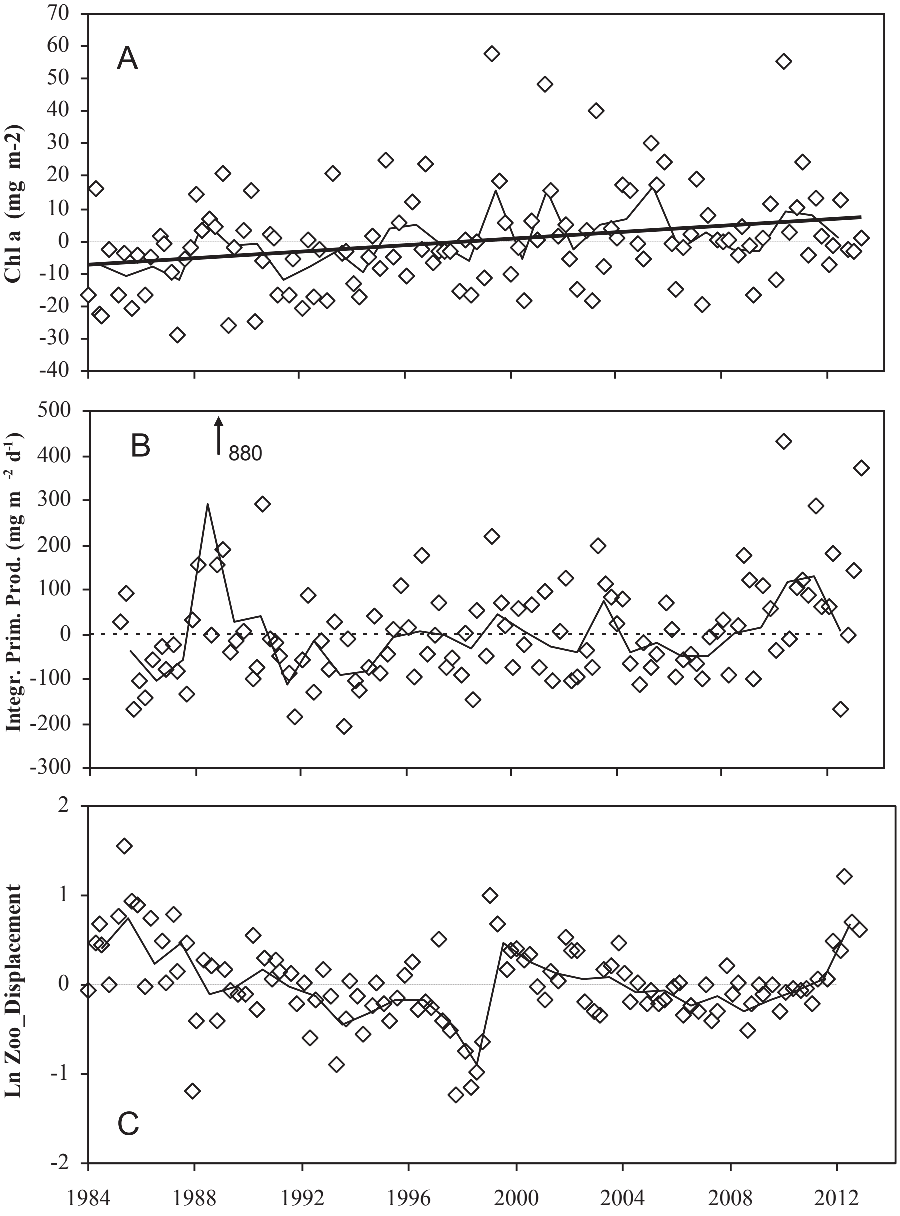

Figure 14. CalCOFI region averages for standing stocks of chlorophyll-*a* (A) and rates of primary production (B) both integrated to the bottom of the euphotic zone and (C) the log of zooplankton displacement volume, all plotted against time.

of a single high and positive anomaly during spring of 2012 (fig. 16).

Zooplankton displacement volume remained high during 2012 through February 2013 continuing an eight-year period of higher than average values (fig. 17). However, euphausiid density was below average between the springs of 2011 and 2012. Copepods have been anomalously abundant since 2010 except for the 2011/2012 winter values.

GELATINOUS ZOOPLANKTON

In this report gelatinous zooplankton are divided into two categories: herbivores and carnivores. Tunicates, the herbivorous filter-feeding forms, include salps, doliolids, pyrosomes, and appendicularians. The carnivorous forms are represented by a variety of taxa, such as jellyfish (e.g., Hydromedusae, Schyphomedusae, siphonophores), pelagic snails (pteropods, heteropods), and arrow worms (chaetognaths).

Northern California

Catches of tunicates in the NWFSC pelagic survey were very low (zero in many cases) from June 2004 until June 2010, after which salp densities spiked over a short period, reaching a maximum of 3400 individuals per 10^6 cubic meters of water sampled by August of

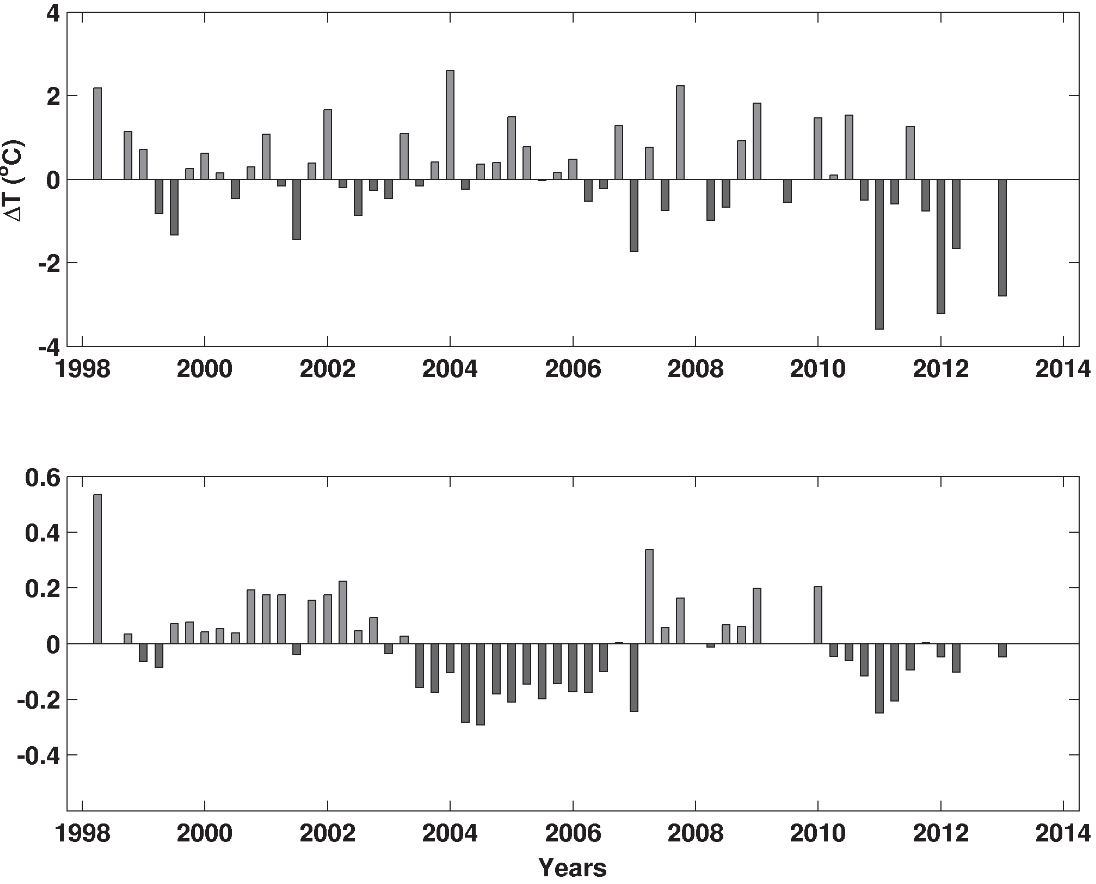

Figure 15. Mixed layer temperature anomaly and mixed layer salinity off Baja California Peninsula (IMECOCAL). Each bar represents each cruise conducted.

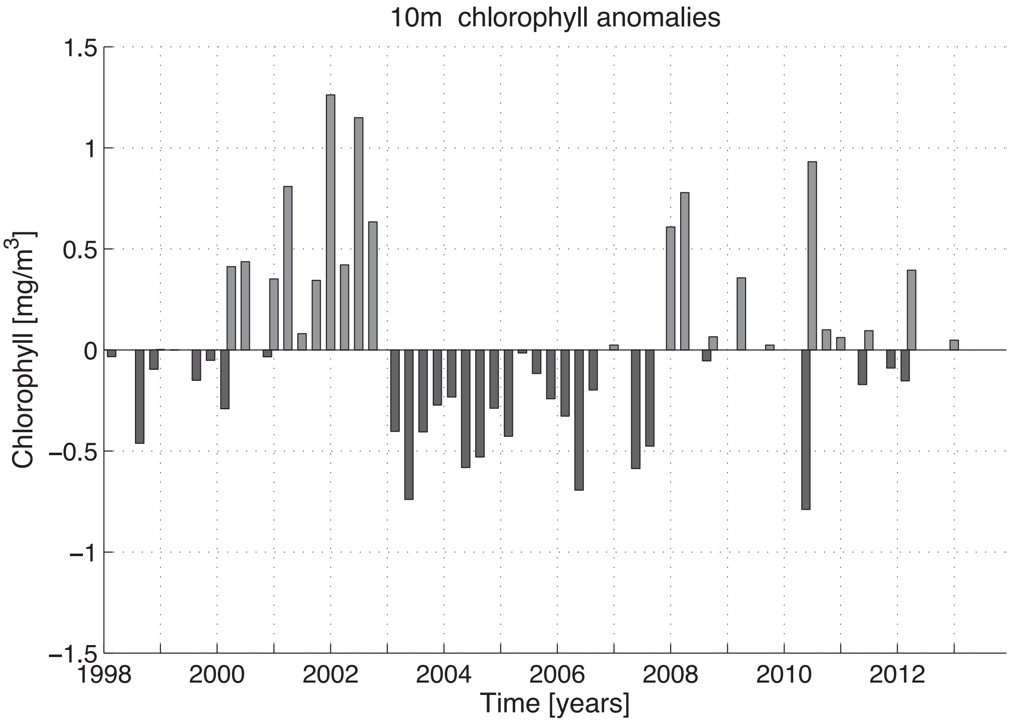

Figure 16. Anomaly time series of 0–100 m integrated chlorophyll *a* off Baja California Peninsula (IMECOCAL). Each bar represents each cruise conducted.

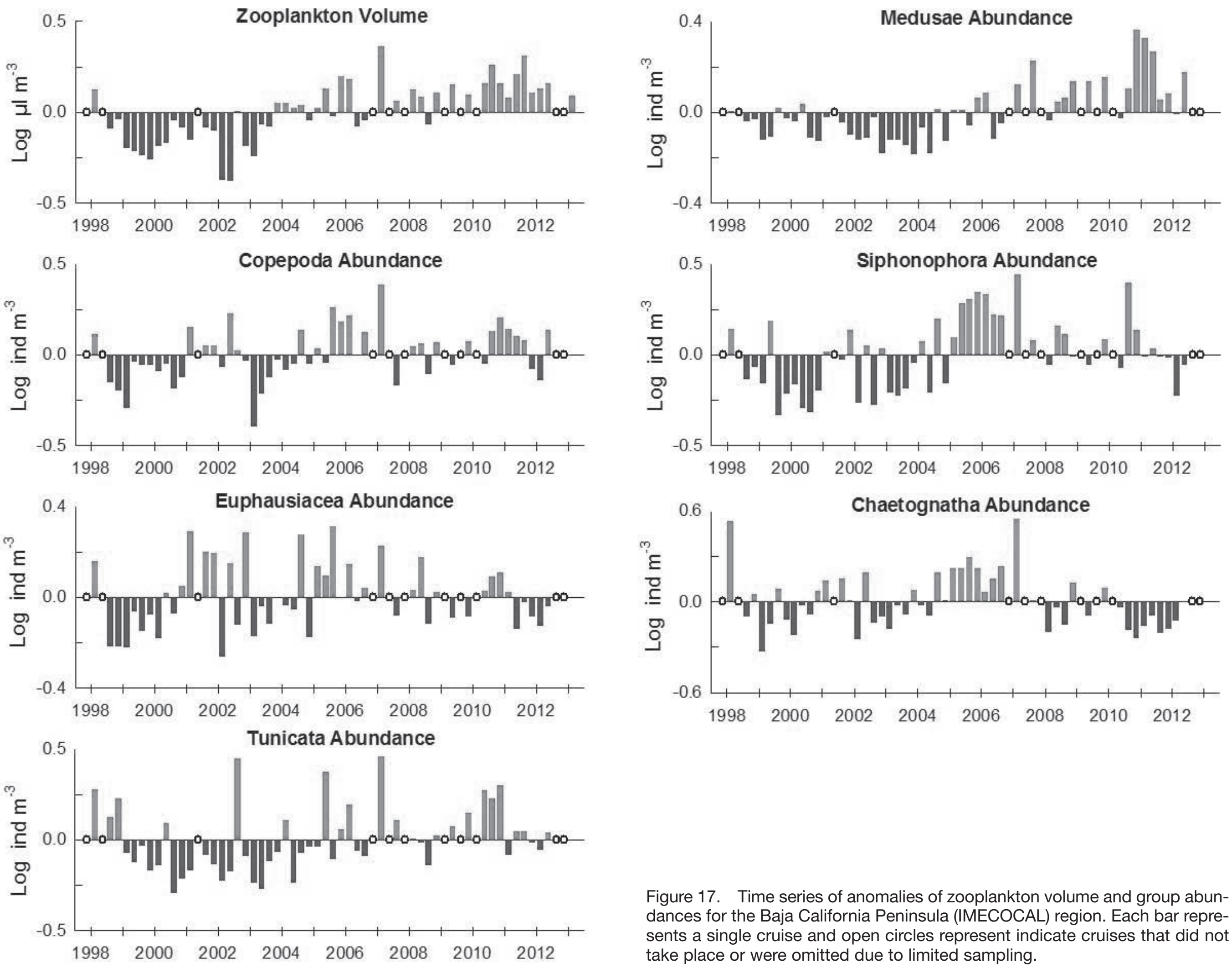

Figure 17. Time series of anomalies of zooplankton volume and group abundances for the Baja California Peninsula (IMECOCAL) region. Each bar represents a single cruise and open circles represent indicate cruises that did not take place or were omitted due to limited sampling.

2010. Densities remained high into early 2011 and then tapered to near normal low catches in 2012 (fig. 18).

Densities of the two dominant larger medusa species in this region, *Chrysaora fuscescens* and *Aequorea* spp., have been monitored as part of a pelagic trawl survey conducted every June and September since 1999 (Suchman et al. 2012)(see supplement for data collection). Catches of both species returned to a more typical level in June 2012, following below-average catches for the last two years (fig. S8). In September 2012, catches of both species were similar to 2011, with densities of *C. fuscescens* being approximately an order of magnitude higher than those of *Aequorea*, similar to that seen earlier by Suchman et al. 2012.

Central California

The major contributors to the herbivorous tunicate catch off Central California were the salps, *Thetys vagina* and *Salpa* spp., as well as pyrosomes, *Pyrosoma* spp. In 2012, the numbers of *S. fusiformis*, other salp species, and pyrosomes in the core region of the SWFSC rockfish recruitment survey (roughly Point Reyes to Point Piños) far exceeded previously recorded values (fig. 19) (Bjorkstedt et al. 2012), although the abundance of *Thetys vagina* remained well within the range of previously observed blooms (fig. 19). The largest salp and pyrosome catches were in the southern region of the expanded coast-wide rockfish recruitment survey (fig. 19). Although there is no baseline data to compare these trawl survey catches, they are consistent with accounts of high salp abundances in this region during 2012 (Bjorkstedt et al. 2012). By spring 2013 salps, pyrosoma, and *Thetys vagina* were near typical values in the core region and reduced in the southern region (fig. 19).

In 2012, within the rockfish recruitment survey's core region, large salp catches mostly occurred at offshore stations, and the magnitude of the catches were substantially larger than the long-term average (fig. 20). Salp

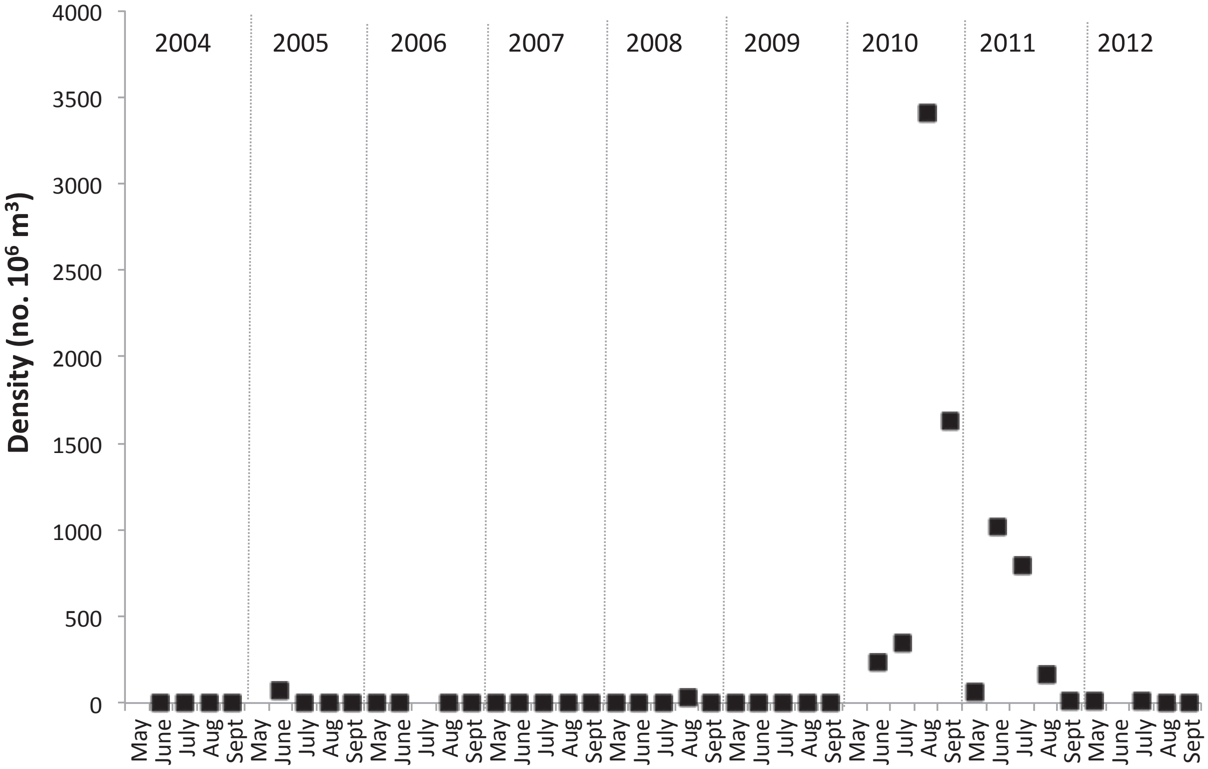

Figure 18. Densities of salps (mostly *Thetys vagina* and *Salpa fusiformis*) observed in the NWFSC pelagic rope trawl surveys off the coast of Oregon and Washington in May–September, from 2004 to 2012.

catches during 2013 have returned to more typical values observed in the survey. The summer salmon survey (fig. 1) that immediately followed the rockfish recruitment survey did not encounter extreme salp concentrations in 2012 and 2013, but this was likely due to the predominantly inshore sampling (data not shown).

The observed abundances of the jellyfish *C. fuscescens* during late spring of 2012 and 2013 were within the range of variability noted since 1990 (fig. 19). As in previous years, the largest catches of *C. fuscescens* occurred within the Gulf of the Farallones while the largest catches of *Aurelia* spp. occurred inside Monterey Bay's upwelling shadow (Graham and Largier 1997).

Southern California

There were large concentrations of gelatinous zooplankton encountered off southern California (predominantly tunicates). A proxy for the abundance of larger, mostly gelatinous, zooplankton is the difference between total zooplankton displacement volume (ZDV) and small fraction ZDV (fig. 21A) leaving the large fraction ZDV (fig. 21B). The latter fraction was substantially increased during 2011 to 2012 compared to the previous decade.

Baja California

At the southern extent of the CCS off Baja, herbivorous tunicates maintained average abundances during the last two years (fig. 17). However high-density patches occurred in discrete locations, such as in Vizcaino Bay. Carnivorous forms were present in similar abundance and composition as the 2011 reported values. Medusae continued to have positive anomalies while chaetognaths maintained negative anomalies. In contrast, the siphonophores shifted from the high positive anomalies in 2010 to a strong negative anomaly in February 2012.

SYNTHESIS OF OBSERVATIONS ON HIGHER TROPHIC LEVELS

Pelagic Fishes off Oregon and Washington

Time series plots of yearly abundance data are presented for each of the five most dominant and consistently collected forage species (jack mackerel, *Trachurus symmetricus*, Pacific sardine, northern anchovy, Pacific herring, *Clupea pallasii*, and whitebait smelt, *Allosmerus elongates*) (fig. 22) measured during the NWFSC-NOAA Bonneville Power Administration (NOAA/BPA) survey surface trawls. The survey also captures Pacific mackerel, *Scomber japonicas*, shown as well. The survey extends from Cape Flattery in northern Washington to Newport in central Oregon from June to September. Although other forage species are caught in these surveys, these five six species represent the bulk of the forage fish catch in surface waters. They include migratory species (Pacific

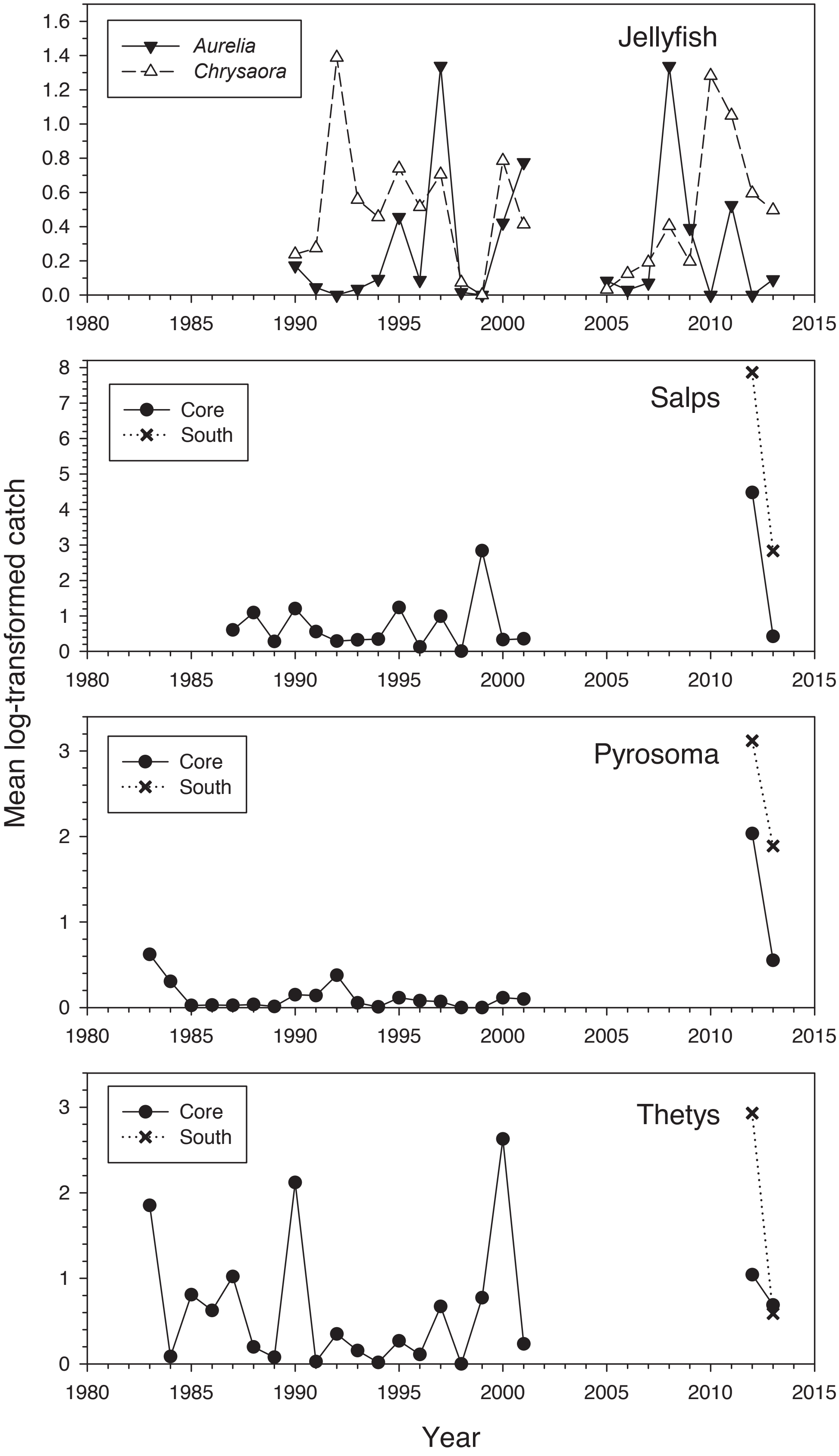

Figure 19. Geometric mean of catches per unit volume of gelatinous zooplankton from the central California rockfish recruitment survey.

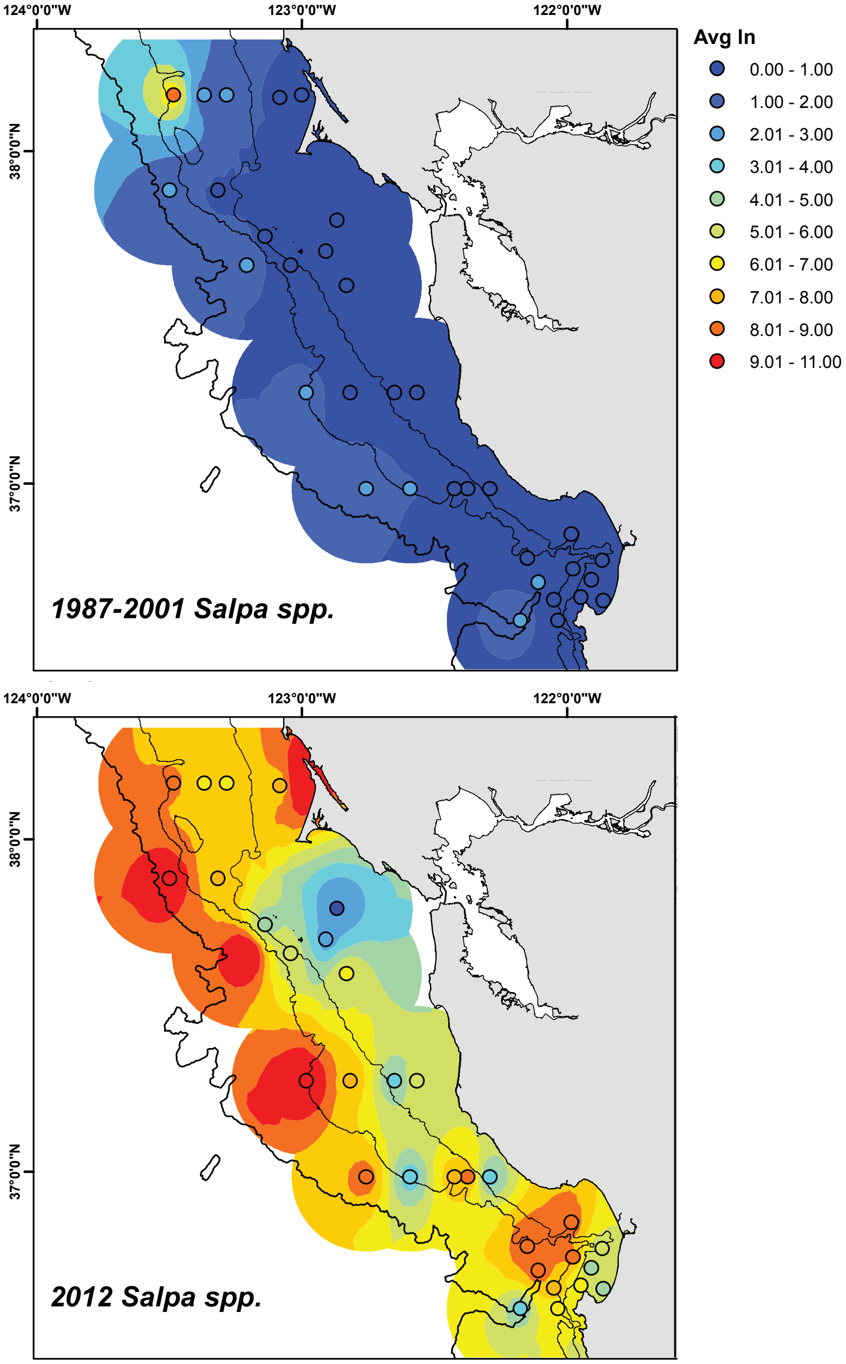

Figure 20. Distribution of the historical geometric mean of catches of salps from central California rockfish recruitment survey, 1987–2011, and those from 2012.

sardines and some northern anchovies) that may spawn off the Pacific Northwest or migrate from California (Emmett et al. 2005; Litz et al. 2008). Jack mackerel serve as a forage fish at younger ages but off Oregon and Washington are too large to be fed upon by most predators such as seabirds or adult rockfishes. Herring and whitebait smelt are likely spawned locally. A number of these species have seasonal trends in abundance (Emmett et al. 2005) so may experience intra-annual variability in abundance that is not captured by sampling two times per year. Ultimately, a number of forage fish are at reduced abundance (fig. 22, survey D, fig. 1). In 2012, Pacific herring, and Pacific sardine were at their lowest observed abundances since the start of the survey in 1998. Northern anchovy abundance was lower than it has been since 2002 (fig. 22).

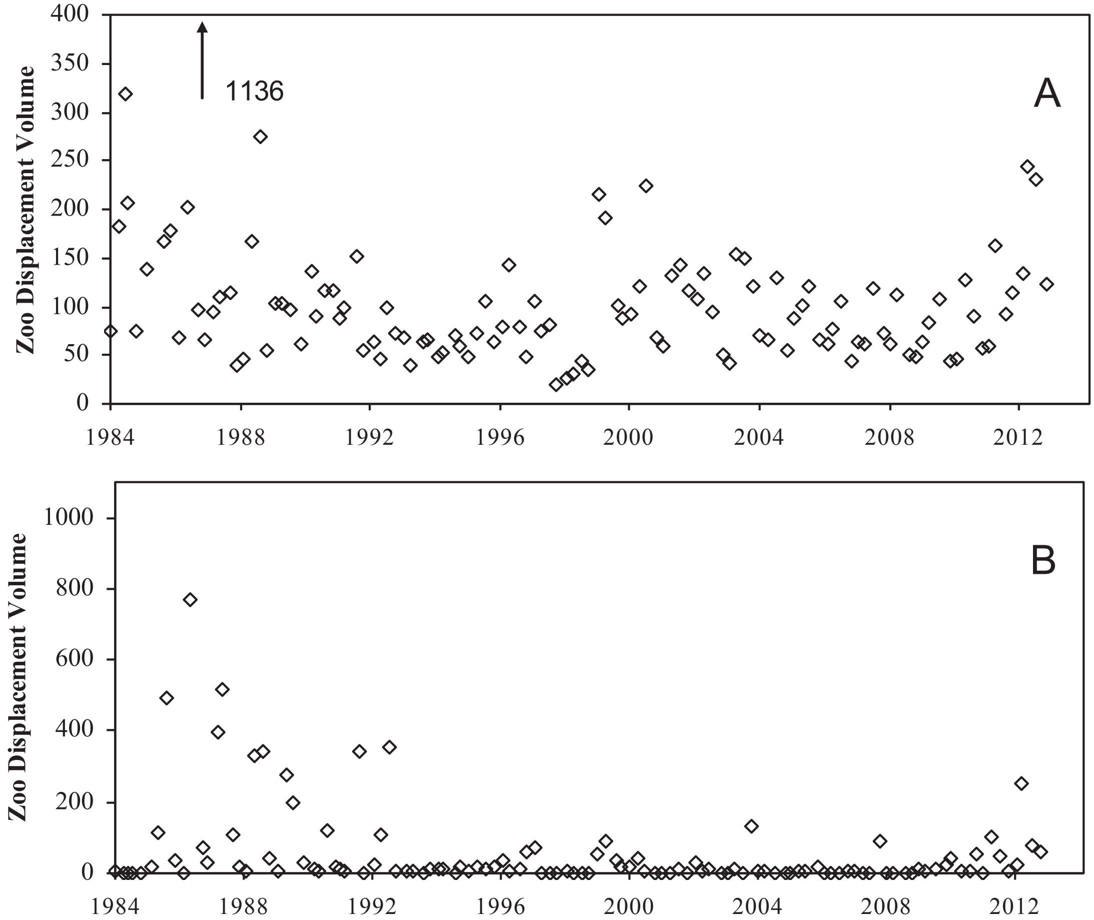

Figure 21. Zooplankton displacement volume (ml per 1000 m^2 seawater) for the small zooplankton fraction (A) and the large fraction (B). The large fraction consists of all organisms whose individual volume is larger than 5 ml. The small fraction is calculated by difference.

The ichthyoplankton and juvenile fish communities along the Newport Hydrographic Line off the coast of Oregon in May 2012 were similar to the average assemblages found in the same area and month during the previous five years both in terms of mean concentrations and relative concentrations of the dominant taxa (fig. 23). However, larval myctophids were found in the highest concentration in July 2012 of the five-year time series, while larval northern anchovy were found in higher concentrations (>3x) in July 2012 than in the same month in 2007–10. In addition, concentrations of the dominant taxa of juvenile fish were higher in July 2012 than in the same month in the previous five years, largely due to the abnormally high concentration of juvenile rockfish found in July 2012 (>10x that of any other year in 2007–11). No juvenile Pacific hake or northern anchovy were collected from the midwater trawl samples in May or July 2012, although age 1 and adult specimens of both species were found. Similarly, the biomass of ichthyoplankton in 2013 from winter collections along the Newport Hydrographic Line were above average (1998–2013), predicting average-to-good feeding conditions for juvenile salmon during the 2013 out migration (see supplemental results, fig. S9).

In the June NOAA/BPA surveys from 2008 and 2009, catches of juvenile spring-run Chinook salmon were high, with record high catches in 2008. Although catches in June 2011 were poor, catches in June 2012 were high, ranking second among the 15 years of surveys (fig. 24) suggesting excellent nearshore forage. However, catches of coho salmon in September 2012 survey were relatively low (fig. 24).

Pelagic Fishes Off Central California

Trends in both 2012 and 2013 showed higher productivity for the species and assemblages that tend to do better with regionally cool, high southward transport conditions, including juvenile rockfish, market squid, and krill (predominantly *Euphausia pacifica* and *Thysanoessa spinifera*) (fig. 25, see supplement for additional results). In 2012, juvenile rockfish catches were above average, as they have been in most years since 2008, and in 2013 the highest catches of juvenile rockfish in the time series of the survey were recorded, with huge numbers of juvenile

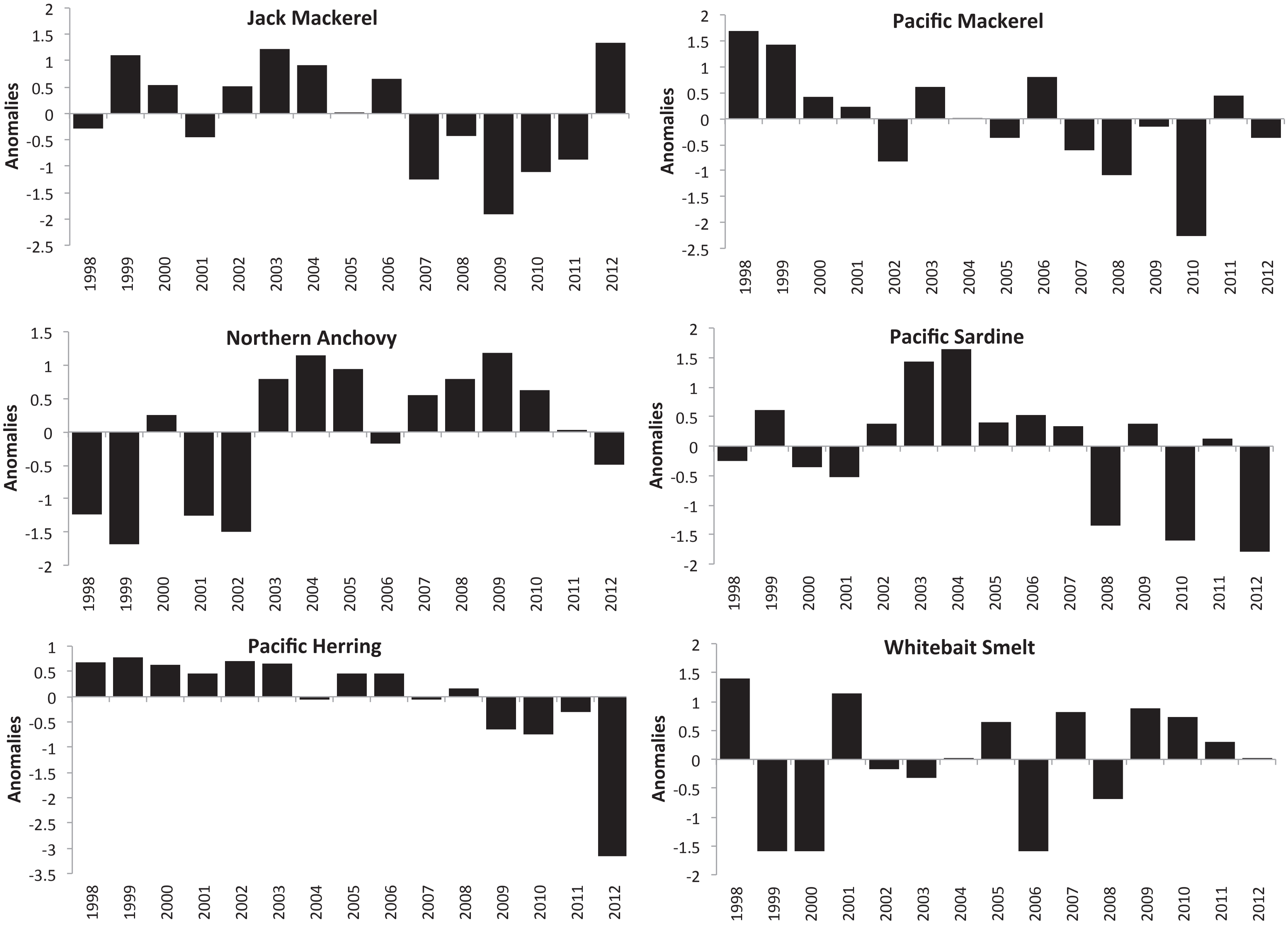

Figure 22. Group anomalies of catches per unit volume for the six most common forage fish collected during the NWFSC pelagic rope trawl survey, 1998–2012.

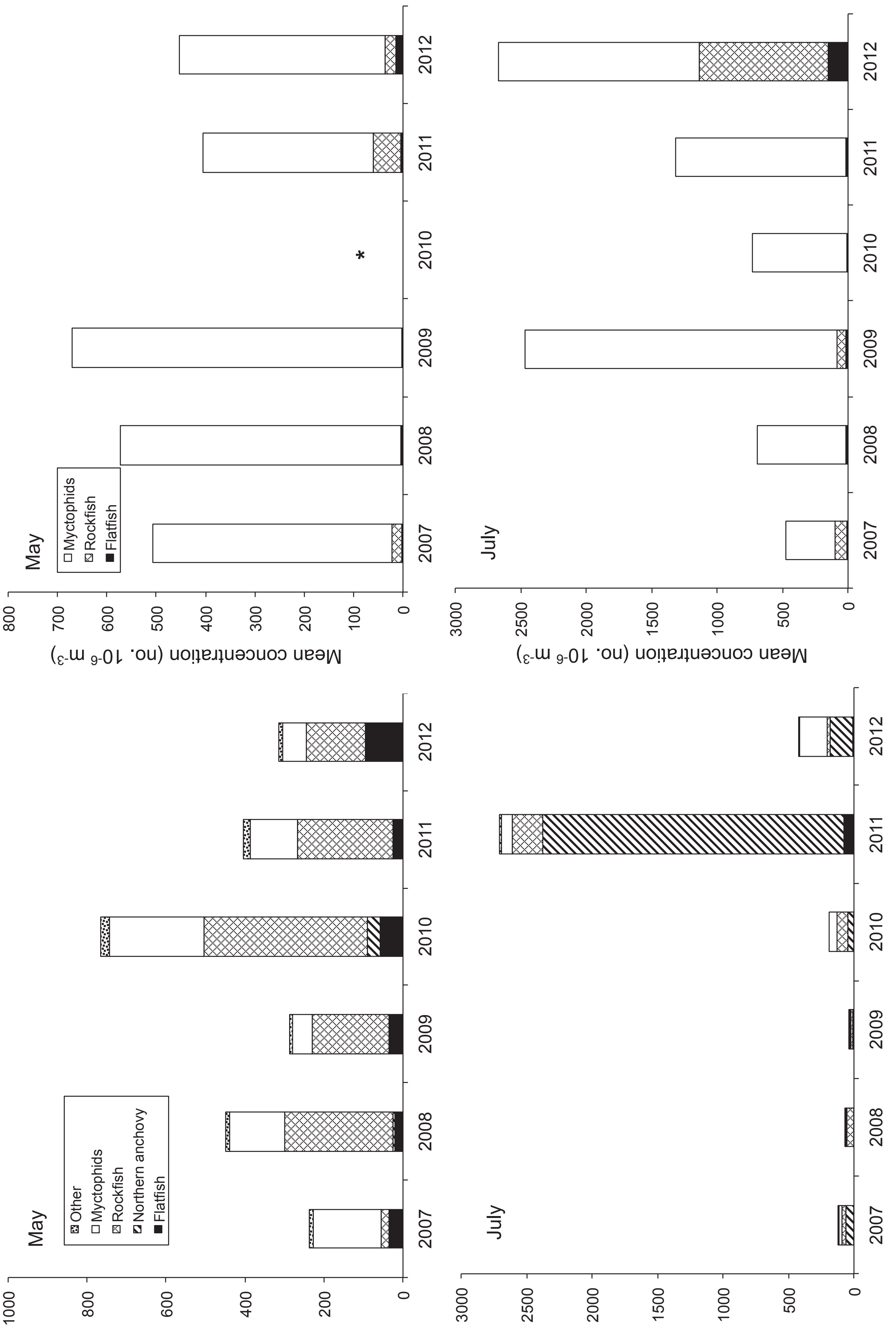

Figure 23. Mean concentrations of the dominant taxa for fish larvae (left) and juveniles (right) collected in May and July in 2007–12 along the Newport Hydrographic (NH) line off the coast of Oregon (44.65°N, 124.41–125.36°W). No midwater trawl samples were collected for juveniles in May 2010.

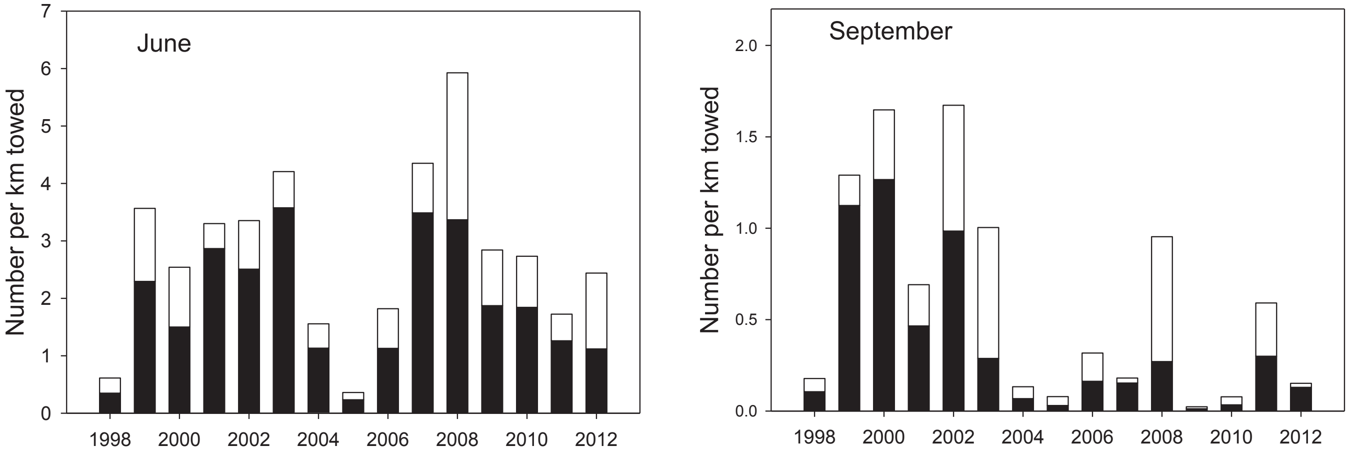

Figure 24. Catches of juvenile coho salmon (black bars) and Chinook salmon (white bars) off the coasts of Washington and Oregon.

rockfish of all species (as well as young-of-year groundfish of other species, such as Pacific hake, flatfishes, and lingcod, *Ophiodon elongates*) encountered throughout both the core and expanded survey areas. Market squid and krill were at very high levels in 2012 and 2013 as well. Although more northern anchovy were encountered in 2013 than in the previous five years, catches of both that species and of Pacific sardine remained well below long-term averages. As with the 2012 results, 2013 continued to indicate a pelagic micronekton community structure dominated by cool-water, high transport, high productivity forage species (juvenile groundfish, krill, and market squid (see Ralston et al. 2013).

Later in the summers of 2010–12 a surface trawl survey was used to characterize juvenile salmon and the micronekton from central California to Newport, Oregon. The summer of 2012 continued a period of extremely low abundance for northern anchovy, Pacific sardine, and Pacific herring. The survey caught no adult northern anchovy in 2011 or 2012 and very few in 2010; no Pacific sardine in 2012 and very few in the two years before that; and very few Pacific herring in all three years, 2010–12. Other important forage fishes such as surf smelt, *Hypomesus pretiosus*, and whitebait smelt were more abundant and were consistently taken in all three years since 2010, but these two osmerid species were primarily encountered in the northern portion of the study area. Market squid was very abundant in all three years and was encountered throughout the study area. Sub-yearling juvenile Chinook salmon (80–250 mm fork length, FL) were less abundant in the catches in 2012 than in the previous two years (fig. 26, see supplement for results concerning additional age classes). Unlike Chinook salmon, the abundance of juvenile coho salmon (100–300 mm FL) was similar in the summer of 2011 and 2012 (fig. 26). Significantly more juvenile coho salmon were caught in either of those two years than in July 2010.

Pelagic Fishes Off Southern California

The spring coastal pelagic species survey showed sardine egg densities were similar in 2012 to those measured in 2011 (methods in supplement, fig. S11). However, densities of sardine eggs and anchovy eggs were lower than those measured in most years since 1997 (fig. 27). Jack mackerel egg densities were similar to those measured during most other years in the time series. In 2013, sardine, anchovy, and jack mackerel egg densities were similar to those measured in the previous two years (fig. 28).

An examination of larval captures from the CalCOFI surveys 1951–2011 demonstrated similar trends (fig. 29). Larval Pacific sardine catches have been relatively stable over recent decades, minus low catches in 2004 and 2010. In general, larval northern anchovy were captured in greater densities than Pacific sardine before the mid-1990s. However, larval northern anchovy catches have declined substantially since the early 1980s (fig. 29). Unfortunately, data on larval catch densities beyond 2011 have not yet been enumerated.

SEABIRDS AND MAMMALS[3]

Breeding Success and Diets of Seabirds at Yaquina Head

Examination of the common murre, *Uria aalge*, diets indicates that smelts were the predominant prey available to the seabirds (fig. S12). When paired with the results from the forage observations in northern CCS, this diet composition was similar to changes in the available proportions in the forage community (fig. 22). The breeding success of common murre remained low relative to 2007–10 (fig. 30, see supplement for data methods). Observations indicate that the reduced

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[3] In addition to seabird and sea lion observations, cetacean density and abundance on the southern CalCOFI lines was quantified. Results are shown in the supplement.

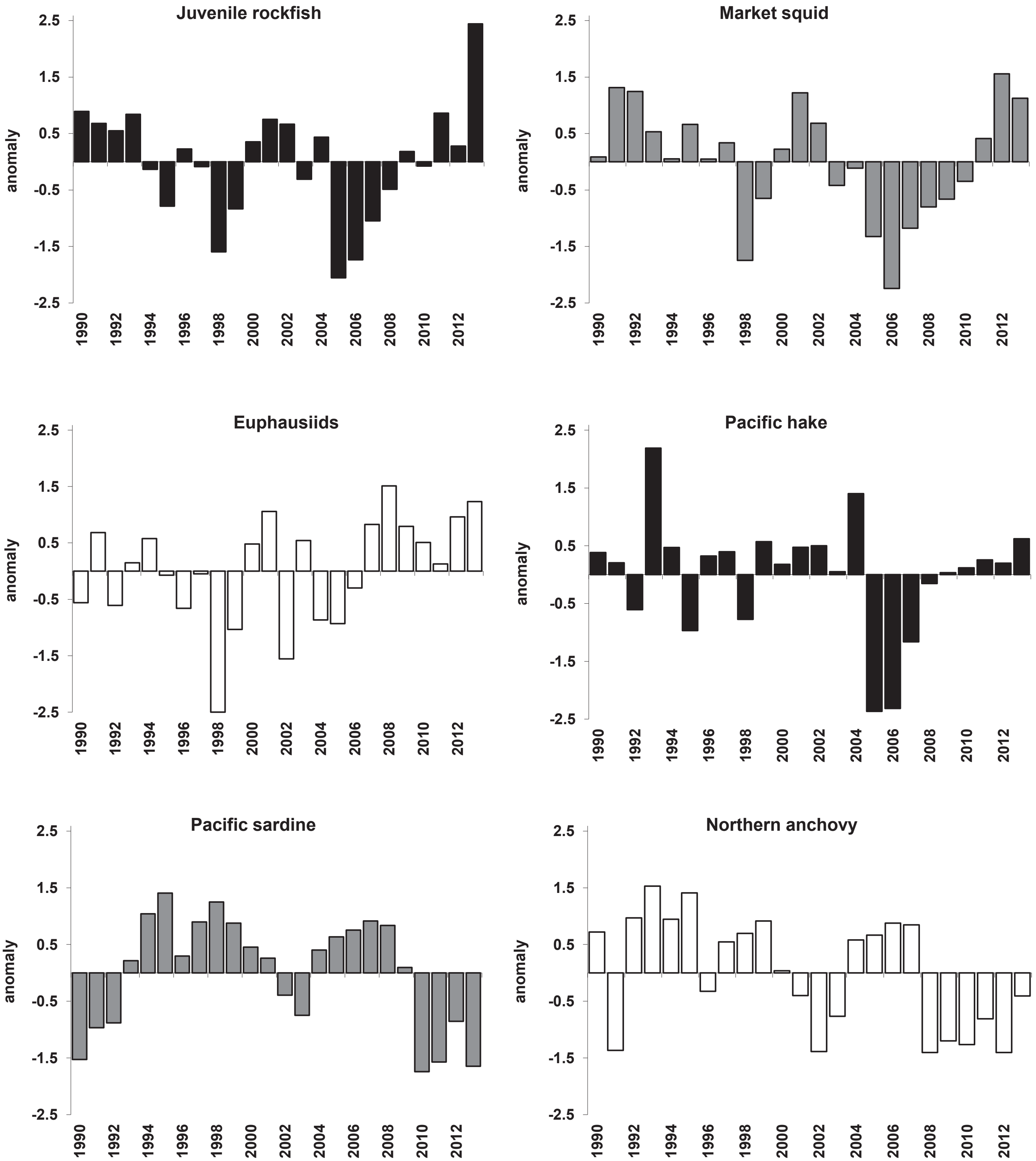

Figure 25. Long-term standardized anomalies of several of the most frequently encountered pelagic forage species from the central California rockfish recruitment survey in the core region (1990–2012).

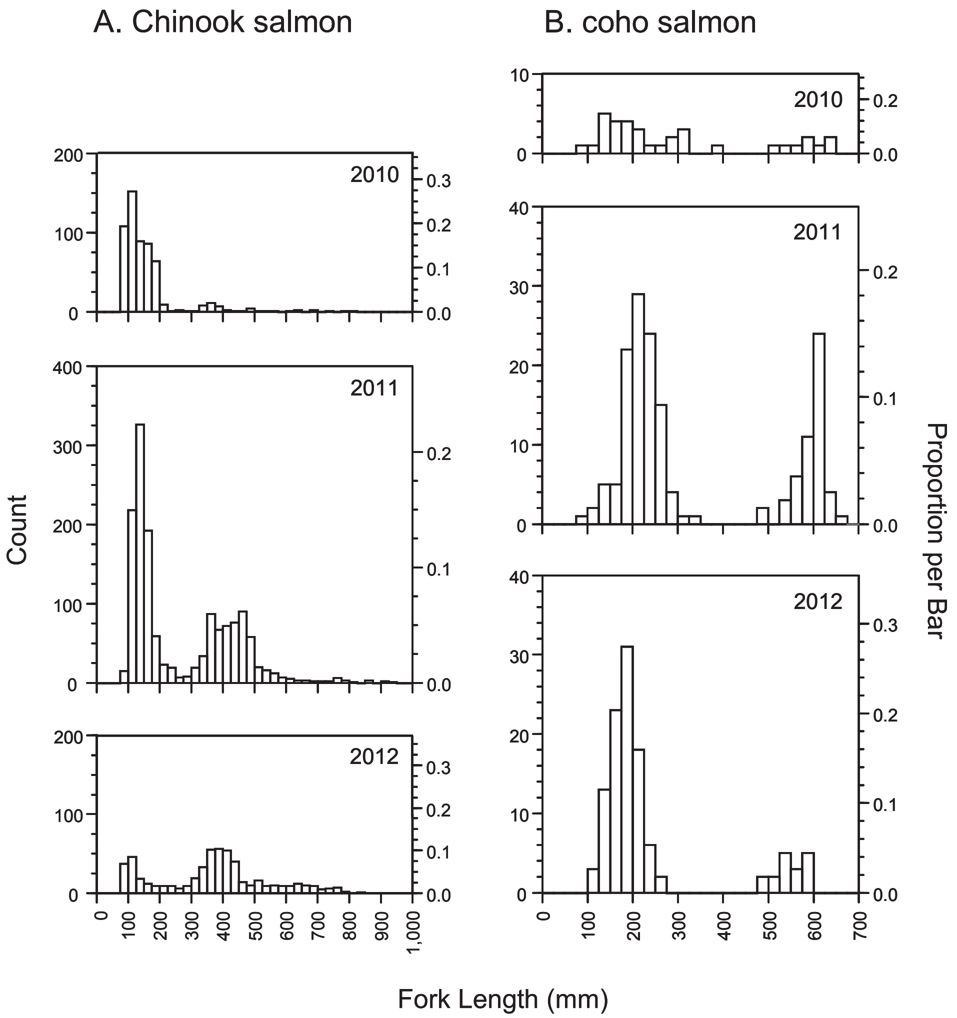

Figure 26. Size frequency distributions of (A) Chinook salmon (*Oncorhynchus tshawytscha*) and (B) coho salmon (*O. kisutch*) captured by rope trawl in the coastal ocean (~1–20 nautical miles offshore) between southern Oregon and central California in June or July of 2010, 2011, and 2012. Counts are total number (not standardized) of fish captured in each year; proportions are fraction of that total count represented by each bar for each year and species. Different scales used for columns A and B.

reproductive success was due to increased predation (e.g., eagles, pelicans, vultures).

Breeding Success of Seabirds at Southeast Farallon Islands

Overall breeding success of seabirds during the 2012 breeding season at Southeast Farallon Island can best be classified as an average year for most species. Cassin's auklets, *Ptychoramphus aleuticus*, which feed primarily on euphausiids, exhibited exceptionally high productivity for the third consecutive year (fig. 31). The average number of chicks fledged per breeding pair was the second highest on record, and reflected both exceptional fledging success and a high rate of successful double brooding. Among the piscivorus seabirds, productivity of common murres was slightly higher than that observed during 2011 while rhinoceros auklets (*Cerorhinca monocerata*) and pigeon guillemots declined to values slightly below the long-term means observed for each species. Pelagic cormorants, *Phalacrocorax pelagicus*, and Brandt's cormorants, *Phalacrocorax penicillatus*, experienced near complete breeding failure in 2012. This is the fifth consecutive year of extremely low reproductive success for Brandt's cormorants but the first breeding failure for the pelagic cormorant since 2005. Productivity of western gulls (*Larus occidentalis*) was slightly higher than during 2011, but continued to be among the poorest years on record, marking the fourth consecutive year of very low reproductive success for this species.

Breeding Success and Diets of Seabirds at Castle Rock

In 2012, the first common murre nest at Castle Rock was initiated on 15 May, between 4 and 32 days later than all other years of study. Although the average nest initiation date could not be determined due to

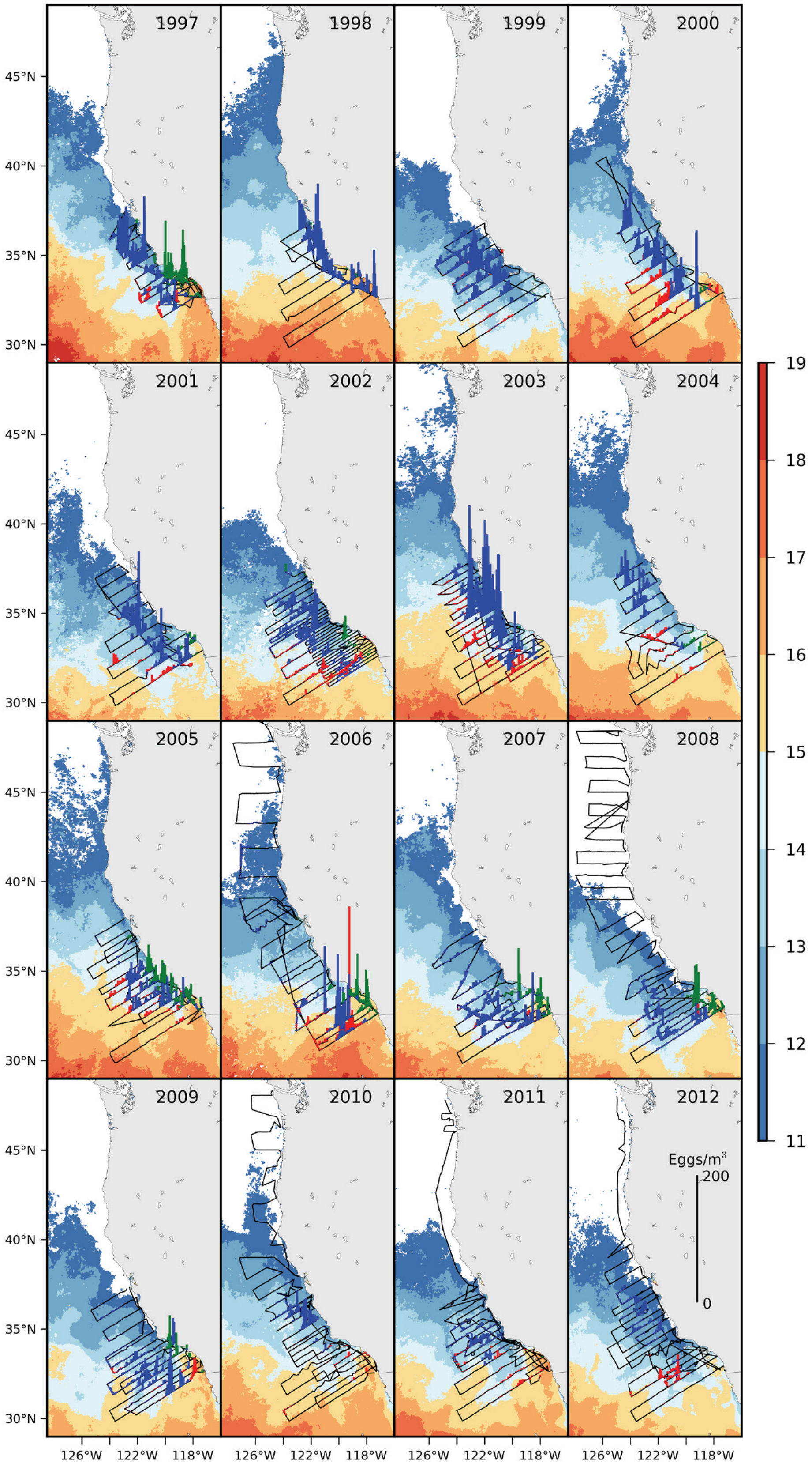

Figure 27. Densities of eggs of Pacific sardine (blue), jack mackerel (red), and northern anchovy (green) collected with the Continuous Underway Fish Egg Sampler (CUFES) along the ship track (black lines) during NOAA spring cruises for 1997 to 2012. The underlying color image shows a monthly composite of satellite AVHRR 1.4 km resolution sea surface temperature (°C) image coincident with the survey period in each year.

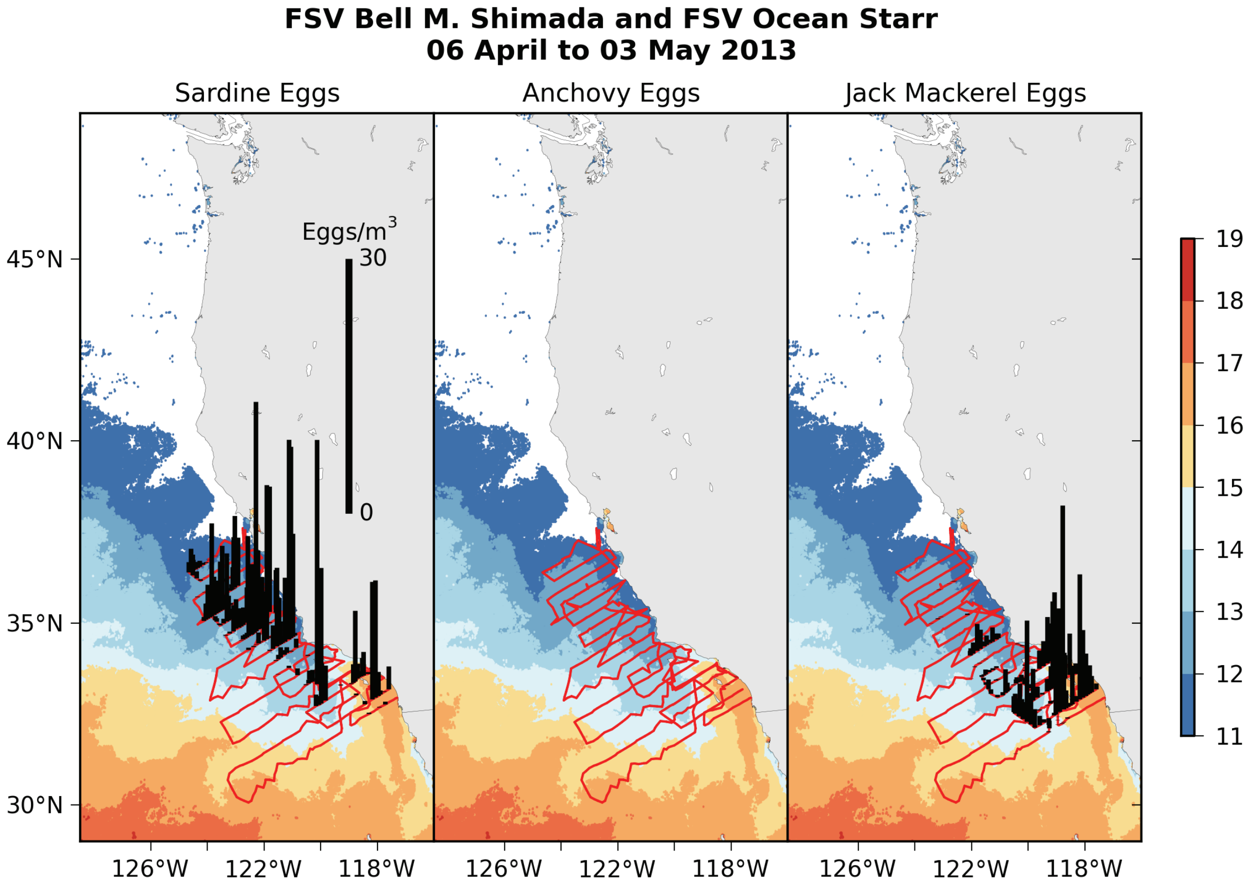

Figure 28. Densities of eggs of Pacific sardine, jack mackerel, and northern anchovy collected with the Continuous Underway Fish Egg Sampler (CUFES) along the ship tracks (red lines) during NOAA coast-wide cruises conducted in spring 2013. The underlying color image shows a monthly composite of satellite AVHRR 1.4 km resolution sea surface temperature (°C) image coincident with the survey period in each year.

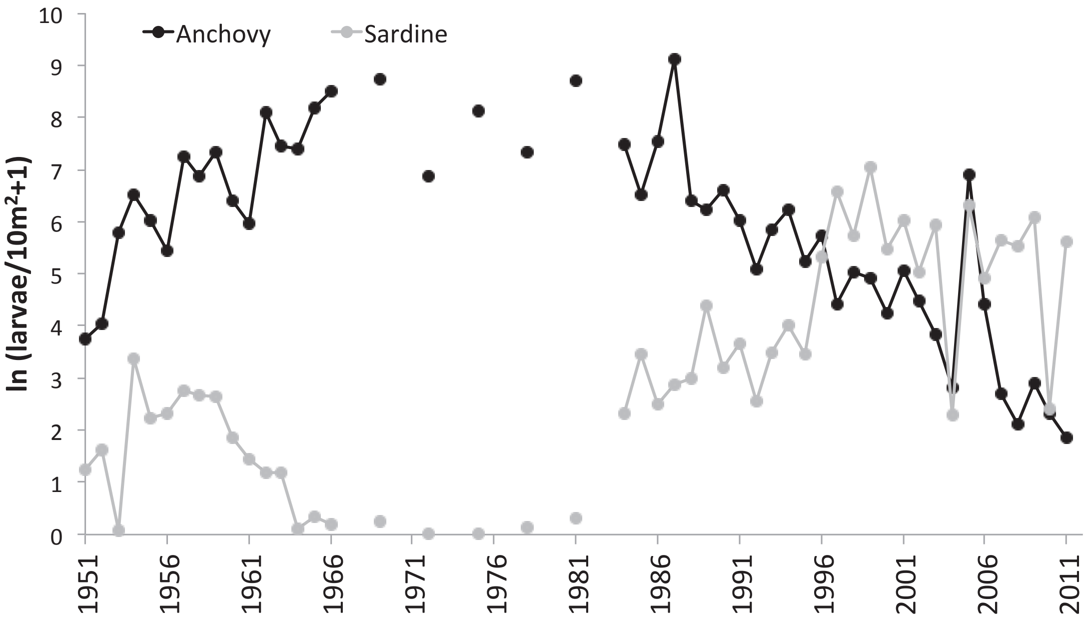

Figure 29. Abundance (ln (number /10 m^2+1)) of northern anchovy and Pacific sardines captured in oblique tows (bongo net) during spring CalCOFI surveys 1951–2011.

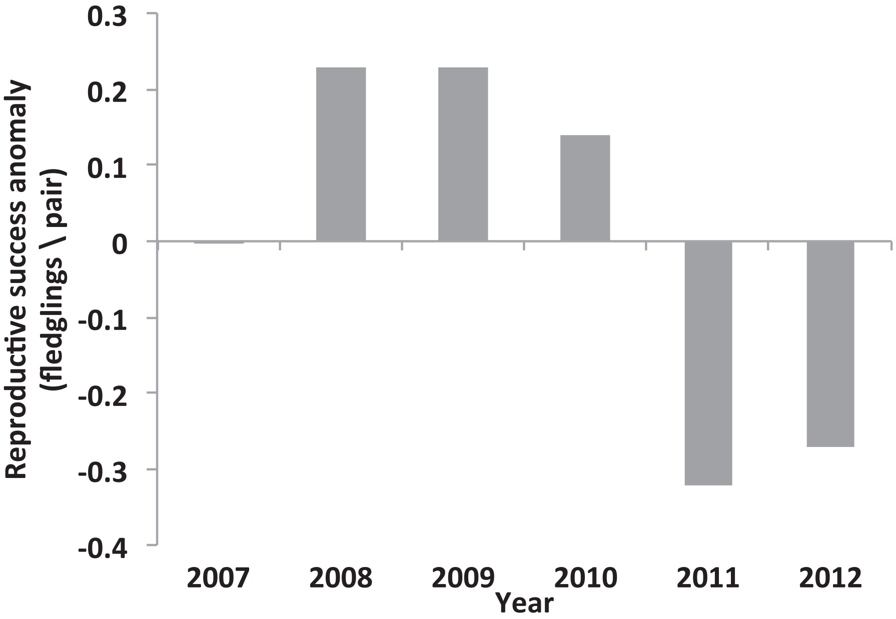

Figure 30. Anomalies of reproductive success (fledglings per breeding pair) of common murre at Yaquina Head.

uncertainties resulting from equipment failure, we concluded that nesting began later than usual in 2012 (see supplement for data collection and additional results, fig. S13).

For Brandt's cormorants, efforts to monitor nest phenology and success began in 2011 and baseline understanding of their reproductive performance is still being developed. Based on nests initiated prior to camera failure in 2012, 71% of first clutches (n = 13) failed during incubation. The failure rate for first clutches was similarly high in 2011, with 68% of first clutches failing during incubation.

At-sea Density of Seabirds off Southern California

Patterns of variability are illustrated in the relative abundance of two species, the sooty shearwater, *Puffinus griseus*, and Cassin's auklet expressed as natural log of density sighted (ln [birds km^{-2} + 1], see supplement for methods). Both species prey upon euphausiid crustaceans, small pelagic fish, and squid. In 2012, there was nothing unusual in the relative abundance of auklets in any season (fig. 32).

In contrast to the resident auklets, shearwaters were most abundant in the study region during the summer (July–August), with lower relative abundance in spring (April–May). During both seasons in 2012, the relative abundance of shearwaters declined (fig. 32). In 2012, numbers were substantially reduced from a recent peak in both spring and summer in 2010. Changes in shearwater abundance may be related to short or long-term changes in food availability. Alternatively, population decreases elsewhere could be affecting our counts; this may be the result of shearwaters declining on some New Zealand islands (Scott et al. 2008).

Productivity and Condition of California Sea Lions at San Miguel Island

California sea lions (*Zalophus californianus*) are permanent residents of the CCS, breeding on the California Channel Islands and feeding throughout the CCS in coastal and offshore habitats. They are also sensitive to changes in the CCS on different temporal and spatial scales and so provide a good indicator species for the status of the CCS at the upper trophic level (Melin et al. 2012). Two indices are particularly sensitive measures of prey availability to California sea lions, pup production, and pup growth through four months of age. Pup production is a result of successful pregnancies and is an indicator of prey availability and nutritional status of adult females from October to the following June. Pup growth from birth to four months of age is an index of the transfer of energy from the mother to the pup through lactation between June and October, which is related to prey availability to adult females during that time and to survival of pups after weaning. The average number of live pups counted at San Miguel Island in July 2012 was 24,993 (fig. 33). The high live pup count in 2012 suggests that pregnant females experienced good foraging conditions from October 2011 to July 2012.

However, the pup growth index for California sea lions at San Miguel Island indicated that dependent pups were in poor condition by the time they reached four months of age. In October 2012, the average predicted

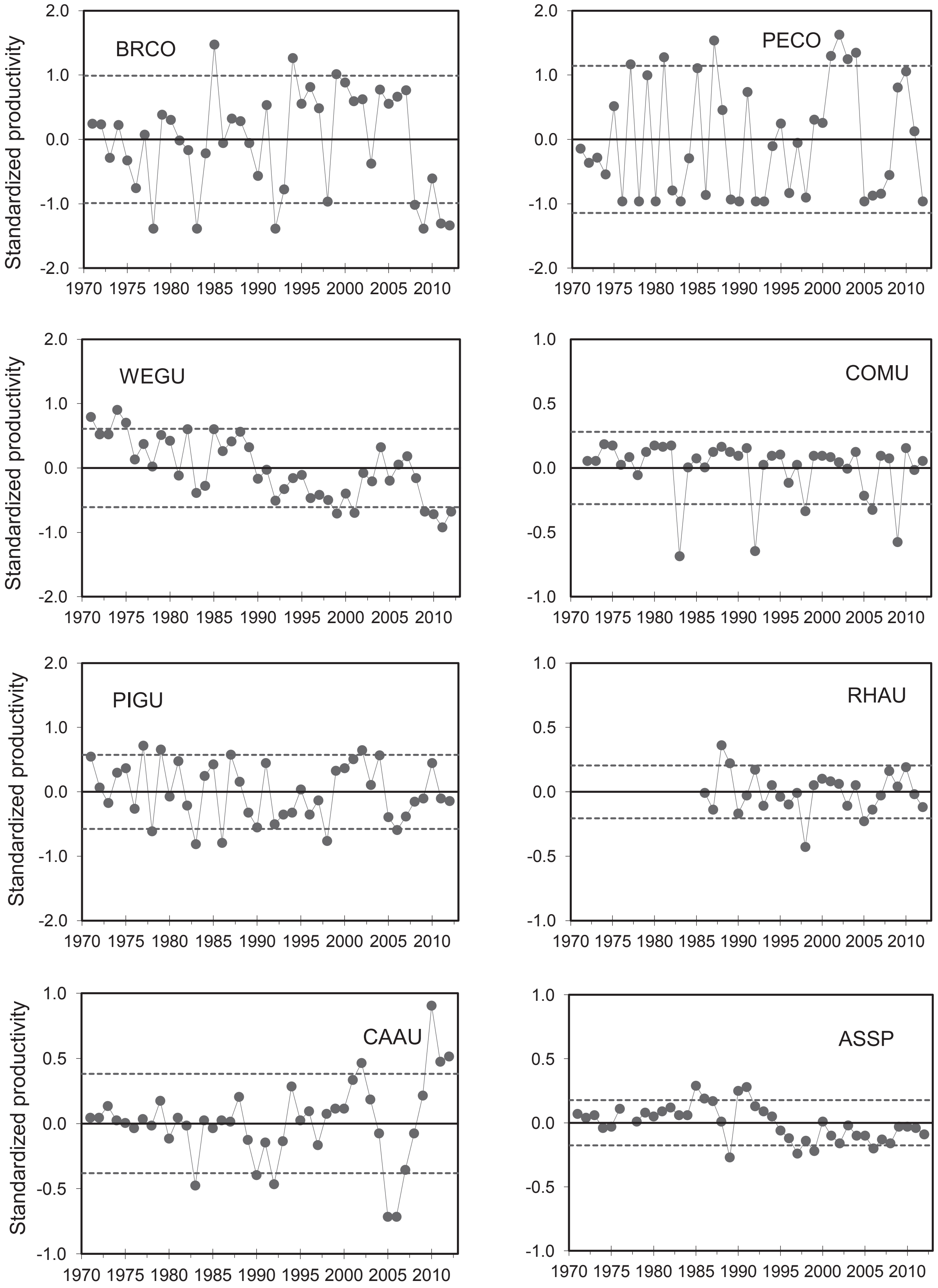

Figure 31. Standardized productivity anomalies (annual production–long term mean) for 8 species of seabirds on Southeast Farallon Island, 1971–2012. The dashed lines represent the 80% confidence interval for the long-term mean. Abbreviations are used fro Brandt's cormorant (BRCO), pelagic cormorant (PECO), western gull (WEGU), common murre (COMU), pigeon guillemot (PIGU), rhinoceros auklet (RHAU), Cassin's auklet (CAAU), and storm petrel (ASSP).

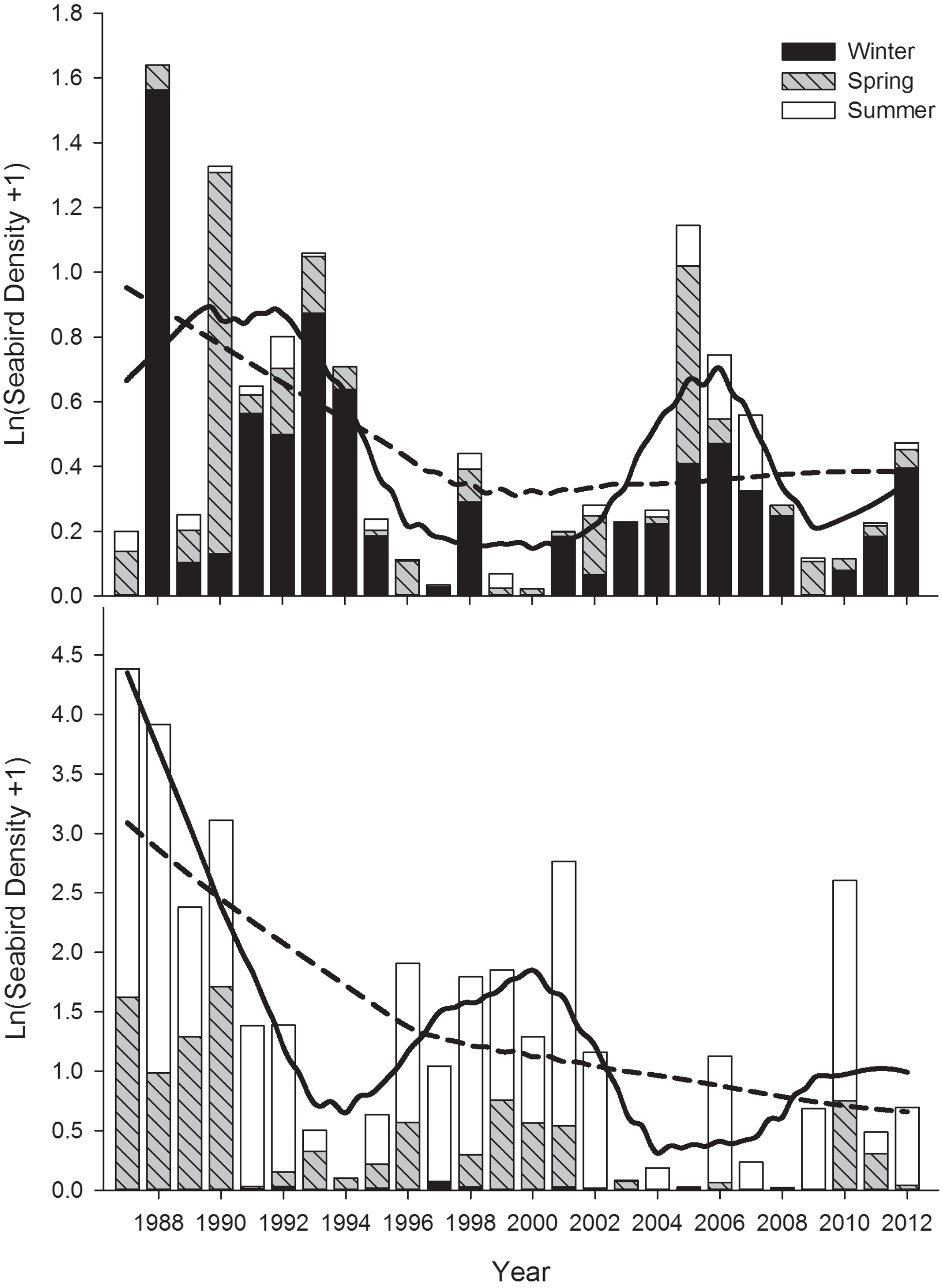

Figure 32. Changes in resident Cassin's auklet (upper panel) and migratory Sooty Shearwater (lower panel) relative abundance (natural log of birds km^{-2}) on 90 CalCOFI/CCE-LTER surveys, May 1987–July 2012. Stacked bars denote seasonal density estimates, with 2 Locally Weighted Regression (LOWESS) smoothing lines on summed annual estimates shown to illustrate short-term (bandwidth = 0.3, solid) and long-term (bandwidth = 0.8, dashed) variability.

weights of four-month-old female (13.0 kg, SE = 0.14) and male (14.5 kg, SE = 0.20) pups were significantly lower compared to the long-term mean for female and male pups (females, mean = 17.4 kg, SE = 0.35; males, mean = 20.2 kg, SE = 0.43) (fig. 34). Average October weights of California sea lion pups have been declining since 2008 but the mean weights for the 2012 cohort were significantly lower than the previous four years. By February 2013, at 7 months of age, pups remained significantly underweight (females, mean = 13.6 kg, SE = 0.55; males, mean = 16.2 kg, SE = 0.69) (fig. 34); an estimated 12 kg and 14.4 kg below the long-term average for females and males, respectively. A longitudinal analysis of pup daily growth rates of branded pups between four and seven months of age showed significantly lower daily growth rates compared to other years for female and male pups (fig. 34). In both October and February, the mean weights for the 2012 cohort were similar to

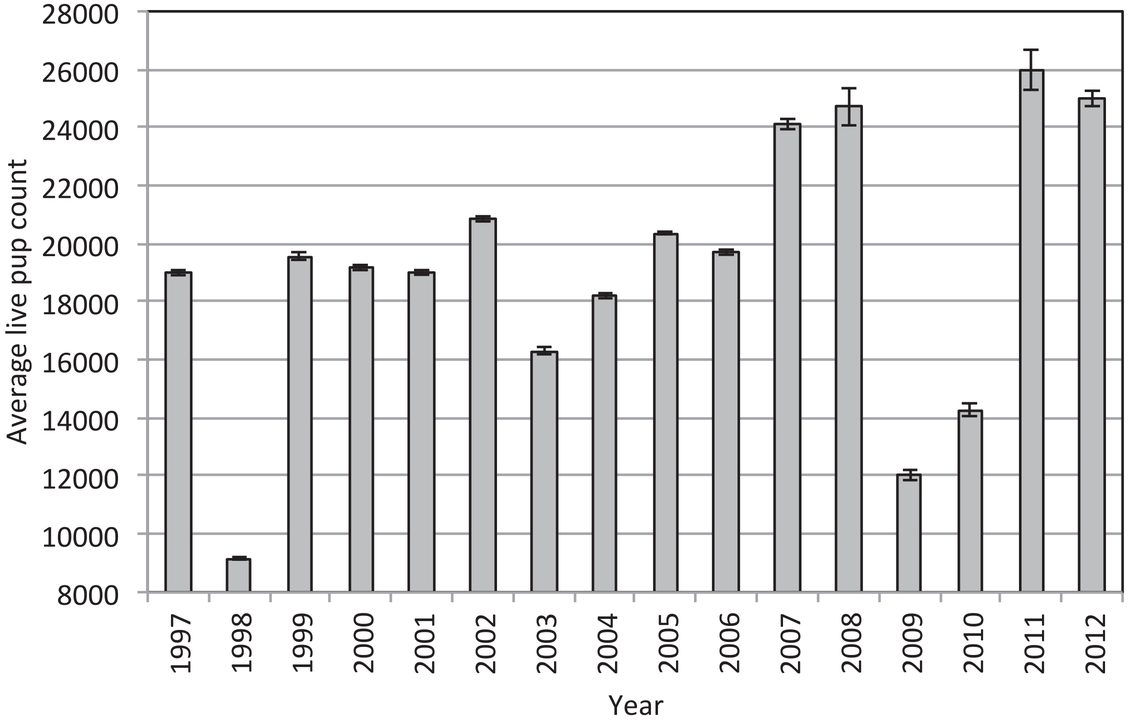

Figure 33. The average number of live California sea lion pups counted at San Miguel Island, California, 1997–2012 in late July when surviving pups were about 6 weeks old. Error bars are ±1 standard deviation.

the 1997 cohort, as were the daily growth rates between October and February. The 1997 cohort was impacted by a strong El Niño event that prevailed in the California Current between May 1997 and May 1998. The oceanographic conditions associated with the El Niño resulted in poor foraging conditions by reducing prey availability for lactating California sea lion females and consequently, their dependent pups were in poor condition (Melin et al. 2012; Melin et al. 2010).

In addition to poor condition of pups on the rookery at San Miguel Island, high numbers of emaciated pups began stranding on southern California beaches in January 2013, indicating that pups were weaning up to three months earlier than normal. High levels of strandings continued into April with three times the normal level of strandings during the four-month period (http://www.nmfs.noaa.gov/pr/health/mmume/californiasealions2013.htm). Although early weaning of pups and emaciated pups at the rookeries could be due to high mortality of adult females, there was no increase in strandings of lactating females during this period and emaciated pups were observed suckling robust females, suggesting that the cause for the poor condition of the pups was not related to mortality of their mothers. In response to the poor condition of pups at the rookeries and the high level of strandings, the National Marine Fisheries Service declared an Unusual Mortality Event of California sea lion pups on March 25, 2013. Two lines of investigation were initiated to explain the Unusual Mortality Event, one focusing on disease in pups or their mothers and the other on a shortage of food available to lactating females (see supplement for comment).

DISCUSSION

In 2012 the basin-scale indices and conditions from regional surveys indicate that oceanographic characteristics of the CCS were similar to recent cool years. The PDO signaled a continued pattern of cool SST and the NPGO was consistent with strong southward transport (fig. 2). The MEI demonstrated a short-lived switch to positive values in the summer of 2012, but was not sufficiently strong to elicit a response in CCS SST. During winter of 2011/2012, upwelling in the northern CCS was substantial, especially north of 39°N (fig. 3). However, in the north, upwelling winds weakened in midwinter and remained weak until resuming to near-average values in May. In the south, upwelling remained strong. Regional hydrographic studies also demonstrated that conditions were not too dissimilar from conditions observed since 2007 for SST or salinity (figs. 7, 10, 12, 13, and 15).

Winter of 2011/2012 presented an uncharacteristic upwelling period and strong southward transport leading into 2012. Between 36°N and 45°N, the winds in December 2011 were unusual because the expected downwelling-producing winds were replaced by moderate upwelling-producing winds, while north of 45°N downwelling winds weakened (fig. 3). The upwelling and weakened downwelling winds resulted in coastal sea levels that suggested transport was more southward than had been observed in the past 45 Decembers (fig. 4). This southward transport was corroborated by HF radar showing anomalous equatorward surface velocities north of Cape Blanco in December 2011 (fig. 5). Consistent with increased southward transport, the northern copepod index calculated for the Newport Hydrographic Line had the largest ever values of northern copepod species during winter 2011/2012 (fig. 9). Interestingly, there was not a similar increase in northern copepods at Trinidad Head, however, an examination of HF radar (fig. 5) suggests that the surface source waters at Trinidad Head during winter 2011 may have been derived from immediately south of Cape Mendocino.

We acknowledge there are limitations and differences between survey designs represented here, but from our available observations, a CCS-wide pattern emerged with reduction of two primary forage fishes, namely northern anchovy and Pacific sardine (as well as Pacific herring where sampled in central and northern California). The abundances of these species along the CCS were near record minima in surveys. In the CalCOFI survey region, egg densities for both northern anchovy and Pacific sardine were low indicating a possible reduction in the spawning stock and/or the spawning stock resided outside the study region (figs. 27 and 28). Similarly, these fishes were caught in reduced numbers in central and northern California (figs. 22 and 25).

Lower observed abundance in northern anchovy in 2012 may have been an extension of a declining trend. Catches of larval anchovy in the southern California waters have declined over the last three decades with the lowest densities recorded in the recent five years ending in 2011 (fig. 29). This pattern indicates either a reduction in spawning stock biomass, early survival, or increased advection from the region (Bakun and Parrish 1982). What made 2012 particularly intriguing relative to forage, was not only that northern anchovy abundance was reduced across the CCS but that Pacific sardine and Pacific herring were at low abundances as well. That 2012 saw a reduction in the clupeiform forage community along the coast suggests that common factors could

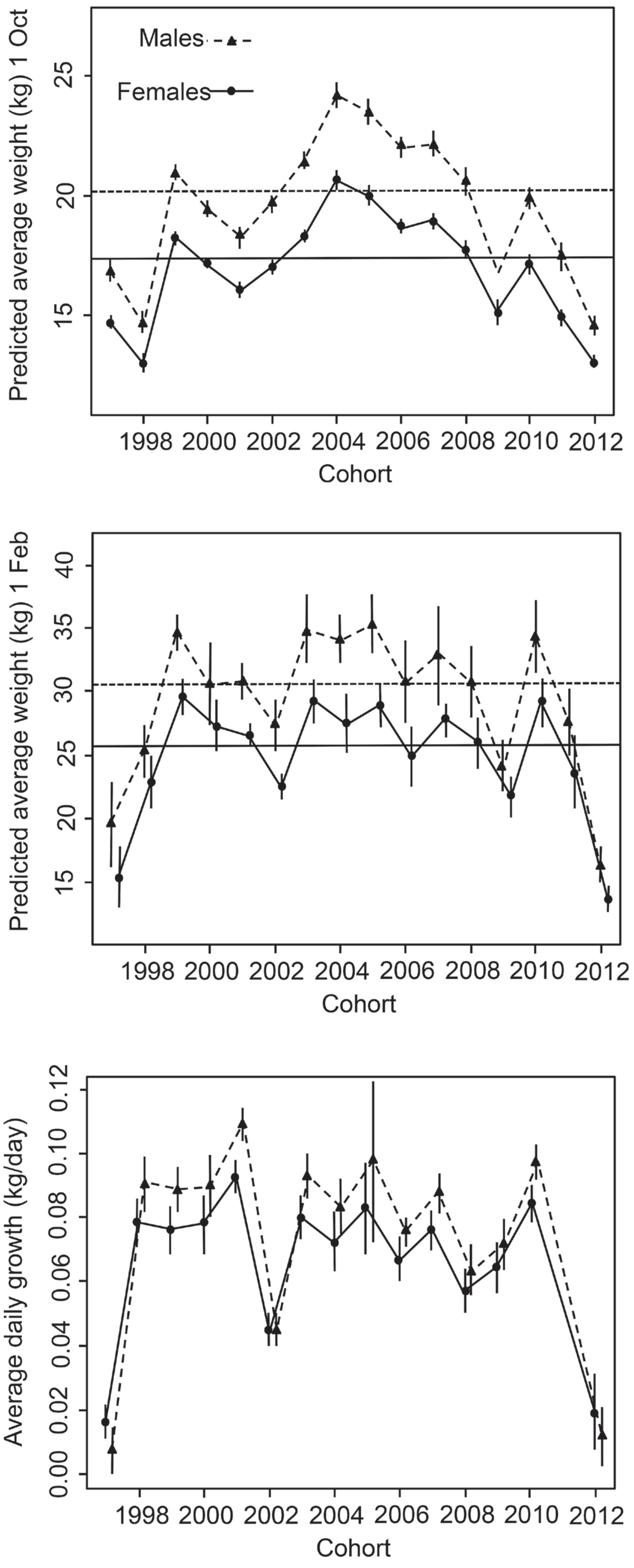

Figure 34. Top panel: Predicted average weights of 4 month old female (circle) and male (triangle) California sea lion pups at San Miguel Island, California, 1997–2012 and long-term average between 1975 and 2012 for females (solid line) and males (dashed line). Error bars are ±1 standard error. Middle panel: Predicted average weights of 7 month old female (circle) and male (triangle) California sea lion pups at San Miguel Island, California, 1997–2012 and long-term average between 1975 and 2012 for females (solid line) and males (dashed line). Error bars are ±1 standard error. Bottom panel: Predicted average daily growth rate of female (circle) and male (triangle) California sea lion pups between 4 and 7 months old at San Miguel Island, California, 1997–2012. Error bars are ±1 standard error.

have led to or exacerbated the reduction in all species, although the data here may be limited for addressing the specific causes.

Strong, early onset of upwelling in the southern CCS region in 2012 had the potential to have distributed forage fishes farther offshore and make them less accessible to the surveys and, possibly, predators (Bakun and Parrish 1982). In fact, at 33°N the cumulative upwelling during the beginning of 2012 was greater than most values on record (fig. S2). However the winds in this southern region relaxed to near climatological means by early spring 2012 (fig. 3). By the time of the 2012 survey, Pacific sardine eggs were distributed in an area narrower than that of 2011, concentrated primarily between CalCOFI line 60–76.7 and reduced numbers were observed between CalCOFI line 85–90 (fig. 27) (Lo et al. 2013). This distribution suggests that fish spawned nearshore, or those offshore did not spawn, or the relaxation of upwelling moved eggs inshore, or something else affected pelagic egg production that is yet to be fully quantified. By contrast, in the north, to where northern anchovy and Pacific sardine migrate, the upwelling winds were more modest and there was not anomalously high offshore advection, therefore, advection would not likely be a primary cause for the reduction in their abundance in those regions (fig. 3). Coming into 2013, a winter and spring of exceptional winds coast-wide, Pacific sardines, northern anchovy, and jack mackerel egg densities in southern California were similar to the previous two years (fig. 28). However, young-of-the-year northern anchovies had increased to near average abundance in the more northern surveys.

Those fishes whose abundance is reliant more on local (typically onshelf) conditions of production (Emmett et al. 2006; Santora et al. 2012) also displayed a CCS-wide signal; in all regions they exhibited improved production/abundance in 2012. For instance, in central California, a micronekton assemblage of rockfish, market squid, euphuasiids (fig. 25), lingcod (not shown), flatfishes (not shown), and octopi (not shown) continued a recent trend of improved production, consistent with increased local upwelling and productive shelf conditions. Similarly, whitebait smelt abundance (Emmett et al. 2006) was at average levels in the north in contrast to the low abundances of northern anchovy and clupeids. It followed that smelt, which sustained an average abundance (fig. 22), comprised a greater proportion of the diets for seabirds located at Yaquina Head than other prey (fig. S12).

The reductions of Pacific sardine and northern anchovy and the improved production of the forage reliant on shelf productivity may point to variability in the quality of the shelf and off-shelf habitats. Namely, over much of the range of northern anchovy, the fish feed, and may even spawn, at and beyond the shelf break (Kramer and Ahlstrom 1968; Smith 1972). In part, the northern anchovy may be held offshore by advection (Bakun and Parrish 1982). This is clear in the central California region where, even during the cool, productive conditions that benefit northern anchovy production (Lindegren et al. 2013), the northern anchovy are not abundant in the survey region (fig. 1). It is only when upwelling subsides, or during relatively unproductive years associated with reduced winds, that northern anchovy become increasingly available to the trawls and the inshore environment. Pacific sardine, as well, reside more offshore at or beyond the shelf break (Kramer 1970). By contrast, the fishes reliant on productive, cool waters inshore have had improved production recently. These fishes, such as rockfish, market squid, lingcod, and others, reside largely in the productive cool nearshore waters during upwelling periods.

While unsubstantiated in the CCS, there is a potential that dense salp concentrations in central and southern California (but not so far south as Baja California) during 2012 could have exacerbated the recent patterns in the forage community (Lavaniegos and Ohman 2003; Loeb et al. 1997). Specifically, research should be considered to examine the negative impacts of massive blooms on feeding rates, growth, reproduction, and survival of fishes in the CCS. The impacts of herbivorous, filter-feeding salps on primary production and food web dynamics can be striking (Alldredge and Madin 1982; Andersen 1998; Madin et al. 2006). These animals are characterized by fast growth rates, short generation times, relatively large body sizes, and very high filtering rates. Their life histories allow them to exist with minimal reproduction during periods of low food supply but also permit rapid, exponential population increases to take immediate advantage of elevated food concentrations. These characteristics underlie episodic population explosions during which time salps can quickly and efficiently remove particulates from large volumes of seawater thereby negatively impacting other herbivores (Alldredge and Madin 1982; Andersen 1998; Madin et al. 2006).

High concentrations of salps occurred in the northern CCS in 2010 and 2011 (fig. 18) and subsequently were anomalously abundant off central and southern California in 2012 (fig. 19), suggesting a spatial-temporal delay in their distribution from north to south. This delay may be due to the advection of seed stocks into, and explosive population growth within, waters offering appropriate conditions. In southern California, there was an increase in the volume of larger zooplankton (mostly salps and pyrosomes) early in 2012 that was about twice as large as values observed in 2011 and larger than any value seen in 20 years (fig. 21). In fact, local abundances were so great that by April 2012 the salps interfered with the coolant system of the Diablo Canyon power plant in south-central California, leading to a shutdown (http://articles.latimes.com/2012/apr/26/local/la-me-0426-jellyfish-nukes-20120426).

Anomalously strong southward transport from northern CCS during December 2011 (figs. 3, 4, and 5) potentially advected abundant seed populations of salps and pyrosomes produced in northern CCS waters during 2010 and 2011, into central and southern California waters as has been demonstrated by Roesler and Chelton 1987. The upwelling event of December 2011 following a downwelling period suggests that any seed populations of salps could have been nearshore when the winds switched, making them particularly vulnerable to southward transport. Once further south, they encountered appropriate primary productivity levels promoting further population increases followed by a reduction in the phytoplankton biomass in the region due to grazing pressure. The regional studies in central and northern California, as well as the remote sensing of the CCS, demonstrated just such a pattern (figs. 6, 10, and 12). In spring of 2011 chlorophyll values in the northern CCS were, indeed, anomalously low but were greater in 2012 (fig. 6). In contrast, central and southern California chlorophyll values were average to above average in spring 2011 but for the most part anomalously low in 2012. The exception in 2012 was a positive anomaly offshore south of Point Conception, near central gyre waters (fig. 6).

Where observed off central California, salps were predominantly at offshore stations (fig. 20; note the log scale). The central California salmon survey, occurring just a month later than the rockfish survey, did not encounter anything so pronounced due to its predominantly inshore stations (fig. 20). Closer inspection of chlorophyll distribution patterns in the spring (fig. 6) suggests higher than typical primary production on the shelf in the Gulf of the Farallones region vitally important to production off central California. By contrast, just south of the Gulf of the Farallones over the Monterey Canyon region, where salps were very abundant (fig. 20), surface chlorophyll values were the lowest on record by June (fig. 12). Off southern California the onshore presence of dense salp aggregations, such as those that shut down the Diablo Canyon nuclear power plant, could have had an impact on coastal ecosystems.

The population dynamics and foraging ecology of seabirds are closely related to ocean conditions and forage abundance, distribution, and composition within the California Current (Ainley and Hyrenbach 2010; Ainley et al. 1995; Santora et al. 2011; Veit et al. 1996). In 2012, seabirds on Southeast Farallon Island had generally average production (few species indicators fell outside of 1 s.d.). However, Cassin's auklet and Brandt's cormorant were notable in the degree to which they had good and poor reproductive success, respectively. These differences may relate to changes in the forage community. Cassin's auklet, who rely on more onshelf (nearer to nesting sites) prey such as *T. spinifera* (Sydeman et al. 2001; Sydeman et al. 1997), had exceptional reproductive success (fig. 31); consider as well the reproductive failures of 2005 and 2006 were associated with reduced prey availability on the shelf. In 2012, Cassin's auklet in southern California also did not demonstrate substantial changes to their foraging behavior that would be indicative of a drastic reduction or redistribution in their forage (fig. 32). Brandt's cormorant rely, in part, on northern anchovy in the neritic environment (Sydeman et al. 1997) and, therefore, reduced availability in northern anchovy inshore is a likely cause of their poor reproductive success.

In the northern CCS at Yaquina Head, common murre did experience reduced fledgling success in contrast to that at Southeast Farallon Island, but this reduction was likely the result of predators at the colony (e.g., brown pelicans, *Pelecanus occidentalis*, and bald eagles, *Haliaeetus leucocephalus*) (fig. 30). The top-down impacts of seabird predators may be related to bottom-up processes affecting prey availability (Hipfner et al. 2012). For example, in 2012 brown pelicans caused dramatic common murre chick mortality at Yaquina Head, more than any previous year recorded. Pelicans were observed grabbing common murre chicks on the colony and consuming some directly, but shaking others until the chicks regurgitated fish, then the pelicans consumed the regurgitated fish. Northern anchovy and Pacific sardine are dominant prey items for pelicans and, with their regional abundance greatly reduced in 2012, the pelicans may have been desperate for alternative prey (Horton and Suryan 2012).

Consistent with a coast-wide change in the forage community was the poor condition and mortality event of California sea lion pups from San Miguel Island. It is suspected that this event was brought on by the inability of mothers to provide sufficient nourishment to their dependent pups through lactation (fig. 34). The population response was very similar to that observed during strong El Niño events when the availability of sea lion prey is diminished in the CCS, and the unusual mortality event in 2012 may be related to the reduced availability of forage fish during 2012. The unusual mortality event is currently under investigation and both forage community dynamics and disease are being considered (see supplement).

Interestingly, the estimated abundances of another predator, juvenile Chinook salmon, in California did not show a pattern of abundance easily attributable to the observed changes in the forage community, as did seabirds and sea lions. This was surprising, as it would be expected that juvenile Chinook salmon, reliant on forage on the shelf (Daly et al. 2009; Wells et al. 2012), would have been universally successful in 2012. Rather, catches of juvenile Chinook salmon in California were observed at lower abundance than the previous two years of the survey. However, what was a reduction in observed abundance of salmon in the California in 2012 may not have been great if a longer time series (more than the current 2010–13) had been available for comparison with the 2012 survey. Consistent with the possibility that 2012 was not as poor a year for California Chinook salmon as the three-year survey may suggest, juvenile Chinook salmon were abundant in the northern CCS during June off Washington and Oregon.

With 2013 came an exceptionally strong winter and spring upwelling period (fig. 3) that acted predictably on the regional hydrography; salinities were greater and surface temperatures lower (figs. 7, 10, and 12). Biological data, for the most part, has yet to be processed, therefore, the biological signal will be discussed in greater detail in the next year's report. However, the May–June juvenile rockfish survey did report record numbers of young-of-the-year pelagic rockfish, and high abundances of many other micronekton forage species as well (other juvenile groundfish, krill, and market squid). While beyond the defined time period of this report, it is also worth noting that by the end of summer and early fall, upwelling relaxed dramatically and, with the associated reduction in advection, anchovy abundance was observed to be very high nearshore in central California leading to impressive feeding aggregations of marine mammals and seabirds (see http://www.santacruzsentinel.com/santacruz/ci_24091445/whale-time-anchovies-bring-record-numbers-humpbacks).

The coming year will offer an opportunity to evaluate the coast-wide effects of strong winds early in the year on the system. Specifically, following on the findings of previous work (e.g., Bakun and Parrish 1982; Cury and Roy 1989; Mackenzie and Leggett 1991; Piatt and Springer 2003) we may observe changes indicative of poor production for a number of the indicators we examine in this report. Namely, increased diffusion of nutrients and phytoplankton away form the coast (i.e., reduced coastal front development due to turbulence) may be noted, forage composition and distribution may be altered, and there may be reductions in seabird production brought on by changes in the seascape. However, 1999 also represented a strong upwelling year and, from that, rockfish, salmon, and seabirds, as well as other taxa, were very productive along much of the CCS. Obviously these species did not experience the hypothesized negative effects of too much upwelling.

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