STATE OF THE CALIFORNIA CURRENT 2011–2012:
ECOSYSTEMS RESPOND TO LOCAL FORCING AS LA NIÑA WAVERS AND WANES

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ABSTRACT

The state of the California Current System (CCS) since spring 2011 has evolved in response to dissipation of La Niña through spring and summer, resurgence of cooler La Niña conditions in fall and winter, and finally a transition towards ENSO-neutral conditions in spring 2012. The resurgence of La Niña was uneven, however, as indicated by variable responses in broad climate indices such as the Pacific Decadal Oscillation and the multivariate ENSO index, and by latitudinal variability in the timing, strength, and duration of upwelling relative to climatological means. Across the CCS, various measures of ecosystem productivity exhibited a general decline in 2011 relative to 2010, but the magnitude of these declines varied substantially among taxa. Available observations indicate regional variability in climate forcing and ecosystem responses throughout the CCS, continuing a pattern that has emerged with increasing clarity over the past several years. In 2011–12, regional variability was again a consequence of southern regions exhibiting a relatively mild response to climate forcing, in this case tending towards climatological means, while northern regions showed somewhat greater effects of delayed or weaker-than-normal upwelling. In addition to the

effects of local and basin-scale forcing, long-term observations off southern California show declines in dissolved oxygen and increases in nutrient concentrations in waters below the mixed layer, trends that are consistent with recent predictions of how global warming will affect the characteristics of upwelling source waters in the CCS. Such trends must be accounted for more comprehensively in ongoing assessment of the state of the California Current and its responses to environmental forcing. At the time of writing, tropical conditions are ENSO neutral and forecast to transition into El Niño in late 2012. This, combined with unusually high abundances of diverse gelatinous taxa throughout much of the CCS during spring 2012, suggests that the ongoing evolution of the state of the California Current might take a particularly unusual path in the coming year.

INTRODUCTION

This report reviews oceanographic conditions and ecosystem responses in the California Current System (CCS) from spring 2011 through spring 2012 in the context of preceding years' observations. This review is based on observations collected and analyzed by a diverse range of government, academic, and private research programs and submitted in response to an open solicitation for contributions. Following the tradition of previous reports in this series, the purpose of this report on the state of the California Current is to serve as a forum for rapid presentation and preliminary synthesis of environmental and ecosystem observations. Our focus is on reviewing recent observations in the context of historical patterns as a means of identifying changes in the state of the CCS ostensibly related to changing climatic conditions. We emphasize evaluation of augmented or new time series of observations, and where possible, develop insights from spatial patterns described in general terms in the text; supporting maps and other "snapshots" of the CCS, including more detailed information on specific cruises, are available online at observing programs' websites (indicated below). This review focuses on description and preliminary synthesis of available observations. The data sets reviewed herein are the subject of ongoing research to understand links between climate and ecosystem processes, work that is well beyond the scope of the present paper. Sparse information on methods related to data collection and analysis is included in footnotes; for many programs, more detailed descriptions of methods are available in previous State of the California Current reports or online.

The report is organized as follows. First, as in previous reports, we review recent historical conditions and describe variability and trends in indices of large-scale climate modes (e.g., the Pacific Decadal Oscillation), followed by a description of recent, basin-scale infor-
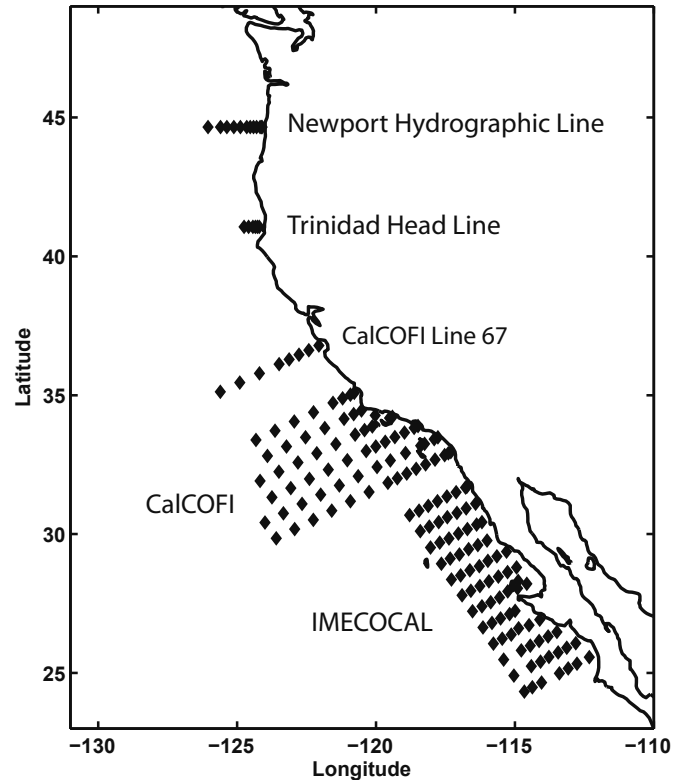

Figure 1. Station maps for surveys that are conducted multiple times per year during different seasons to provide year-round observations in the California Current System. The CalCOFI survey (including CalCOFI Line 67) are occupied quarterly; the spring CalCOFI survey grid extends just north of San Francisco. The IMECOCAL survey is conducted quarterly or semiannually. The Newport Hydrographic Line is occupied biweekly. The Trinidad Head Line is occupied at biweekly to monthly intervals.

mation from the tropical and northern Pacific Ocean. This review provides a broad temporal and spatial context for observations that focus more specifically on patterns and structure in physical forcing and responses at scales that span the entire CCS. Second, we summarize the state of the CCS in terms of available hydrographic and plankton data collected during repeated ship-based surveys that occupy designated stations at more or less regular intervals throughout the year (fig. 1). Third, building from our synthesis of the state of the ecosystem "base" of the CCS, we review data on abundance or productivity of several taxa at higher trophic levels based on observations from directed surveys or place-based study sites (fig. 2). Such taxa can respond to climate variability and change on multiple time scales, ranging from days to decades (Melin et al. 2010; Sydeman et al. 2012), and as such, may be useful as integrative indicators of ecosystem state. Finally, in the Discussion, we synthesize observations throughout the CCS to assess how the state of the CCS has evolved through the past year, and provide a look towards the future.
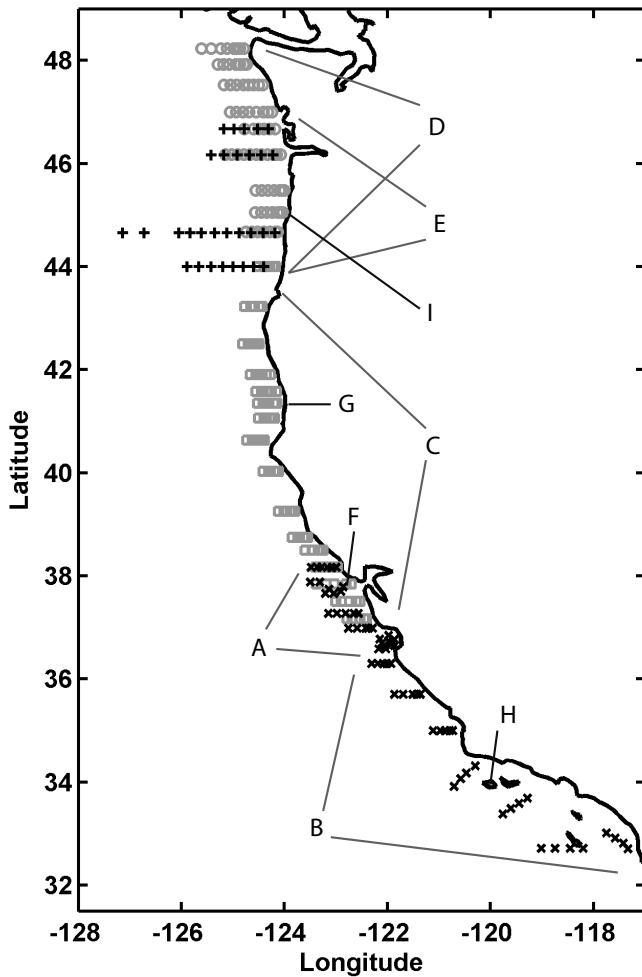
Figure 2. Location of annual or seasonal surveys, including locations of studies on higher trophic levels, from which data are included in this report. Different symbols are used to help differentiate the extent of overlapping surveys. A. SWFSC FED midwater trawl survey core region (May–June) B. SWFSC 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. NWFSC 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 spatial extent of California Current Ecosystem surveys is partly indicated by data shown in Figure 22, but also extends northwards through much of the CCS.

RECENT EVOLUTION OF THE STATE OF THE CALIFORNIA CURRENT

A shift to cool conditions following the 1997–98 El Niño (Bograd et al. 2000; Peterson and Schwing 2003; Chavez et al. 2003, 2011) drove ecosystem responses consistent with those expected for such a transition, e.g., increased phytoplankton and zooplankton production, as well as occasional shifts in zooplankton community structure (Brinton and Townsend 2003; Lavaniegos and Ohman 2007). Two events impinged on the CCS in 2002–03: an intrusion of subarctic waters (the signature of which was detectable in parts of the CCS into 2007) and a mild tropical El Niño (Venrick et al. 2003). Strong ecosystem responses to the intrusion

of anomalously cool, fresh, and nutrient-rich waters (e.g., enhanced productivity) were observed only in the northern CCS (e.g., off Oregon); it is thought that the effects of El Niño were likely to have countered any similar responses off southern California and Baja California (Venrick et al. 2003; Wheeler et al. 2003; Bograd and Lynn 2003; Goericke et al. 2004). Since 2004, regional variability has dominated over coherent CCS-wide patterns (Goericke et al. 2005, 2007; Peterson et al. 2006; McClatchie et al. 2008, 2009; Bjorkstedt et al. 2010, 2011). The late onset of upwelling in 2005 and 2006 led to delayed spin-up of productivity in coastal waters, with strongly negative consequences for higher trophic levels in the northern CCS (Brodeur et al. 2006; Peterson et al. 2006; Sydeman et al. 2006; Lindley et al. 2009; Takahashi et al. 2012). Cool conditions associated with La Niña prevailed from mid-2007 through 2008 into early 2009, but regional variability was again dominant: increases in productivity in the central and northern CCS were not matched by similar responses off southern California and Baja California despite evidence of hydrographic effects of La Niña (McClatchie et al. 2008, 2009). The general pattern of substantial contrasts between the northern and southern regions of the CCS persisted into the short-lived, relatively weak El Niño event in late 2009 through early 2010, during which southern California returned to near climatological mean values and did not indicate any subsequent response to El Niño, while the northern CCS warmed substantially following the decline of La Niña and was strongly affected by intense downwelling during winter 2009–10 (Bjorkstedt et al. 2010). Moreover, as the El Niño diminished rapidly in early 2010, upwelling off central and southern California resumed unusually early and strongly for a spring following an El Niño, but recovery from El Niño in early 2010 appears to have been less robust in the northern CCS (Bjorkstedt et al. 2010). This regional variability persisted into fall 2010 and through the 2010–11 winter as upwelling continued at climatological mean intensity in the south, while shutting down in the north, giving way to a mix of downwelling associated with winter storms and extended periods of quiescent conditions that persisted well into spring 2011 (Bjorkstedt et al. 2011). Ecosystem responses tracked these patterns, with relatively robust productivity in the south and evidence for relatively poor productivity in the north similar to that observed in the lead up to the 2009–10 El Niño (Bjorkstedt et al. 2011).

NORTH PACIFIC CLIMATE INDICES

In contrast to the consistently warm conditions that dominated the CCS prior to the strong 1997–98 El Niño, the Pacific Decadal Oscillation (PDO) (Mantua
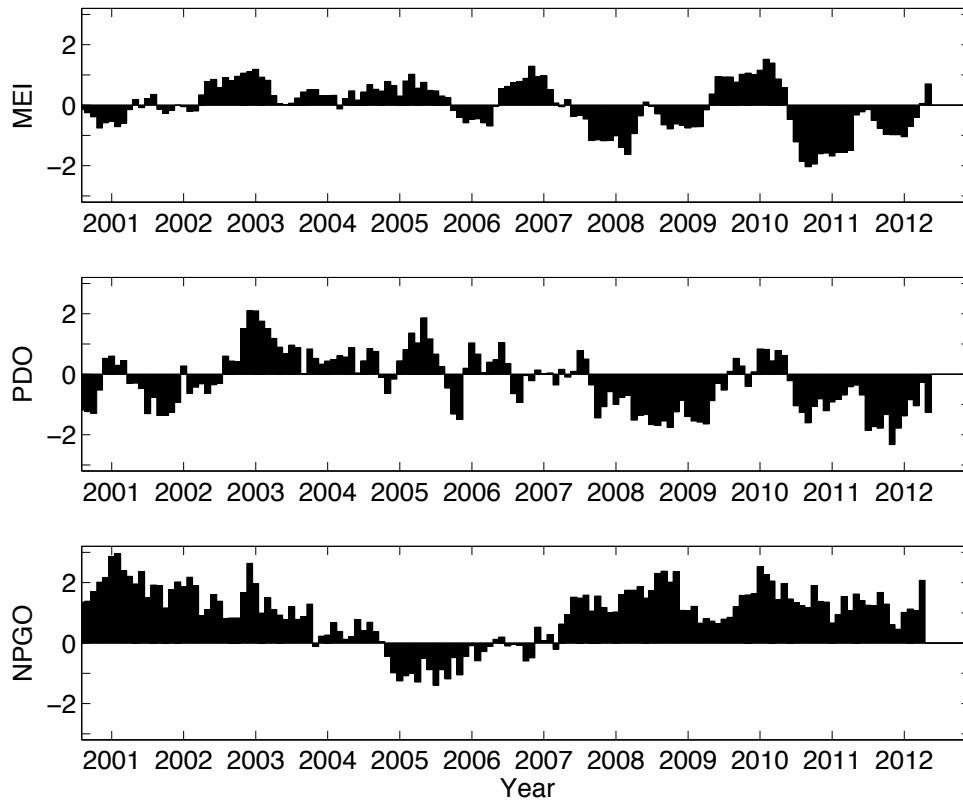
Figure 3.   Recent time series of monthly mean values for three ocean climate indices especially relevant to the California Current: the multivariate ENSO index (MEI; top panel; data retrieved from http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/table.html), the Pacific Decadal Oscillation (PDO; middle panel; data retrieved from http://jisao.washington.edu/pdo/PDO.latest), and the North Pacific Gyre Oscillation (NPGO; bottom panel; data retrieved from http://www.o3d.org/npgo/data/NPGO.txt) for January 1984-May 2012).

et al. 1997) index suggests that the North Pacific has since been in a generally cooler state (fig. 3a). However, the PDO has been for the past decade fluctuating at intervals of approximately two to four years between cool states marked by negative values of the PDO index and associated negative anomalies in sea surface temperature throughout the CCS (e.g., 1998–2001, 2008–09) and warmer states of positive PDO and positive SST anomalies (e.g., 2003–06) (fig. 3a, and see below). This pattern appears to be continuing through the past year: following the strong La Niña conditions that developed in summer 2010, the PDO briefly reverted towards neutral values in spring 2011 before again shifting to strongly negative values, including some of the most negative (cool) values observed in the past decade (e.g., –2.33 in November 2011; fig. 3a). Over the past several years, since at least 2008, variability in PDO has exhibited a high degree of coherence with the Multivariate El Niño Southern Oscillation Index (MEI) (Wolter and Timlin 1998) (figs. 3a,b). The MEI shifted dramatically from El Niño to La Niña conditions in early 2010 and remained in a strongly La Niña state until increasing rapidly towards neutral values into early 2011. In contrast to the PDO, the

MEI did not indicate a return to stronger La Niña conditions in summer 2011 and has instead remained between a moderate La Niña and neutral (fig. 3b). Moderate to weak La Niña conditions had prevailed in the tropical Pacific since July 2010, but the negative SST anomalies steadily weakened in the first half of 2012. ENSO-neutral conditions were present by April 2012, with the Niño 3 index turning slightly positive. The persistence of such variability means that the question of whether a sustained decadal "regime" has been established in the CCS remains open and subject to some debate. The North Pacific Gyre Oscillation (NPGO) (Di Lorenzo et al. 2008), which is a measure of the strength of gyral circulation in the North Pacific, has also covaried with MEI and PDO, but has been predominantly positive since the late 1990s, indicating anomalously strong equatorward flow in the CCS (fig. 3c). Negative NPGO during 2005 and 2006 corresponds to the period of unusually low productivity observed through much of the CCS. The NPGO index was variable but generally remained positive through 2011 and into 2012, reflecting the persistence of stronger-than-normal gyral circulation in the North Pacific (fig. 3c).
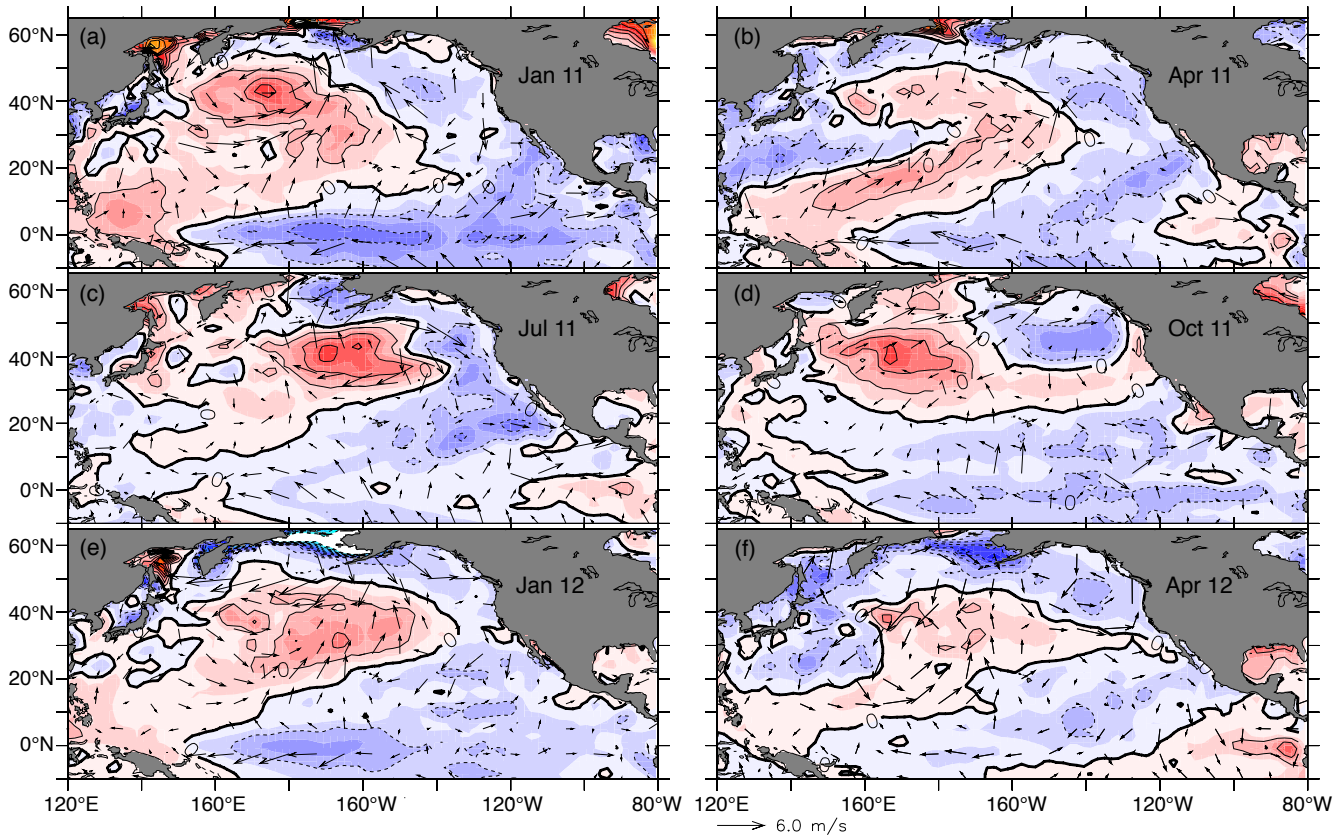
Figure 4.   Anomalies of surface wind velocity and sea surface temperature (SST) in the north Pacific Ocean, for (a) Jan 2011, (b) April 2011, (c) July 2011, (d) October 2011, (e) Jan 2012, and (f) April 2012. Arrows denote magnitude and direction of wind anomaly (scale arrow at bottom of figure). Contours denote SST anomaly. Shading interval is 0.5°C and contour interval is 1.0°C. Negative (cool) SST anomalies are shaded blue; positive (warm) SST anomalies are shaded red. Wind climatology period is 1968–96. SST climatology period is 1950–79. Monthly data obtained from the NOAA-CIRES Climate Diagnostics Center.

NORTH PACIFIC CLIMATE PATTERNS[1]

Figure 4 illustrates the spatial evolution of climate patterns and wind forcing over the North Pacific related to trends in the basin-scale indices reviewed above. SSTs along the North American coast were close to normal in winter 2011 (fig. 4a) but transitioned through spring (fig. 4b) and summer (fig. 4c) 2011 to cooler conditions (SST anomalies of –0.5° to –1.0°C) coupled with warmer-than-normal SST (>+1.0°C) in the western and central North Pacific, a pattern that has persisted in recent years. Strong anticyclonic wind anomalies dominated the Northeast Pacific through summer 2011, resulting in cool SST anomalies throughout the Gulf of Alaska and California Current (fig. 4c). A brief period of warm SST anomalies in the eastern North Pacific in September–October 2011 (fig. 4d) transitioned back to cool SST anomalies in early winter 2011–12, driven by anticyclonic wind anomalies (fig. 4e). This pattern weakened going into spring 2012 with warm SST anomalies emerging in the eastern equatorial Pacific (fig. 4f).

[1]Further details on month-to-month and interannual global ocean climate variability can be found at CPC's "Monthly Ocean Briefing" archive (http://www.cpc.ncep.noaa.gov/products/GODAS).

Upwelling in the California Current

The onset of upwelling in spring 2011 was relatively early and strong from Baja through central California (fig. 5). In contrast, the date of the "spring transition" off Oregon was very close to the long-term mean (mid-April) following anomalously strong and late downwelling associated with spring storms in the northern part of the CCS. Upwelling was more or less normal across much of the CCS through spring and early summer 2011 (but was anomalously strong off Baja California). Stronger than normal upwelling developed across much of the CCS during midsummer 2011, reflecting persistently strong anticyclonic wind anomalies over the North Pacific (figs. 4b,c, 5). Upwelling strength declined significantly across the CCS in September, leading to an unusually early termination of the upwelling season off Oregon (the 2011 upwelling season off Oregon was among the shortest observed: only 153 days relative to a mean of 179 days) (fig. 5). Despite this decline, continued upwelling events (see review of buoy observations below) contribute to anomalously strong net upwelling (weak net downwelling) through much of the California Current south of 40°N into autumn 2011. A period of
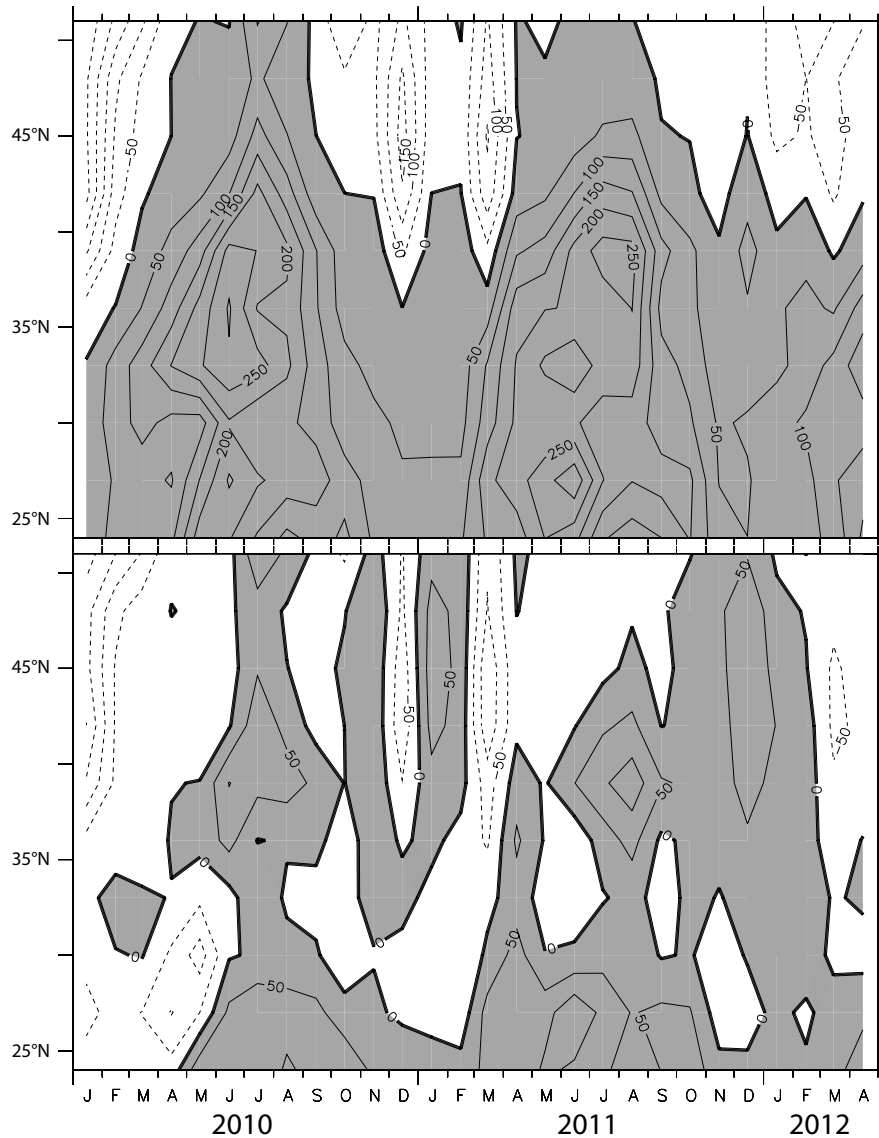
Figure 5.   Monthly upwelling index (top) and upwelling index anomaly (bottom) for January 2010–April 2012. Shaded areas denote positive (upwelling-favorable) values in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1948–67 monthly means. Units are in m³ s⁻¹ per 100 km of coastline.

unusually strong upwelling occurred throughout much of the CCS (up to nearly 45°N) in winter 2012, but this was followed by a return to weaker-than-normal upwelling, including predominantly southerly winds and downwelling well into spring 2012.

Trends in cumulative upwelling[2] (measured from November 1 to better capture ecologically important winter dynamics, c.f. Logerwell et al. 2003; Schroeder et al. 2009; Black et al. 2010, 2011) illustrate the potential contribution of upwelling-driven enrichment to ecosystem pre-conditioning in late fall and late winter along

much of the coast (i.e., between 36°N and 48°N), as well as the consequences of subsequent periods of sustained downwelling that push 2011–12 trajectories towards those observed during the preceding year (fig. 6). The effects of downwelling in late spring are weaker in the south, where cumulative upwelling remains comparable to (33°N) or high relative to preceding years (36°N).

Observations at coastal NDBC buoys reflect these large-scale patterns in the form of highly coherent time series of surface wind and SST observations but also reveal strong variability at "event" scales of a few days to weeks in both alongshore surface winds and SST (fig. 7). As in 2010, 2011 was marked by numerous upwelling-relaxation events during the spring and summer and

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[2]Cumulative upwelling was calculated from the 6-hourly Bakun Index obtained from the NOAA Fisheries Environmental Research Division obtained through http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/PFELindices.html.
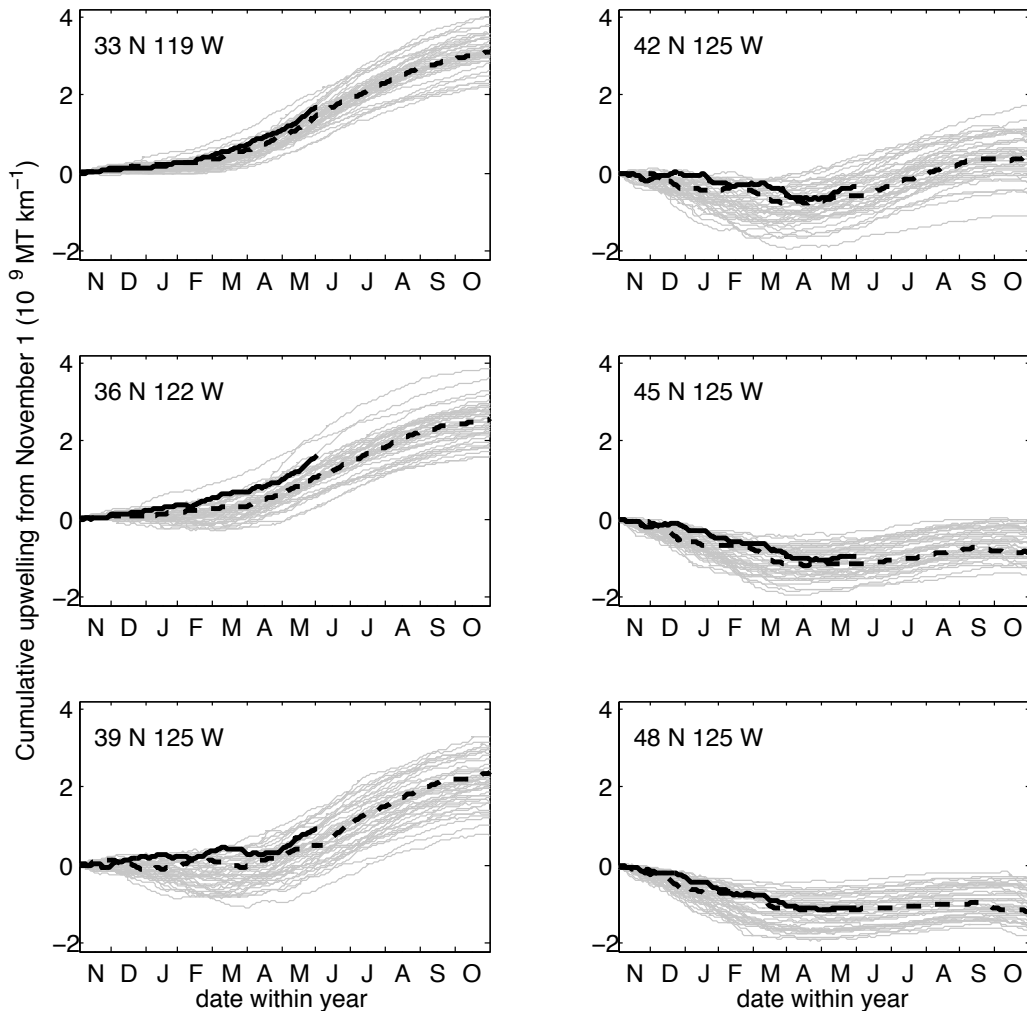
Figure 6. Cumulative upwelling from November 1 (of previous year) calculated from the Bakun Index at indicated locations along the West Coast of North America for 1967–2010 (grey lines), 2011 (dashed line), and 2012 (solid line). Calculation of cumulative upwelling from November captures important variability during the winter "pre-conditioning" period (cf. Schroeder et al. 2009; Black et al. 2010).

strong upwelling-downwelling transitions throughout the fall and winter, with much of this variability observed in the northern CCS (fig. 7). The persistence of strong variability in event-scale forcing, as has been apparent since 2007, may be linked to high intraseasonal (30–60 day) variability in the tropics associated with the Madden-Julian Oscillation[3] (Zhang 2005).

Cooler SSTs persisted through much of summer and autumn 2011, except for the warming event in October, reflecting the cumulative effect of numerous strong coastwide upwelling events (figs. 4d, 7). Persistent, anomalously strong upwelling (weak downwelling) affected much of the CCS during early 2012, resulting in strong negative SST anomalies. SSTs throughout much of the CCS shifted towards climatological values in April 2012.

[3]http://www.cpc.noaa.gov/products/precip/CWlink/MJO/mjo.shtml

HF Radar Surface Current Observations[4]

Seasonal mean surface currents observed with HF radar reveal a characteristic pattern of southerly currents in spring developing into marked offshore flow in summer with a general weakening in the fall and a tendency for weak northward flow in winter. In spring 2011 (March–May), offshore jets are evident south of several major headlands, including Cape Mendocino, Point Arena, and Cape Blanco (fig. 8). Offshore flow, although weaker than in the north, is also seen at Point

[4]High Frequency (HF) Radar currents presented herein are calculated hourly at 6-km resolution using optimal interpolation (Kim et. al. 2008; Terrill et. al. 2006) and further averaged to 20-km resolution prior to display. Real-time displays of HF-Radar surface currents can be viewed at the regional association websites: http://www.sccoos.org/data/hfrnet/ and http://www.cencoos.org/sections/conditions/Google_currents/. HF radar observations are supported by NOAA's Integrated Ocean Observing Systems (IOOS) and participating universities (listed at http://cordc.ucsd.edu/projects/mapping/) and make use of a network of radars initially constructed with support from the state of California and the NSF.

Sea Surface Temperatures 2010 to 2012
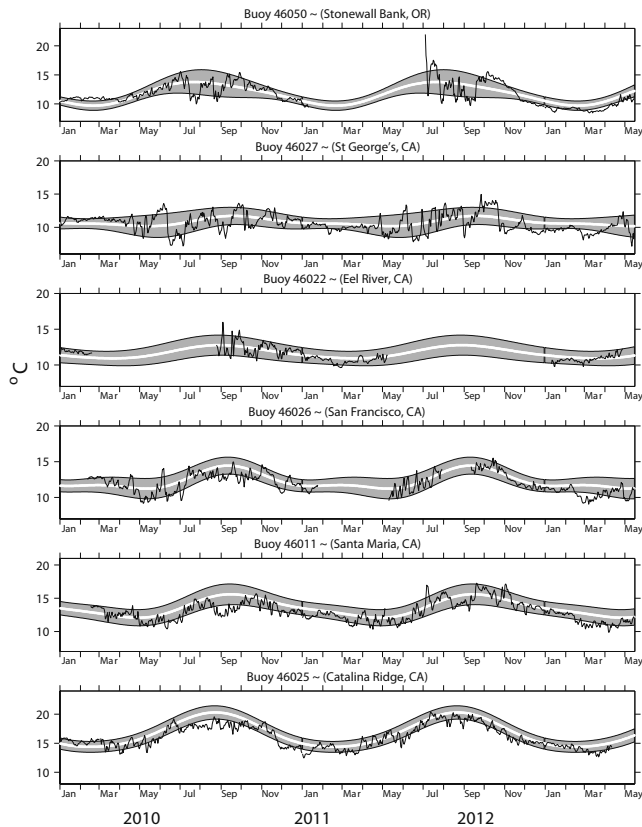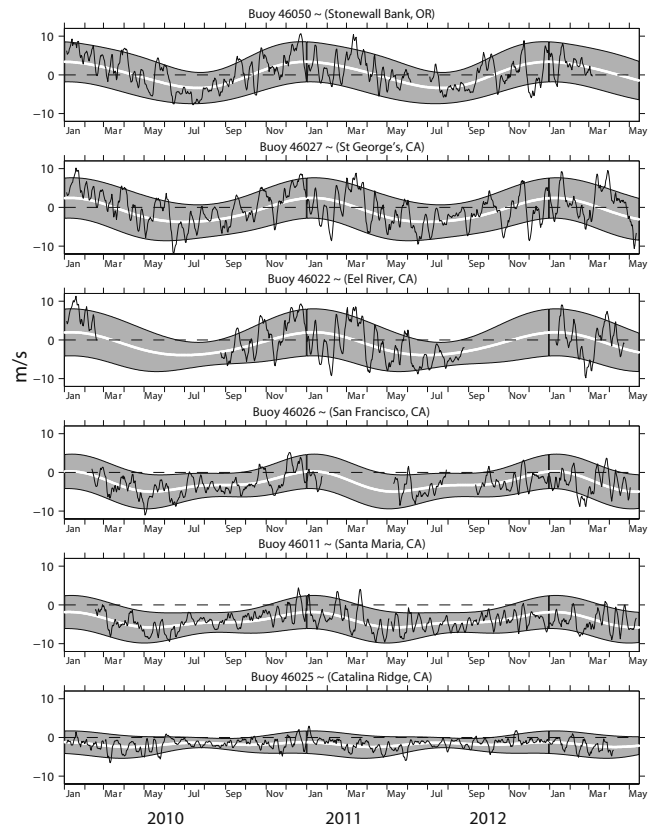
Alongshore Winds 2010 to 2012

Figure 7. Time series of daily-averaged SST (left) and alongshore winds (right) for January 2010–April 2012 at selected NOAA National Data Buoy Center (NDBC) coastal buoys. Bold white lines are the biharmonic annual climatological cycle at each buoy. Shaded areas are the standard errors for each Julian day. Series have been smoothed with a 7-day running mean. Data provided by NOAA NDBC. Coordinates for buoy locations are at http://www.ndbc.noaa.gov/to_station.shtml.

Conception, and mean flows were predominantly south-ward throughout the Southern California Bight. Mean surface currents are generally stronger during summer 2011 than in spring, with a general offshore flow marked by broad maxima south of Cape Blanco, Cape Mendocino and Point Sur (fig. 8). In contrast, offshore flows are not enhanced and remain relatively weak over the shelf and slope in the greater Gulf of Farallones (36°–38°N) and in the Southern California Bight (32°–34°N) during summer 2011. In fall, weak poleward flow develops and dominates in the Southern California Bight and offshore flow weakens between Cape Blanco and Point Conception (34°–43°N). In contrast to previous years, mean northward flow during winter (December 2011 to February 2012) is evident only north of Cape Blanco, particularly in the vicinity of the Columbia River plume, while broad offshore flows persist off Cape Blanco, Point Arena, and Point Conception (fig. 8). This contrasts with winter 2009–10 when an average northward flow was observed throughout the CCS during the weak El Niño (Bjorkstedt et al. 2010) and with winter 2010–11 when northward flow dominated north of Cape Men-

docino (Bjorkstedt et al. 2011). More strikingly, in neither 2009–10 nor 2010–11 did offshore flow features persist through winter, yet the signature of such features is apparent during winter 2011–12.

A time series of surface flow past Point Reyes illustrates variability in the timing, strength, and duration of southward flows over the past 11 years (fig. 9). The Point Arena coastal jet seen in Figure 8 shows up here as strong southward flow past Point Reyes in April–June but quickly diminishes to negligible net alongshore flow nearshore and weakens at offshore locations through the summer. This pattern is consistent with previous years, but the net flow is generally weaker than in previous years, such that flows in summer 2011 are comparable with those observed in 2006. Weak flows occur in spite of a marked seasonal peak in upwelling index in summer. However, alongshore currents continue to covary strongly with monthly water level at Point Reyes. Alongshore flow is more coherent across the shelf in winter 2011–12 and includes strong southward flows in early 2012 that are captured in the broader pattern of southward and offshore flow during winter 2011–12
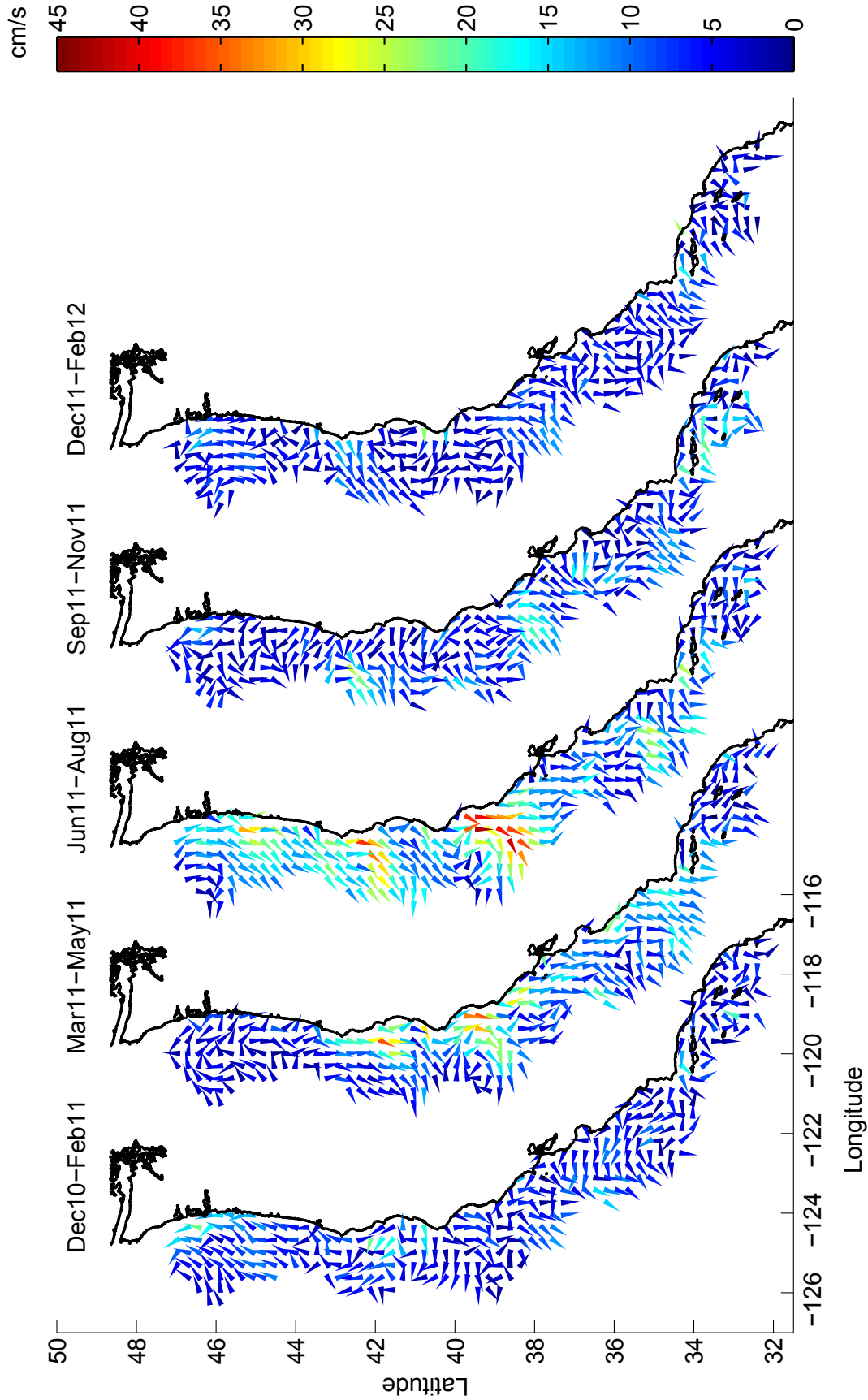
Figure 8. Maps of seasonal mean surface current in the CCS measured with HF radar for December 2010 through February 2012. From left to right, the seasons are winter (December–February 2011), spring (March–May), summer (June–August), fall (September–November), and winter (December–February). Mean surface currents are calculated at 20-km resolution from hourly HF-radar observations. Current speed is indicated by color and current direction indicated by orientation of arrowheads. The base of the arrow is at the observation location. For clarity, currents are displayed for every fifth grid cell in both north-south and east-west directions.
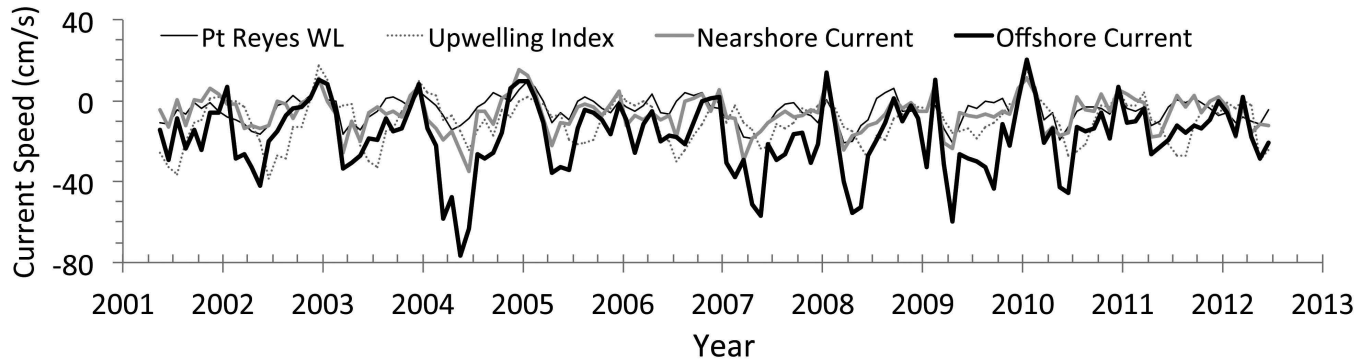
Figure 9. Monthly averages of spatially averaged surface flow past Point Reyes, California between 30 km and 60 km offshore (38°00' to 38°10'N and 123°20' to 123°40'W; thick black line) and between 0 and 15 km offshore (38°00' to 38°10'N and 123°00' to 123°10'W; thick grey line). Positive values indicate poleward flow. Also shown are monthly mean cross-shelf Ekman transport indexed by the negative Upwelling Index at 39°N (fine, grey dashed line; plotted as onshore Ekman transport, in units of 10 m³/s per 100 m of coastline) and monthly mean sea level measured at at Point Reyes NOAA tide gauge (fine black line; plotted as sea level relative to 1m above MLLW, in units of cm).
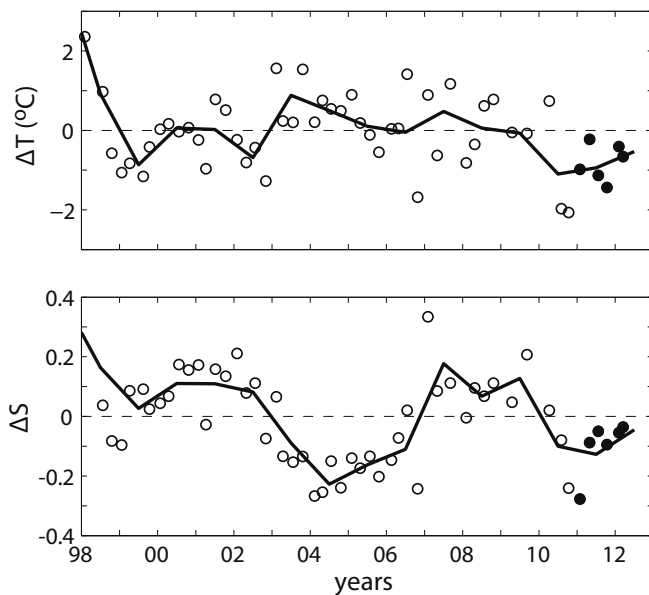

Figure 10. Mixed layer temperature anomaly (°C) and mixed layer salinity anomaly off the Baja California Peninsula (IMECOCAL grid). Each symbol represents the average anomaly for each cruise conducted. Data from the 2011 and 2012 surveys are plotted as solid symbols. The thick solid line indicates annual average.
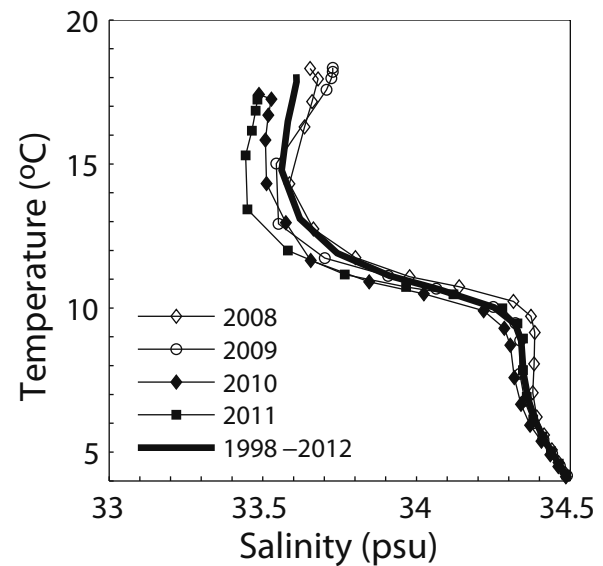

Figure 11. Annual mean T-S curves for 2008–2011 across the IMECOCAL region. The long-term mean (January 1998–March 2012) is indicated by the thick line. Each data point indicates one standard depth, from surface to 1000 m.

(figs. 8, 9). Southward flow again develops in spring 2012 and can be expected to weaken through the summer, as has been observed in previous years.

REGIONAL SUMMARIES OF HYDROGRAPHIC AND PLANKTON DATA

Several ongoing surveys provide year–round hydro-graphic and plankton observations across the CCS but vary substantially in terms of spatial extent and temporal resolution (fig. 1). In the following section we review recent observations from these surveys from south to north.

Baja California (IMECOCAL[5])

Following the trend described in last year's report, mixed layer temperatures off Baja California remained cooler than the long-term average during 2011 and into 2012, with some evidence from recent surveys for a weak trend towards the climatological mean (fig. 10). This modest warming was especially apparent in the region north of Punta Eugenia (ca 28°N) that is more strongly affected by northern waters (data not shown),
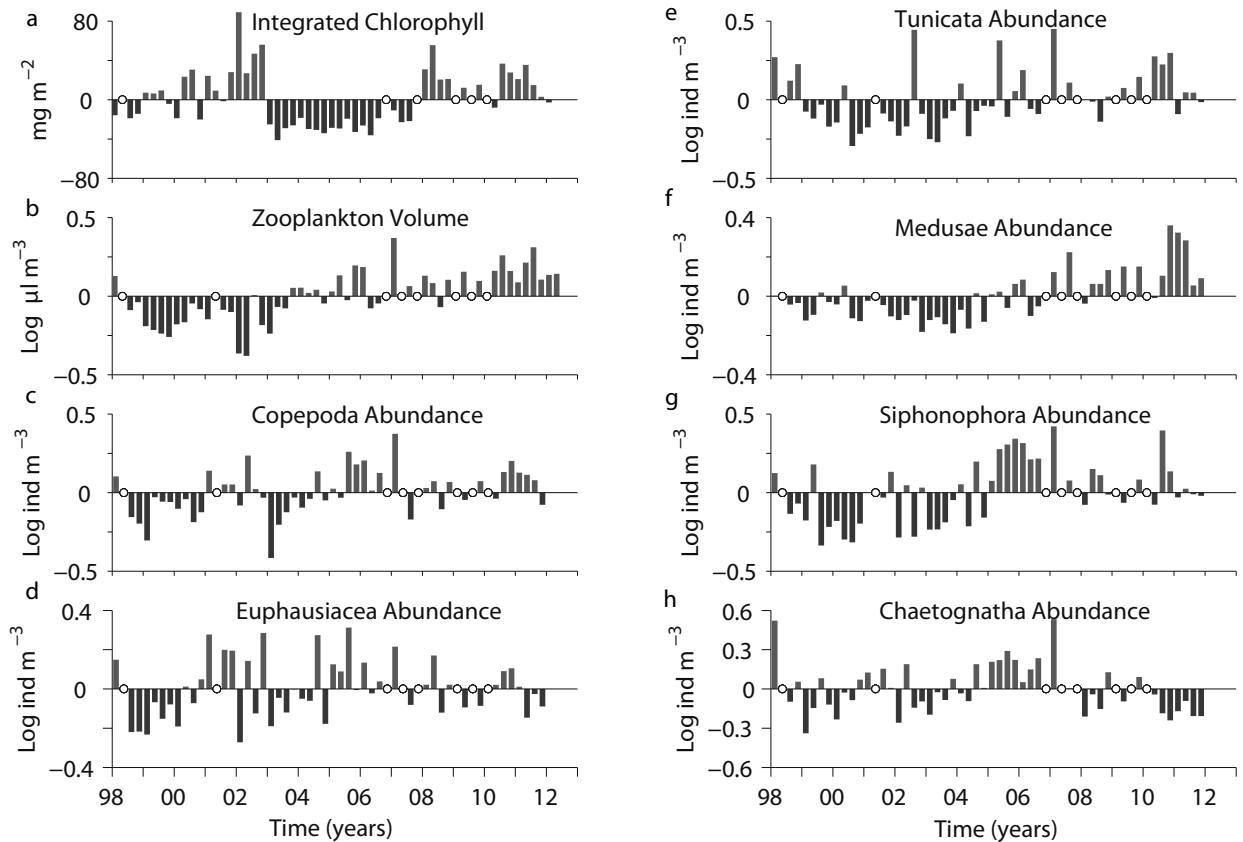

Figure 12.   Time series of anomalies in 0–100 m integrated chlorophyll *a*, zooplankton volume and group abundance anomalies for the IMECOCAL region. Each bar represents the anomaly for a single cruise from the long-term mean. Open circles indicate cruises that were not conducted or were omitted due to limited sampling.

while mixed layer temperatures south of Punta Euge-nia remained consistently cooler than mean conditions during 2011–12. Salinities within the mixed layer also continued to be below (fresher than) the climatological mean (largest anomalies in December 2010 and Janu-ary 2011), after the effects of an intrusion of subtropical waters towards the coast starting in 2008–09 dissipated with the transition to La Niña conditions following the weak 2010 El Niño. By 2012, mixed layer salini-ties returned to climatological means north of Punta Eugenia, even as relatively fresh conditions persisted over the region to the south. Dissipation of positive salinity anomalies in the upper water column and freshening of the upper water column that began during 2010 con-tinued into 2011 as depicted by the annual TS averages (fig. 11). Consistent with the trends in mixed layer prop-erties, TS mixing curves for two cruises in early 2012 (January and March, not shown) also indicate a return to climatological conditions in the upper 200 m.

Relatively high concentrations of chl *a* in the upper water column (0–100 m) persisted into 2011 but declined in late 2011 through early 2012 (fig. 12a). Bulk zooplankton (measured as displacement volume) con-tinued to be well above the mean for the observational record, a pattern that reflects the ongoing dominance of gelatinous groups that have a large influence on vol-ume biomass measured (figs. 12b–h). During 2010, tuni-cates were numerically dominant, with a large increase in hydromedusae by fall 2010 that persisted through 2011 (figs. 12e,f). The apparent resurgence of crusta-cean zooplankton reported last year (Bjorkstedt et al. 2011) appears to have reversed, with both copepod and euphausiid densities declining through 2011 and into early 2012 (figs. 12c,d). The decline in (numerical) density appears to have been rather general across zoo-plankton taxa, although the shift to greater dominance by hydromedusae appears to have prevented a parallel decline in displacement volume (figs. 12b–f).

Southern California (CalCOFI[6])

Mixed layer temperatures were below long-term, sea-sonally adjusted averages during the last year (fig. 13a), consistent with the basin-wide trends (figs. 4, 7). Con-
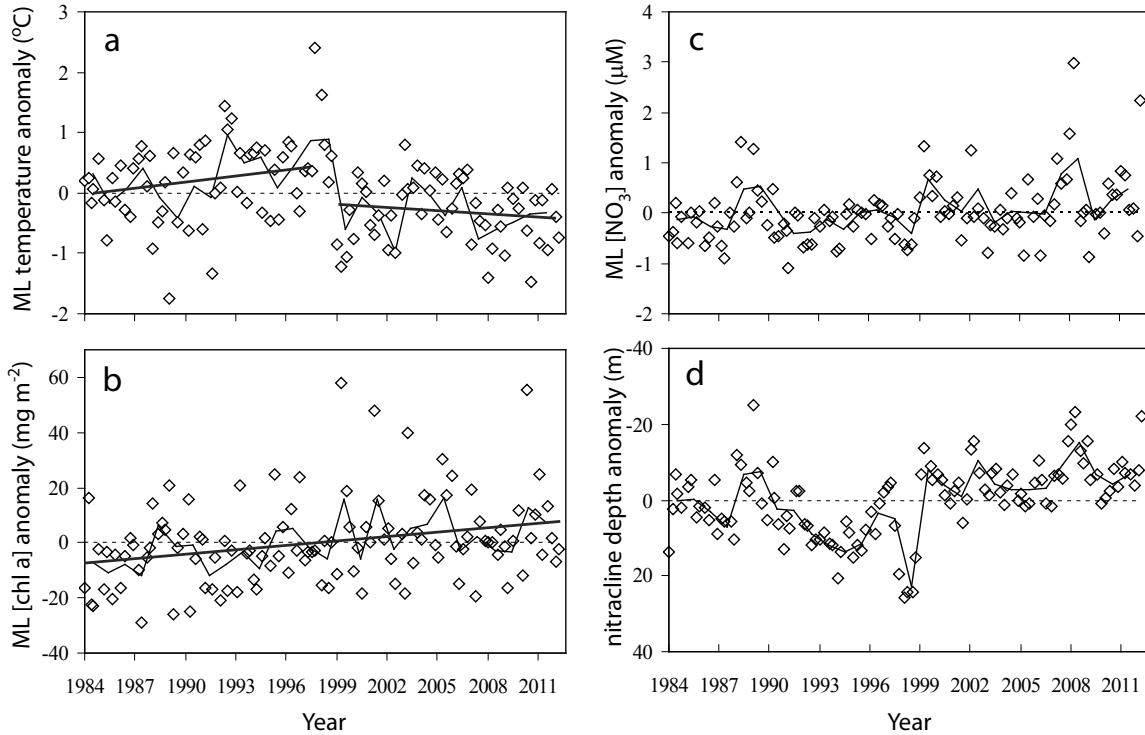
Figure 13.   Property anomalies from long-term, seasonally-adjusted means for the mixed layer of the CalCOFI standard grid: (a) temperature, (b) chl *a* concentration, (c) nitrate concentration, and (d) nitracline depth. Data from individual CalCOFI cruise data are plotted as open diamonds. The thin solid lines represent the annual averages. Dotted lines represent zero anomaly for reference. Straight solid lines, when present, indicate long-term linear trends. The discontinuous trend in temperature is based on separate fits to anomaly data for the periods prior to and after, but not including, the 1998–99 ENSO event.
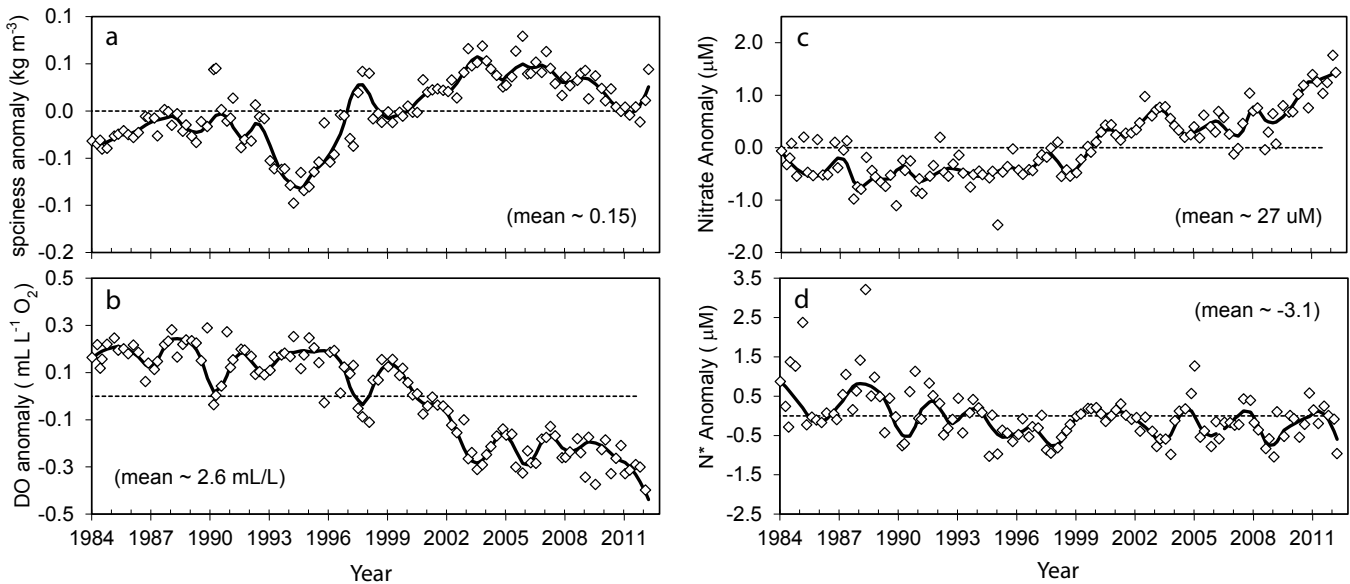

Figure 14.   Anomalies of hydrographic properties at the σ_t 26.4 isopycnal (open diamonds) averaged over the standard CalCOFI stations: (a) spiciness, (b) dissolved oxygen, (c) nitrate concentration, and (d) N*, a biogeochemical indicator which reflects the deficit of nitrate in a system relative to concentrations of phosphate (Gruber and Sarmiento 1997). The solid line represents a loess fit to the data; average values for the properties are given as well.

centrations of chl *a* were close to long-term seasonally adjusted averages (fig. 13b), as were concentrations of nitrate, except for the spring 2012 values, which were extremely high (fig. 13c). The apparent discrepancy between spring 2012 nitrate and chl *a* can be explained

by the relatively early initiation of upwelling in the spring of 2012 (fig. 5) and the early date of the cruise. Mixed layer temperatures observed off Point Conception during the February 2012 CalCOFI cruise were about 13°C. By March 2012 temperatures in that area
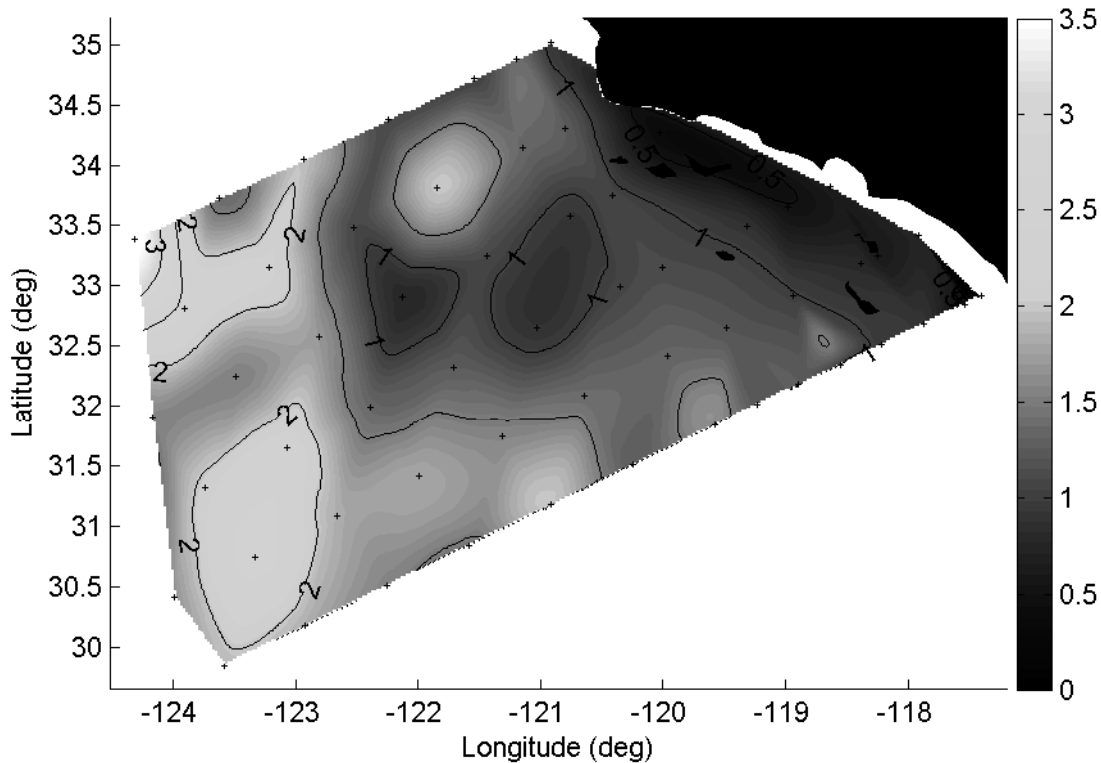
Figure 15. The spatial distribution of nitrate concentration anomalies (μM) at the 26.4 isopycnal for the time period summer 2011 to spring of 2012 relative to the 1984 to 2008 time period. Note that nitrate concentrations are consistently higher than in the early period (i.e., all anomalies are positive), but that anomalies are smaller near the coast and large anomalies are observed only in the western portion of the sampled region.

ranged from 11°C to 12.5°C, a sign of strong upwelling[7]. Concentrations of chl *a* concentrations at that time were still low, likely because the spring bloom had not yet occurred. The very shallow depth of the nitracline (fig. 13d) during the spring of 2012 is due to the strong upwelling, i.e., lifting of isopycnals, and may also reflect basin-wide changes (see below).

Conditions at the σ_t 26.4 isopycnal[8] (fig. 14) continued to change (cf. Bjorkstedt et al. 2011). Spiciness at the isopycnal has been fairly constant over the last decade (fig. 14a), suggesting that no dramatic changes in water masses have occurred. However, concentrations of oxygen continued to decrease (fig. 14b) and those of nitrate to increase (fig. 14c), reaching values that have not been observed since these measurements began in 1984. The relatively constant values of N* (fig. 14d), at least over the last decade, are consistent with the hypothesis that the balance of remineraliza-

tion and denitrification in the tropical North Pacific has not changed significantly[9]. The spatial expression of the nitrate increase shows the strongest signal in the offshore areas and relatively weak signals along the coast (fig. 15), consistent with a basin-wide mechanism forcing the observed changes rather than the effects of local processes changing properties of the California Undercurrent. The mechanisms driving observed trends in nitrate and DO concentrations are a focus of active ongoing research, but we note that the trends in nitrate concentration are consistent with the process described in a modeling study by Rykaczewski and Dunne 2010, i.e., that concentrations of nitrate will increase in the CCS as a consequence of global warming due "to enrichment of deep source waters entering the CCE[cosystem] resulting from decreased ventilation of the North Pacific." An alternative explanation for such increases is increased remineralization of organic matter at the depths where the nitrate increases are observed; however, this mechanism requires increased rates of production or increased rates of export production, rate changes that have so far not been observed.

Zooplankton displacement volume (ZDV), a proxy for zooplankton biomass, was near the long-term mean

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[7]Cruise-by-cruise spatial plots of hydrographic and associated data are available at http://data.calcofi.org/bottle-data/cruise-hydrographic-data/hydrographic-figures.html; preliminary data for 2012 cruises are available at http://www.calcofi.org/component/content/article/50-datareports/468-soc-maps.html.

[8]The σ_t 26.4 isopycnal is located within the pycnocline and is typically found at a depth of about 200 m off S. California. It provides a useful reference layer because it is insensitive to local forcing affecting the surface mixed layer. Changes in water properties at this isopycnal therefore indicate evidence of changes in regional water masses, and changes in the depth of this isopycnal indicate the effects of circulation patterns (e.g., eddies) or large scale waves (e.g., Rossby waves).

[9]N* is a biogeochemical indicator which reflects the deficit of nitrate in a system relative to concentrations of phosphate (Gruber and Sarmiento 1997).
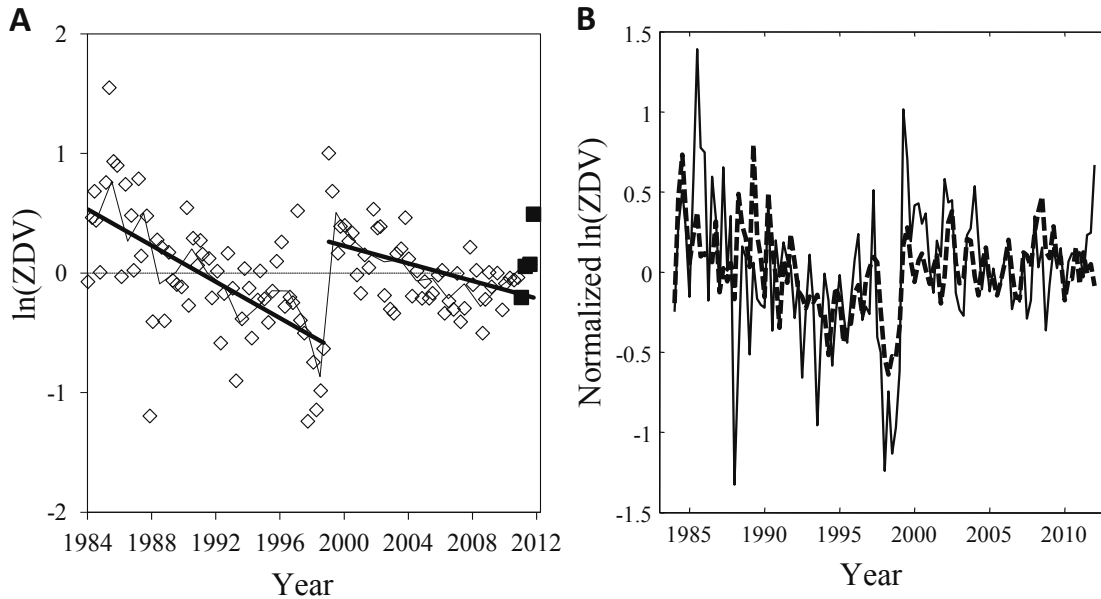
Figure 16.   (a) Average anomalies of log-transformed zooplankton displacement volumes (ZDV) for each cruise plotted against time. Solid lines indicate trends based on linear fits to data prior to and after the 1998–99 ENSO event. (b) Detrended ZDV anomalies (solid lines) and predicted values based on an autoregressive model with external inputs (ARX [4, 2, 0]), cf. Box and Jenkins 1970 fitted to ZDV and nitracline depth (dashed lines). Note that zooplankton data are only available up to the fall of 2011.

during 2011 (fig. 16a). The spring 2012 cruise was especially remarkable for the abundance of gelatinous zooplankton captured (see Gelatinous Zooplankton, below). A visual comparison of ZDV anomalies and nitracline depth (fig. 13d) suggests that these two variables continue to covary through 2011 (ZDV data for early 2012 are not yet available). An autoregressive model[10] fit to the data (fig. 16b) identified a significant negative relationship between ZDV and nitracline depth at zero lag (regression coefficient -0.028 ± 0.009 [95% c.i.]) and a significant positive relationship at a lag of one season (approximately 3 months; 0.014 ± 0.011) (fig. 16b). The negative relationship between ZDV and nitracline depth at zero lag is easily understood: decreases in nitracline depth will support increases in phytoplankton biomass likely to be dominated by larger phytoplankters (Goericke 2011) and thereby support zooplankton production. However, the delayed positive relationship between ZDV and nitracline depth is more difficult to understand.

Central California

Observations in Monterey Bay[11] show that surface waters remained cooler and fresher than mean conditions through spring 2011 and into early summer 2011 consistent with runoff from heavy late-season rains,

after which cooler temperatures continued but salinity increased to exceed climatological mean (fig. 17). Concentrations of chl *a* throughout the upper water column remained lower than climatological means well into summer 2011, but unusually high concentrations had developed by fall (fig. 17). Cooler, saltier water and greater chl *a* concentrations are apparent in early 2012. Deeper waters were consistently cooler and saltier than long–term mean conditions (fig. 17). Primary productivity and concentrations of chl *a* continued to remain relatively high since 1997–98 (Chavez et al. 2011).

Northern California Current:
Northern California (Trinidad Head Line[12])

Hydrographic observations along the Trinidad Head Line during 2011 and early 2012 reflected the broad basin-scale patterns: generally weak upwelling in 2011 throughout the northern CCS with an early cessation of upwelling in fall 2011, evidence for upwelling events during winter 2012, and subsequent effects of downwelling events in early 2012 (fig. 18). Concentrations of chl *a* were relatively high over the shelf in spring and summer 2011 but, in contrast to observations off central California, transitioned rapidly to low concentrations following the cessation of sustained upwelling in September 2011, and remained low into early 2012, presumably as a consequence of limited upwelling–driven enrichment during periods with sufficient light for phytoplankton blooms to develop.

[10]An autoregressive model was fit to accommodate significant autocorrelation in ZDV at lags of 1 and 3 seasons. The analysis presented here is based on fitting an autoregressive model with external inputs (ARX [4, 2, 0]), cf. Box and Jenkins, 1970 using the Statistics and System Identification toolboxes of Matlab (Version 7.12, The MathWorks Inc., Natick, MA, 2012).

[11]Data on temperature and salinity at the surface and 100 m for Monterey Bay are based on MBARI monthly cruises and mooring data.

[12]See http://swfsc.noaa.gov/HSU-CFORT/ for a description of methods. Surveys are carried out on Humboldt State University's R/V *Coral Sea*.
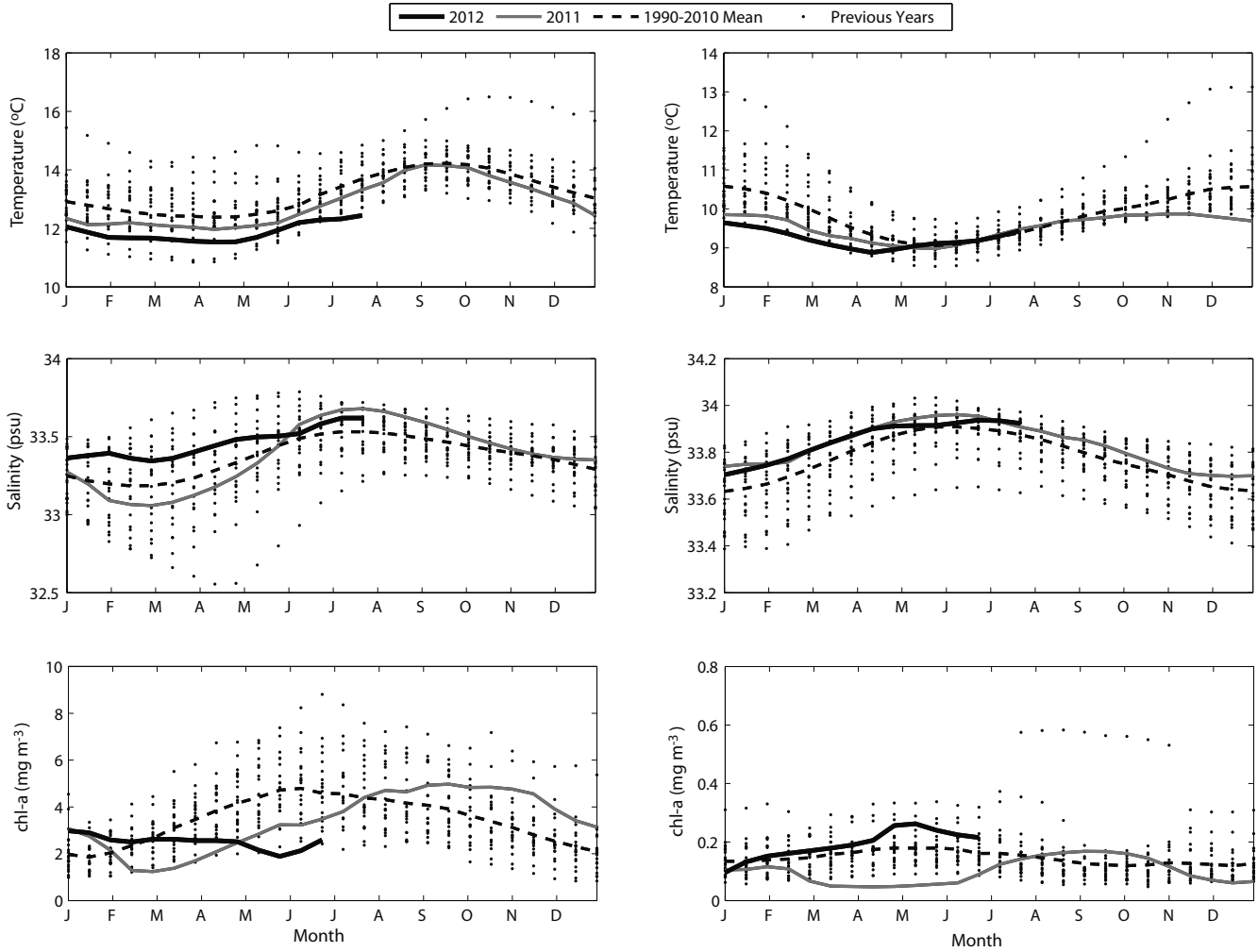
Figure 17. Temperature (top panels), salinity (middle panels) and chl *a* concentration (bottom panels) at the surface (left hand column) and at 100 m (right hand column) observed at the M1 mooring. Note changes in y-axis scale between surface and 100 m plots for each variable.

The copepod assemblage[13] observed at a mid–shelf station (TH02: 41.06°N, 124.27°W, 77 m water depth) reflects variability in hydrographic conditions. The productive period coincident with the 2011 upwelling season was marked by a substantial presence of northern neritic species in the copepod assemblage (fig. 18). Northern neritic species, which had been exhibited greater variability and in 2010, declined rapidly in abundance and frequency of occurrence following the cessation of upwelling in fall 2011. The assemblage has since been dominated by species with more southern or oceanic affinities (fig. 18). Interestingly, the observed pattern in copepod assemblage structure in 2011–12 resembles that observed during the weak El Niño of 2009–10. Preliminary examination of surface currents derived from HF radar in this region (fig. 8) suggests that unusual cir-

culation patterns in the lee of the Cape Blanco upwelling jet may have favored retention of southern and oceanic taxa near the coast, disrupted connections between coastal waters off northern California and sources of boreal taxa to the north (see below), or caused conditions unfavorable to northern neritic species to persist into spring 2012 off northern California.

Northern California Current:
Oregon (Newport Hydrographic Line[14])

Despite strongly negative PDO and very cold SST anomalies at NOAA Buoy 46050 (approximately 32 km off Newport, OR) related to recent La Niña conditions,

[13]Copepod data are based on samples collected from near the sea floor (or a maximum depth of 100 m) to the surface with vertical tows of a 0.5 m ring net fitted with 202 μm mesh and a TSK flowmeter, following a protocol identical to that implemented on the Newport Hydrographic Line.

[14]Regular sampling of the Newport Hydrographic Line continued on a biweekly basis along the inner portions of the line (out to 25 nautical miles from shore). Details on sampling protocols are available in previous reports and at http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/ka-hydrography-zoo-ichthyo-plankton.cfm. Temperature anomalies along the Newport line are based on the Smith et al. 2001 climatology. Copepod data are based on samples collected with a 0.5 m diameter ring net of 202 μm mesh, hauled from near the bottom to the sea surface. A TSK flowmeter was used to estimate distance towed.
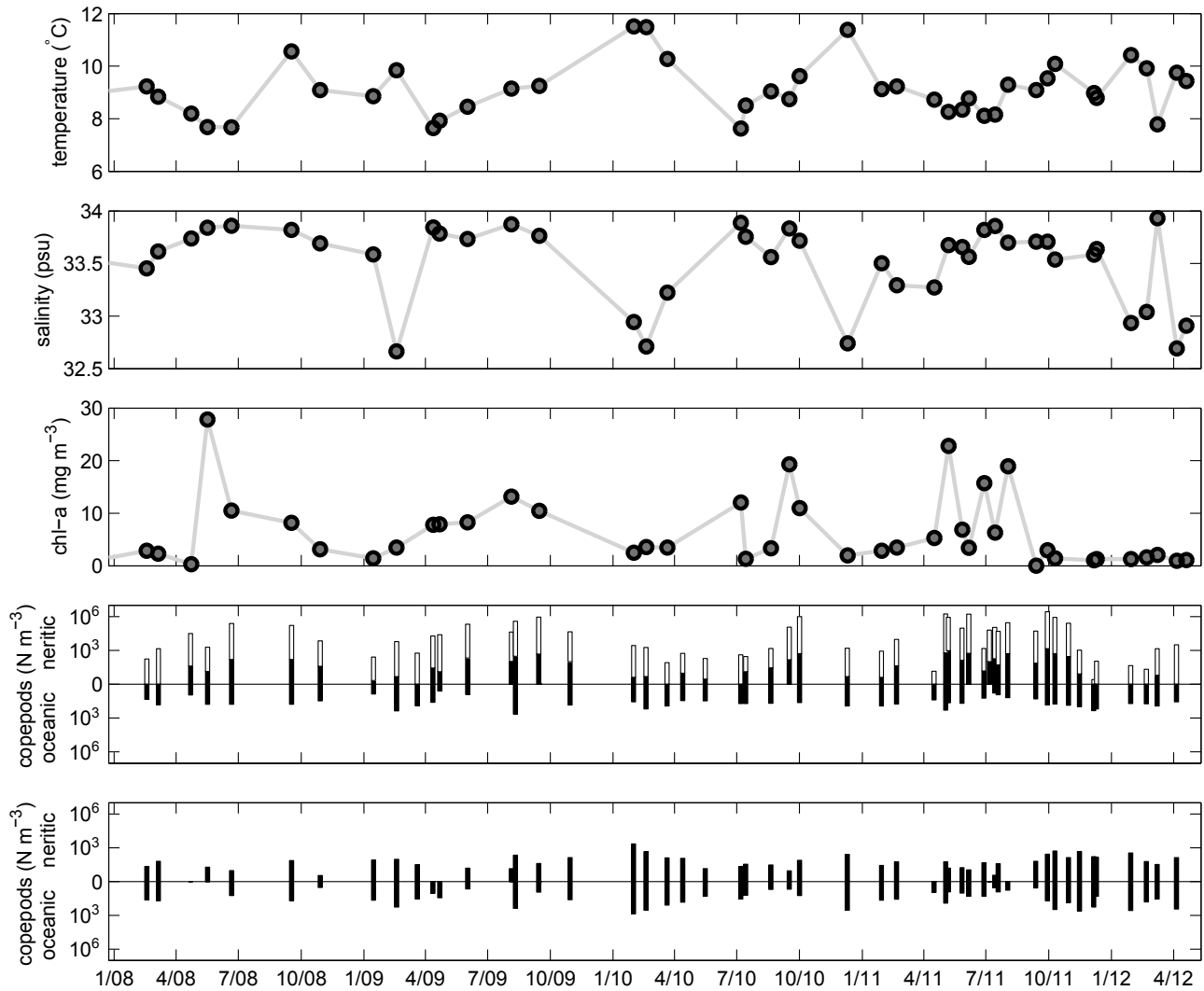
Figure 18. Top three panels: Near-bottom temperature, near-bottom salinity, and mean water-column chlorophyll *a* concentration, respectively, at station TH02 along the Trinidad Head Line. Bottom two panels: numerical density of northern and southern copepods, respectively, with ascending bars indicating neritic species and descending bars, oceanic species. Species assignments are based on Hooff and Peterson 2006. In the plot of northern neritic species, total density is indicated by the open bars and the solid bars represent species other than the dominant *Pseudocalanus* to highlight the loss of northern neritic species in 2012. Note that abundance scales are logarithmic.

shelf waters off central Oregon have not been unusually cold. Deep water at a mid–shelf station (NH-5: 44.65°N, 124.18°W, 60 m water depth) has been neither very cold nor salty during spring 2011 or spring 2012 (fig. 19, left panel), which is a consequence of the absence of strong upwelling in the northern CCS (figs. 5, 6). The effects of weak upwelling persisted through the summer, with summer 2011 near-bottom temperatures being among the warmest observed in the past 15 summers (fig. 19, right panel). Deep water temperatures during the autumn 2011 and winter 2012 were slightly below normal. Across all seasons, averaged temperature and salinity were near median values.

In mild contrast to patterns in local forcing (i.e., weak upwelling), the copepod community on the Oregon shelf (indexed by observations at station NH05) continued to reflect cool conditions, consistent with broader indices (e.g., PDO and offshore SST anomalies) and the presence of persistent, equatorward flow throughout the spring and summer (fig. 9). Species richness remained relatively low throughout 2011, an indicator of a "boreal copepod community" and greater–than–average transport of subarctic water into the northern California Current (fig. 20) (cf. Kiester et al. 2010). This pattern is corroborated by the "northern copepod biomass anomaly" time series[15], which has been strongly positive since spring 2010 (fig. 20). The biomass of northern copepod spe-

[15]This index captures the relative changes in the biomass of three lipid-rich boreal neritic copepod species: *Pseudocalanus mimus*, *Calanus marshallae* and *Acartia longiremis*.
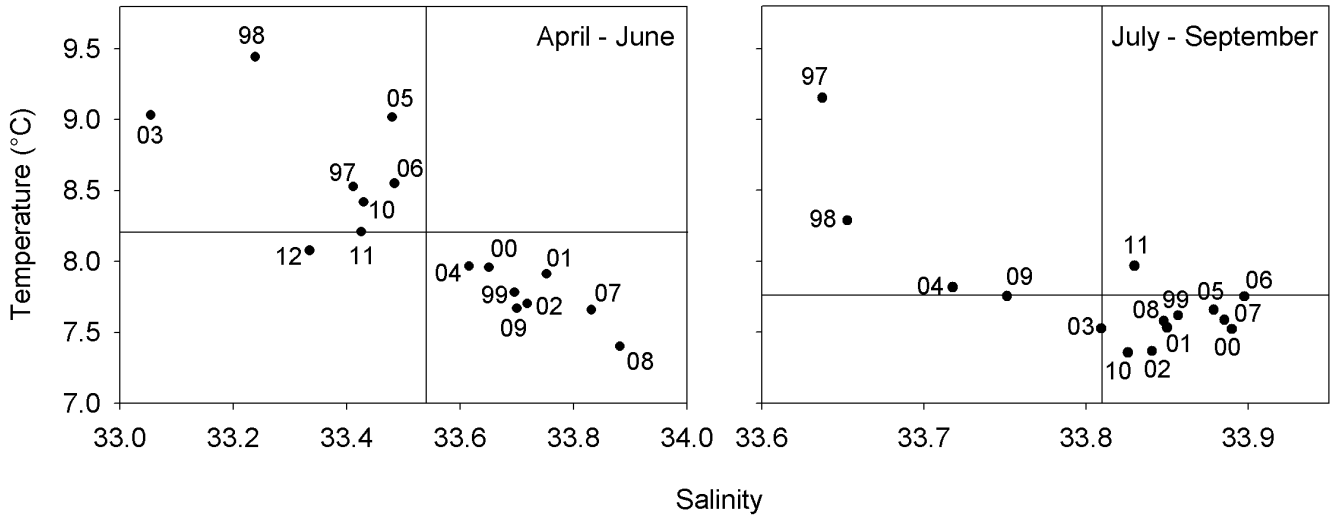
Figure 19. Seasonal mean temperature and salinity at 50 m depth at NH-5 along the Newport Hydrographic Line for spring (top panel) and summer (bottom panel). Note changes in scale on both temperature and salinity axes. Numbers next to points indicate year of observations.
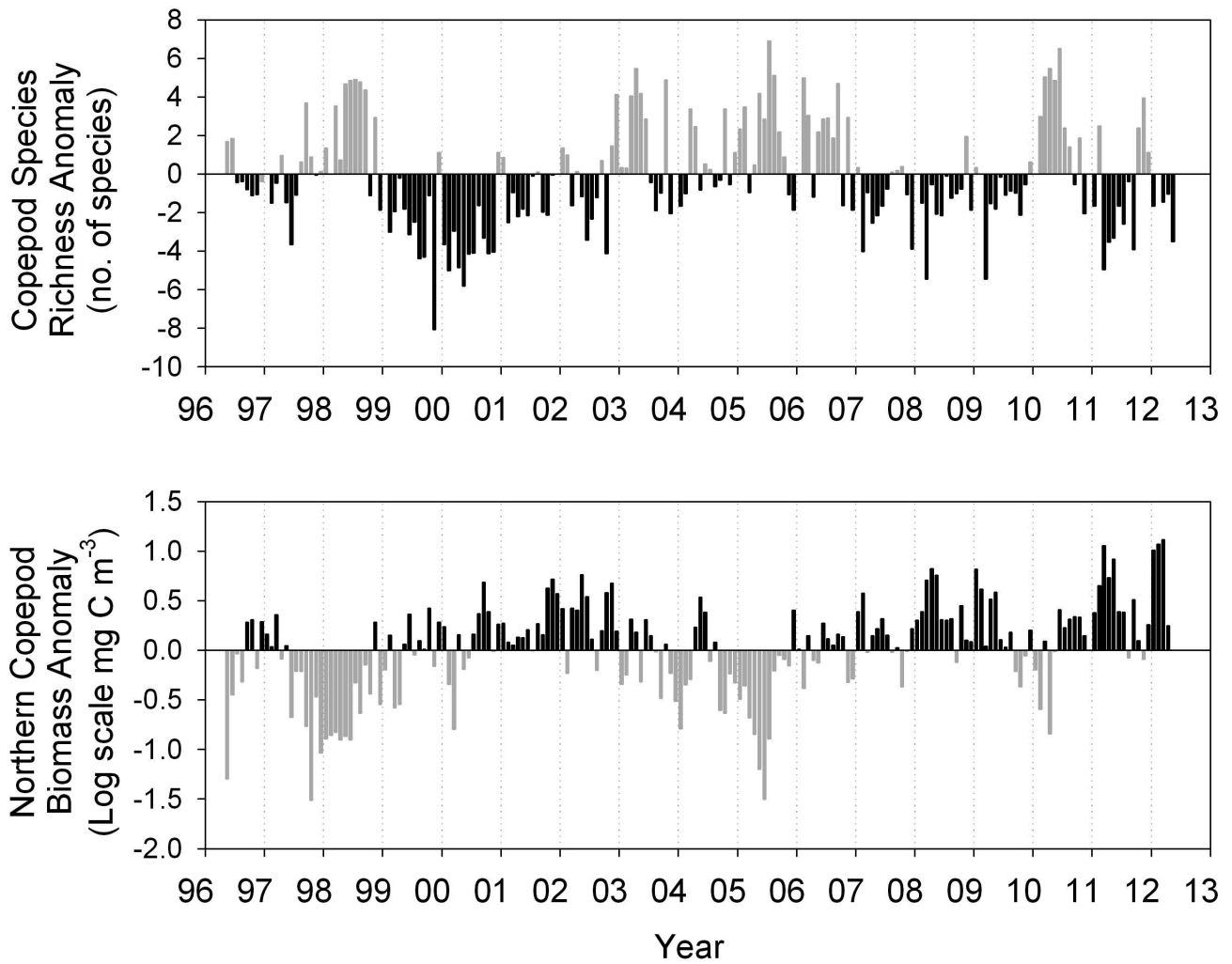
Figure 20. Monthly averaged anomalies in copepod species richness (upper panel) and biomass of three dominant 'northern' copepod species (*Pseudocalanus mimus*, *Calanus marshallae* and *Acartia longiremis* copepods (lower panel) based on biweekly sampling at station NH-5 off Newport, Oregon.
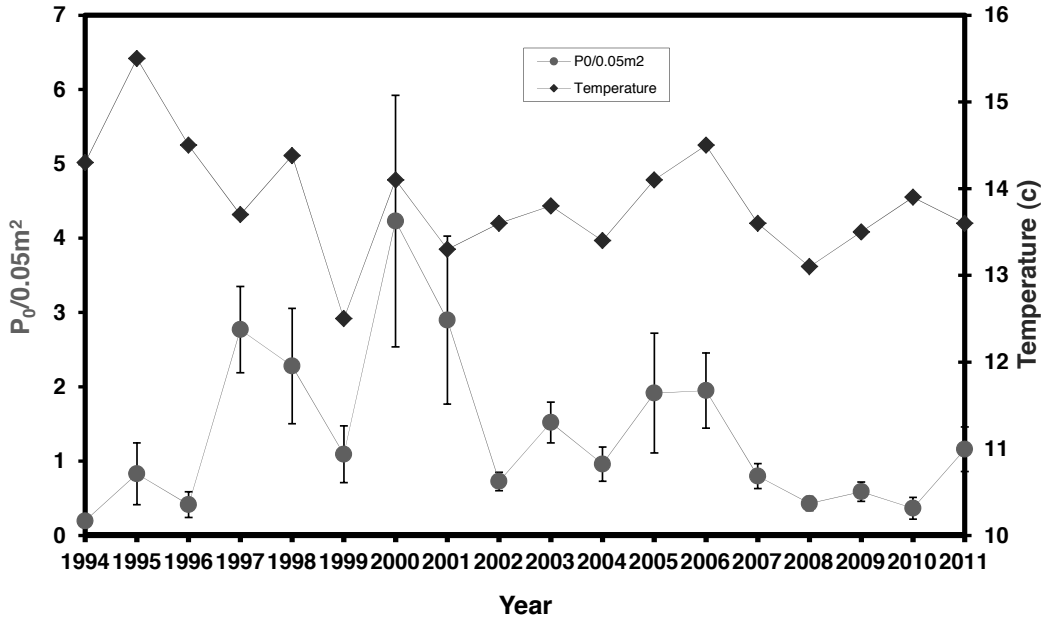
Figure 21. Time series of daily egg production ($P_0/0.05$ m²) of Pacific sardine (circles; ±1 standard error) and average sea surface temperature (°C) (diamonds; ±1 standard error) during pelagic egg surveys conducted during March–April of each year.
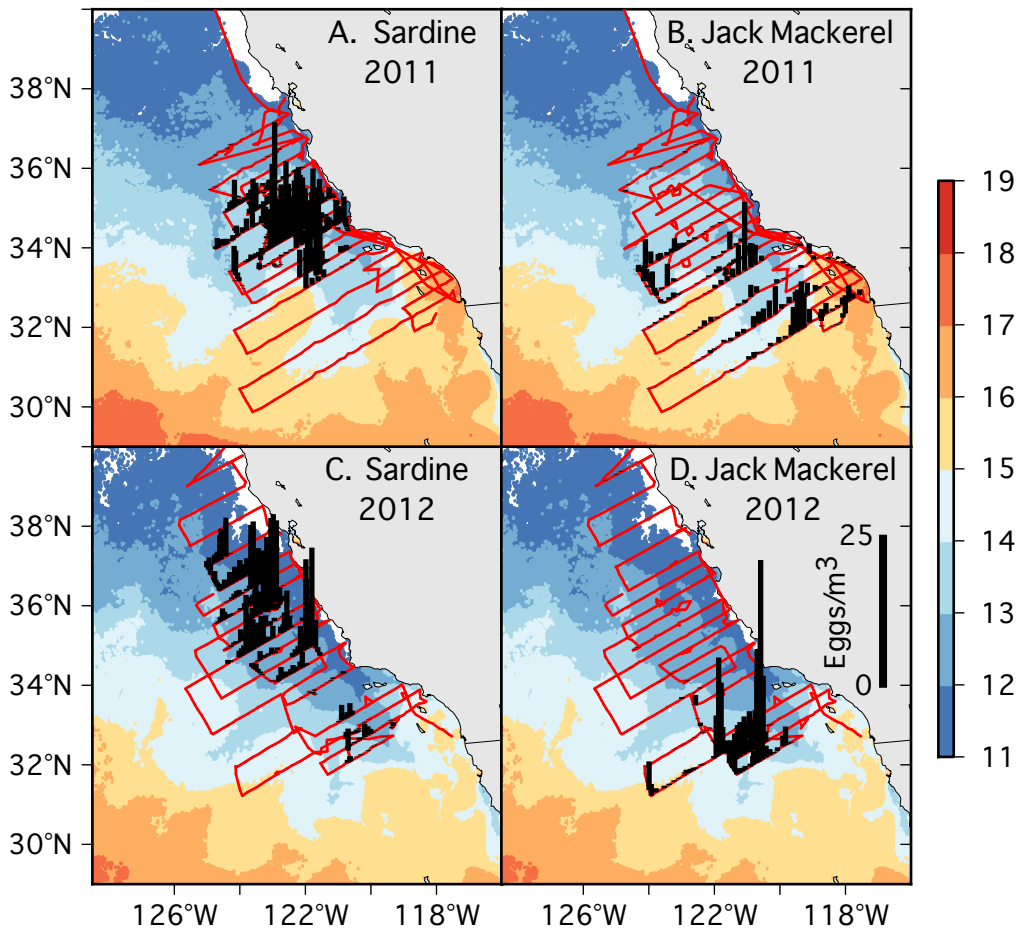
Figure 22. Densities of eggs (black bars) of Pacific sardines (right-hand panels) and jack mackerel (left-hand panels) collected with the Continuous Underway Fish Egg Sampler (CUFES) along the ship tracks (red lines) during NOAA coast-wide cruises conducted in spring 2011 (upper panels) and spring 2012 (lower panels). The underlying color image shows a monthly composite of satellite AVHRR 1.4 km resolution sea surface temperature (°C) coincident with the survey period in each year.

cies in winter 2012 (January–March) was the highest recorded in the 17–year time series, as was total copepod biomass, which was more than double the normal winter-time average.

SYNTHESIS OF OBSERVATIONS ON HIGHER TROPHIC LEVELS

Pelagic Fishes Off Southern California[16]

In spring 2011, Pacific sardine (*Sardinops sagax*) egg densities were higher than in previous years but not as high as had been observed in 2005 and 2006. As in 2010, daily egg production in 2011 again departed from an apparent historical pattern of increased daily egg production coinciding with increased mean sea surface temperature (fig. 21), indicating that the fluctuation of sardine egg densities is likely due to not only temperature but other factors, such as spawning biomass (Jacobson and MacCall 1995; McClatchie et al. 2010).

In 2011, sardine eggs were distributed over a wider area to the south than what had been observed in 2010 (fig. 22). No sardine eggs were observed north of CalCOFI line 68 or south of CalCOFI line 90. Preliminary data suggest that the spatial distribution of sardine eggs in the spring of 2012 was even broader than in 2011, ranging from San Francisco to offshore from the Southern California Bight, with the greatest concentrations observed between San Francisco and Point Conception (fig. 22). Coupled with the expanded distribution, however, egg densities appeared to be lower than in 2011 by perhaps a factor of two, although no quantitative comparison has been made yet. Northern anchovy (*Engraulis modax*) eggs were rarely encountered (data not shown), but this is not surprising because they spawn primarily earlier in the year. Jack mackerel (*Trachurus symmetricus*) eggs showed an interesting separation from sardine eggs: the jack mackerel were common in the Southern California Bight (SCB), while the sardine eggs were found mostly off central California (fig. 22). It is more common to find jack mackerel eggs further offshore than sardine eggs, but this is not always the case, as shown by the north-south separation observed in 2012.

Central and Northern California Pelagic Ecosystems

Analysis of catch composition and abundance of key taxa from annual mid-water trawl surveys[17] off central California indicated relatively high productivity in 2011 and 2012 for the species and assemblages that tend to do better with cool, high transport conditions, including juvenile rockfish (*Sebastes* spp.), market squid (*Dorytehuthis opalescens*) and euphausiids (primarily *Euphausia pacificus*, *Thysanoessa spinifera*, and *Nematoscelis difficilis*) (fig. 23). In 2011, juvenile rockfish were more abundant

then they had been since the early 2000s, and although abundance of juvenile rockfish was lower in 2012, it remained relatively high (fig. 23). Market squid and euphausiids were at above-average levels in 2011 and very high levels in 2012, with the relative abundance of market squid in particular estimated to be at its highest level in the time series (fig. 23). Other coastal pelagic species (adult northern anchovy and Pacific sardine) continued to be encountered at low levels, although this is likely a greater reflection of their local availability and ocean conditions rather than their coastwide or regional abundance.

The six indicators shown in Figure 23 continue to represent trends across a broader suite of taxa within this region[18] (fig. 24). As in 2010 and 2011, observations in 2012 continued to indicate a pelagic micronekton community structure similar to that seen in the early 1990s and early 2000s (fig. 25). These trends reflect (1) persistent, strong, positive covariance among young-of-the-year groundfish (e.g., rockfishes, sanddabs [*Citharichthys* spp.] and Pacific hake [*Merluccius productus*]), cephalopods and euphausiids, (2) positive covariance among coastal pelagic and mesopelagic species, and (3) negative correlation over time between the respective "groundfish" and "pelagic" assemblages.

The 2012 survey was unusual in that the abundance of several types of gelatinous zooplankton (reviewed below) was extraordinarily high, resulting in damaged sampling gear and some offshore trawl stations being abandoned for the first time in the 30-year history of this survey. Moreover, there is some evidence that distributions of several taxa in 2012 differed from patterns typical of previous cool, productive periods, in that during 2012,

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[16]Spring California Current Ecosystem (CCE) surveys are executed from late March through April. In spring 2011, the survey was conducted aboard the NOAA ship *Bell M. Shimada* and the F/V *Frosti*, during which time the *Bell M. Shimada* also supported sampling for spring CalCOFI cruise. During such surveys, CalVET tows, bongo tows, and surface trawls are conducted aboard both vessels, and samples are collected using the Continuous Underway Fish Egg Sampler (CUFES). In spring 2012, the survey was conducted aboard the NOAA ship *Bell M. Shimada* and the FSV *Ocean Starr*. Data from both CCE and spring CalCOFI cruises in 2011 were included in the estimation of spawning biomass of Pacific sardines. Data from all spring cruises were used to examine the spatial distributions of Pacific sardine, northern anchovy, and jack mackerel.

[17]Observations reported here are based on midwater trawl surveys that target small (1–20 cm) pelagic fishes and invertebrates conducted off central California (a region running from just south of Monterey Bay to just north of Point Reyes, CA, and from near the coast to about 60 km offshore) since 1983 (see Sakuma et al. 2006 for methods and details on spatial extent of survey). Cruises have been conducted on the NOAA ship *David Starr Jordan* (1983–2008), the NOAA ship *Miller Freeman* (2009), the F/V *Frosti* (2010), the F/V *Excalibur* (2011), and the NOAA ship *Bell M. Shimada* (2012). Certain taxa were not consistently enumerated prior to 1990 (e.g., krill and market squid). Data for the 2012 survey presented here are preliminary, and data collected since 2009 do not account for potential vessel-related differences in catchability. Most taxa reported are considered to be well sampled, but the survey was not specifically designed to accurately sample krill.

[18]Principal Components Analysis (PCA) was applied to the covariance among fifteen of the most frequently encountered species and species groups. The first and second principal components explain 36% and 16% of the variance in the data respectively.
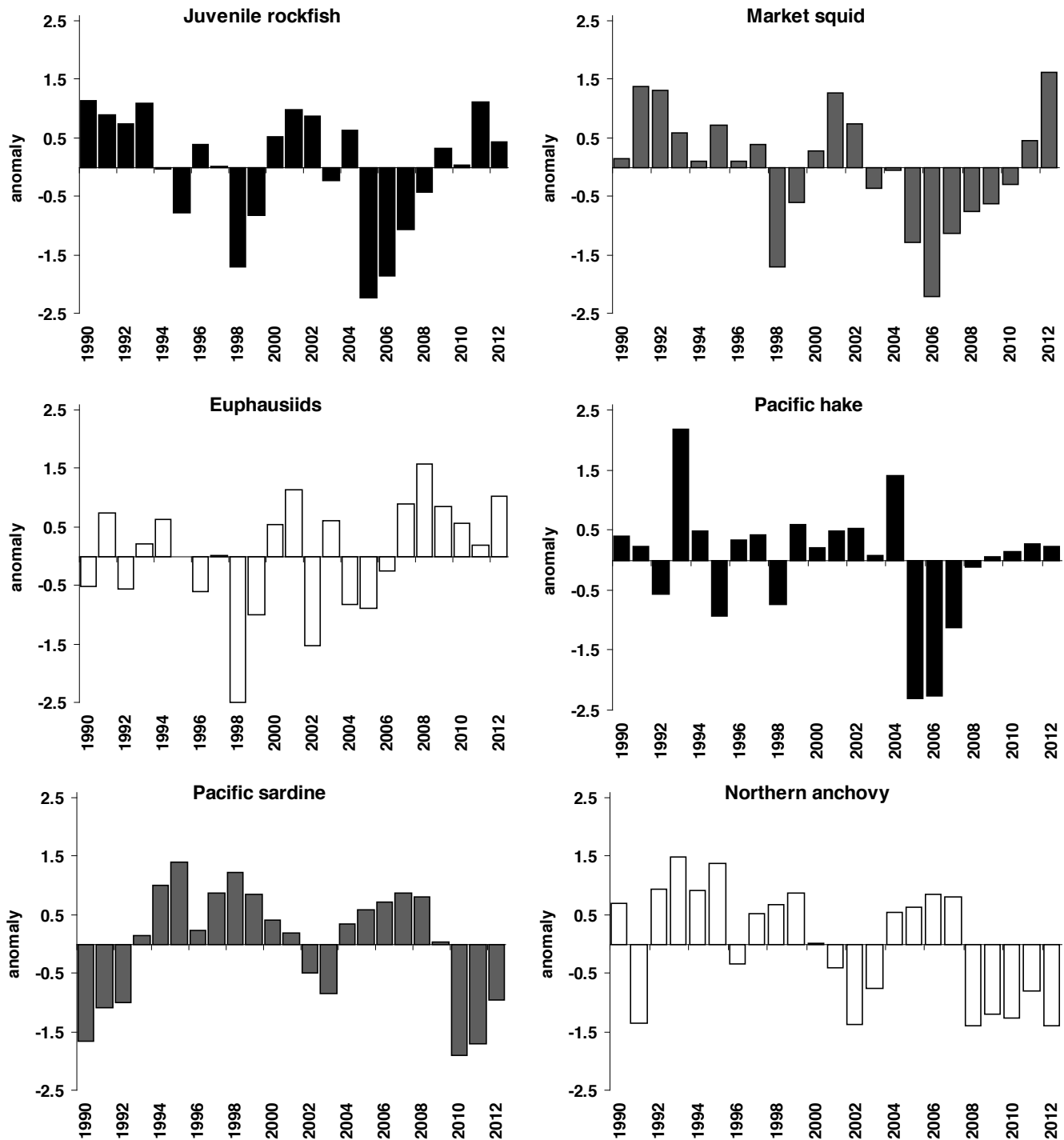
Figure 23.   Long-term standardized anomalies of several of the most frequently encountered pelagic forage species from the SWFSC FED midwater trawl survey in the core region off central California from 1990 to 2012.

small gelatinous zooplankton more abundant in offshore waters, while krill, squid, and juvenile groundfish were more concentrated in coastal waters rather than more broadly distributed across and off the shelf. Future analysis will examine the patterns and causes of this spatial variability in abundance.

Several of the trends reported during the mid-water trawl survey were also apparent in surveys that target juvenile salmon off central and northern California (reported below) and that often directly followed the mid-water trawl survey. Several clupeids (northern anchovy, Pacific sardine, and Pacific herring [*Clupea pal-*
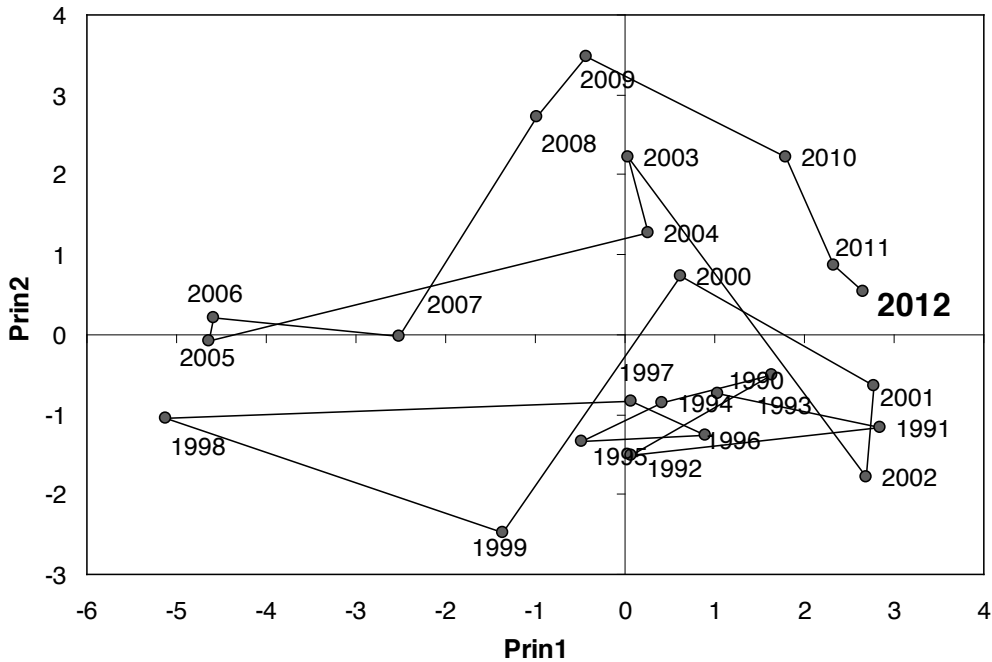
Figure 24. Principal component scores plotted in a phase graph for the fifteen most frequently encountered species groups sampled in the SWFSC FED midwater trawl survey in the core region off central California from 1990–2012.
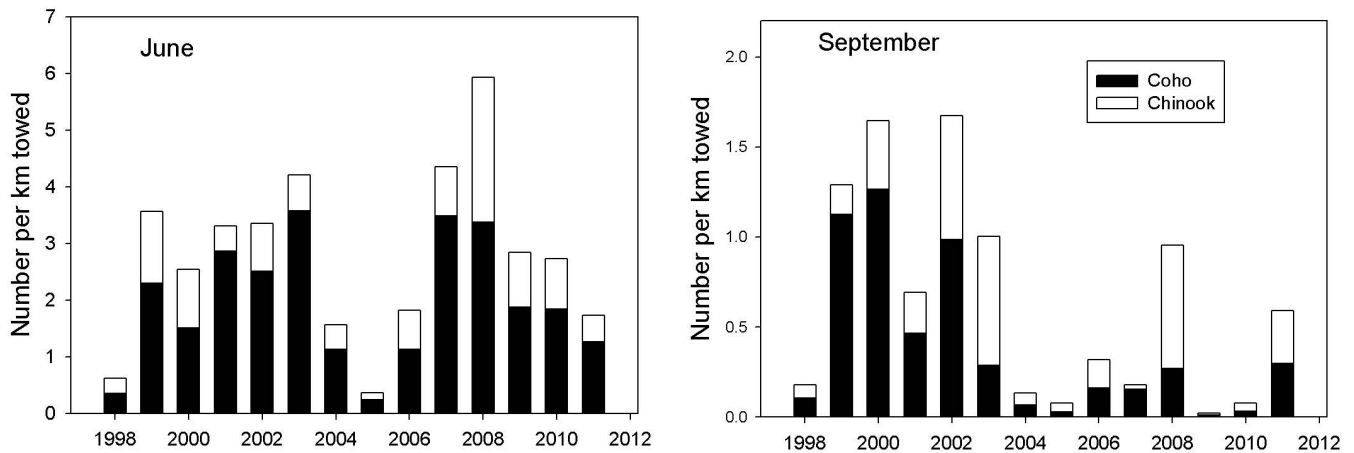

Figure 25. Catches of juvenile coho (black bars) and Chinook (white bars) salmon off the coast of Oregon and Washington in June and September, from 1998-2011.

lasii]) which had been abundant in 2007 were absent or rare in 2010 and 2011, but market squid had become unusually abundant. In contrast, juvenile rockfish, which were abundant in the rope-trawl catches during summer 2010, were observed at much lower densities in summer 2011. Causes for this discrepancy are being investigated, but may relate to latitudinal or seasonal differences in the surveys, to variability in the species each survey encounters, or to variability in the birthdate distributions of surviving juveniles from year to year.

Juvenile Pacific Salmon

Catches of juvenile coho salmon (*Oncorhynchus kisutch*) in pelagic rope trawl surveys off Oregon and Washington[19] were about average in June 2011 yet were relatively high in September 2011 (i.e., after the juveniles' first summer at sea), ranking 5th most out of 14 years of sampling (fig. 25). In contrast, catches of juvenile (primarily sub-yearling) Chinook salmon (*O. tshawytscha*) in June 2011 were relatively low (10th most out of 14 years of sampling), but catches of older juveniles (including yearling migrants) was greater in September 2011 than in previous years (fig. 25). Data from surveys in June 2012 are not yet verified, but preliminary indications are that catches were higher than in 2011.

[19]Survey protocols are available at http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/kb-juvenile-salmon-sampling.cfm.
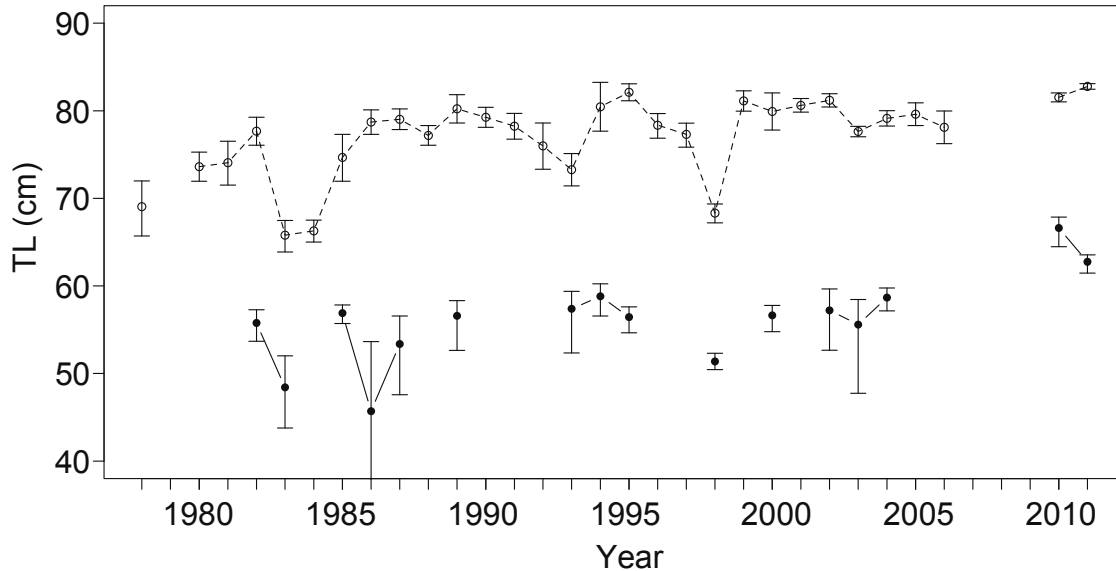
Figure 26. Mean total length (cm) of age-2 (filled circles, solid lines) and age-3 (open circles, dotted lines) Sacramento River fall-run Chinook recovered in recreational ocean fisheries in July of each year, 1978–2011. Error bars are 95% confidence intervals on maximum likelihood estimates. Convergent estimates could not be obtained for some years due to fishery closures, small sample sizes, or if fish were small relative to the legal size limit for retention (often 50 cm, sometimes 55–60 cm), which causes problems for the truncated likelihood methods used to fit these data (Satterthwaite et al. 2012).

Rope trawl surveys for juvenile salmon have recently been re-implemented in the coastal waters off central and northern California[20]. In contrast to low abundances (mean catch rate of 0.2 fish per 10^6 m^3 in 2007) associated with the collapse of the Central Valley Fall-Run Chinook salmon fishery (Lindley et al. 2009), recent midsummer surveys encountered high densities of juvenile Chinook salmon in both 2010 and 2011 (6.9 and 9.0 fish per 10^6 m^3, respectively). Although no quantitative comparisons have yet been made, preliminary data from the 2012 survey suggest that densities one-third to one-half those observed in 2010 and 2011. The 2010 cohort of juvenile Chinook salmon was still present in high numbers as subadult fish in July 2011, indicating relatively low mortality during the first year. Densities of juvenile Chinook salmon remained high into fall 2011, suggesting low over-summer mortality and good recruitment. The number of subadult fish was again high in the 2012 survey, despite evidence of higher over-winter mortality than in the previous year.

In July 2010, densities of juvenile coho salmon (fish that entered the ocean in spring 2010) off central and northern California were low relative to catch rates for juvenile Chinook salmon (0.3 versus 6.9 fish per 10^6 m^3, respectively), which is likely due, in part, to large differences in hatchery production of the two species in California. Subsequent catches of this cohort as subadults in 2011 suggest high survival during the first year at sea,

similar to observations of Chinook salmon. Abundance of juvenile coho salmon appeared to be higher in July 2011 than in July 2010 (0.9 versus 0.3 fish per 10^6 m^3, respectively), but very few juvenile coho were captured during the fall survey in 2011. It is unclear whether this decline is due to poor over-summer survival, to movement to depths below the reach of the surface trawl, or to dispersal outside the survey area. Early results from the 2012 survey indicate that overwinter survival for this cohort may have been much lower than for the winter of 2010–11. Preliminary data from the 2012 survey indicate that juvenile coho salmon were caught in densities similar to those observed in 2011.

In addition to evidence that abundance remained high throughout 2011, growth conditions[21] for Sacramento River fall-run Chinook salmon appear to have been favorable in spring 2011 (although not as favorable as in spring 2010). Age-2 fish recovered in July of 2011 (which entered the ocean in spring of 2010) were among the largest on record, exceeded only by age-2 fish in 2010 (fig. 26). The unusually large size of age-3 fish in 2011 provides additional evidence that conditions in 2010 were favorable for salmon growth. Record numbers of age-2 fall-run Chinook returned to the Sacramento and Klamath Rivers in 2011 (PFMC 2012), suggesting high survival through 2010 and 2011, or unusually high rates of early maturation.

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[20]These surveys are closely coordinated with the surveys off Oregon and Washington, and implement similar protocols.

[21]See Satterthwaite, et al. 2012 for further description of the data and modeling approach. The results presented here are based on independent maximum likelihood estimates for each year.
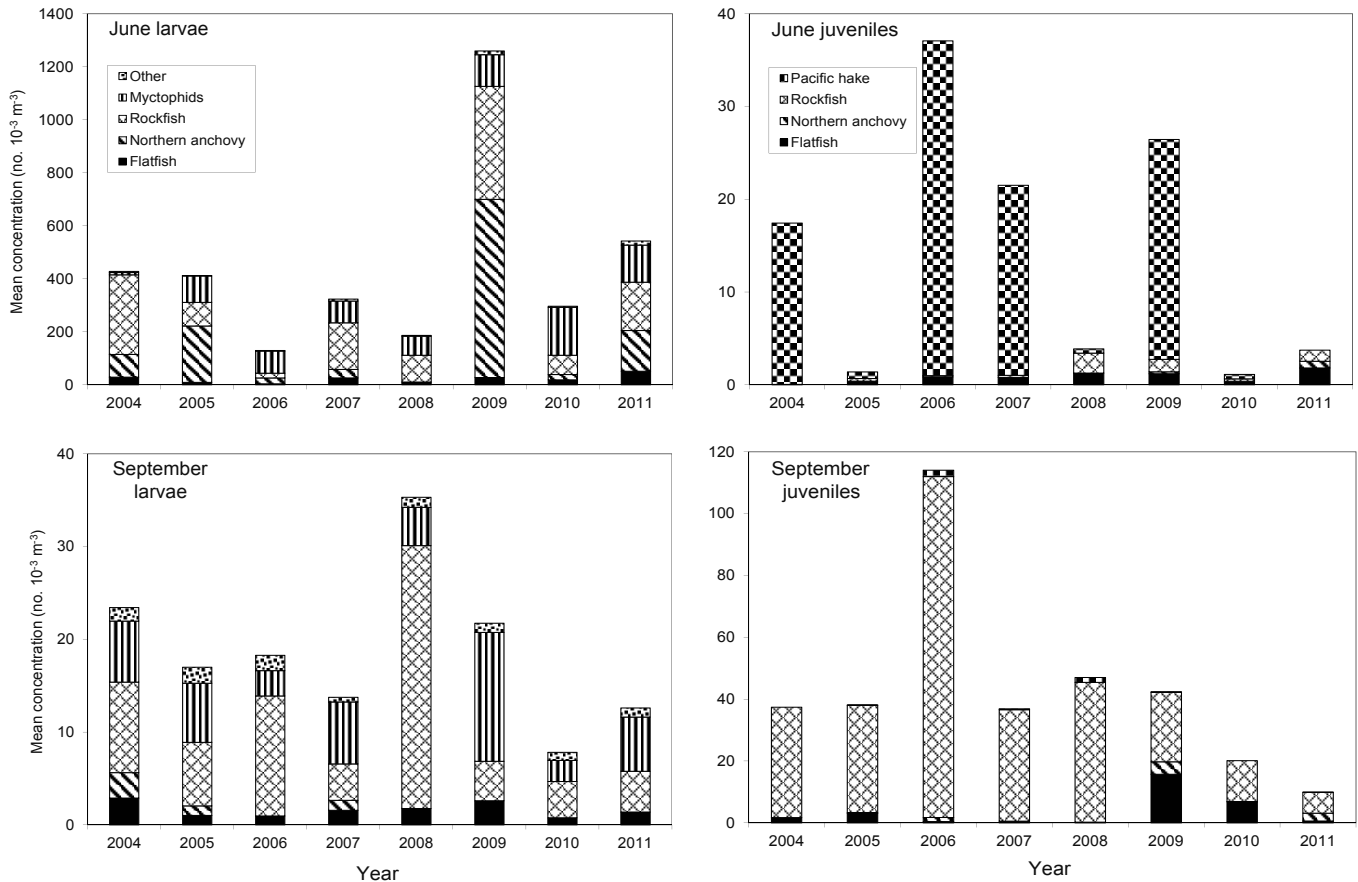
Figure 27.   Mean concentrations of dominant taxa for fish larvae (left) and juveniles (right) collected in June (upper) and September (lower) off the coasts of Oregon and Washington in 2004–11. Note that y-axes scales from June to September are reduced ~35-fold for larvae and are increased ~3-fold for juveniles.

Early Life History Stages of Fishes in the Northern CCS

Ichthyoplankton assemblages[22] off the coasts of Oregon and Washington in June and September 2011 exhibited mean concentrations and relative abundance of the dominant taxa that corresponded closely to the average community structure found in the same area and months during the previous seven years (fig. 27). However, the juvenile fish community[23] exhibited low concentrations in June 2011 relative to similar seasons in previous years, while the September 2011 concentrations were the lowest recorded in the eight-year time series (fig. 27). Within this overall pattern, however, the abundance of juvenile rockfishes in June showed recent changes similar to that observed off central California, but September catches continued to decline; further analysis is needed

to evaluate these patterns with respect to individual species. Myctophids (combined juveniles and adults) comprise the majority (~55%) of the pelagic midwater trawl catches of fish in this region and occurred at concentrations near seasonal means observed over the previous seven years in both June and September 2011.

The nearshore (9–46 km from shore) ichthyoplankton community along the Newport Hydrographic (NH) line (44.65˚N) during winter (January–March) 2012 exhibited relatively high biomasses of Pacific sand lance (*Ammodytes hexapterus*) and low biomasses of rockfish (*Sebastes* spp.), which is consistent with cooler oceanic conditions in the northern California Current (Brodeur et al. 2008; Auth et al. 2011). These patterns may reflect the influence of cross-shelf transport during upwelling in winter 2012, i.e., offshore dispersal of larvae from beach-spawning sand lance and transport of rockfish larvae from adult populations on the shelf and upper slope to waters beyond the range of the survey.

Pink Shrimp

Catch rates of pink shrimp (*Pandalus jordani*) were unusually high in 2011, and have been so since 2009, with

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[22]See Auth 2011 and Phillips et al. 2009 for details on sampling methods for larval and juvenile fishes. Briefly, samples were collected primarily at night using oblique tows of a 60 cm bongo net (335 µm mesh) from 100 m (or within 5 m of the sea floor). Samples were preserved in 95% ethanol, which was replaced after ca. 72 hours. All larval fish in each sample were removed, counted, and identified to the lowest taxonomic level possible.

[23]Data on juvenile fishes presented here have been corrected to resolve a database error, and supercede those presented in Bjorkstedt et al. 2011.
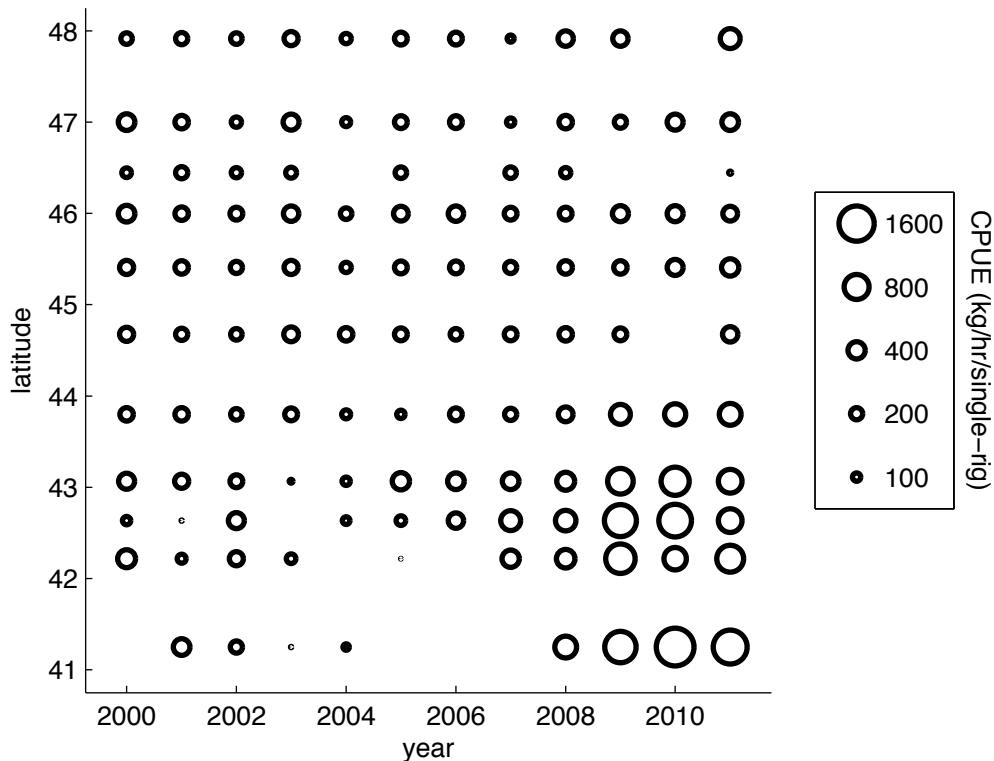
Figure 28. Catch-per-unit-effort (CPUE) in the pink shrimp (*Pandalus jordani*) fishery off Washington, Oregon and northern California. Missing symbols indicate insufficient data to calculate a robust estimate of CPUE as a consequence of low effort.

the greatest catch rates occurring south of Cape Blanco and into northern California (fig. 28). Catches in both 2010 and 2011 have been dominated by shrimp from the 2009 year class (i.e., shrimp hatched in spring 2009), particularly south of Cape Blanco. More recent recruitments are difficult to evaluate quantitatively due to fishers avoiding areas with smaller shrimp; however, fishers' observations appear to corroborate forecasts of average recruitment of shrimp hatched in spring 2011, based on environment-recruitment relationships (Hannah 2011).

Gelatinous Zooplankton

Oregon/Washington. Large gelatinous zooplankton taxa have been quantified in large pelagic surface trawls off Oregon and Washington since June 1999[24]. The dominant species, *Chrysaora fuscescens*, was not very abundant in June the first two years of sampling, but since that time has become the majority of the jellyfish catch (fig. 29), consistently occurring in high abundance in the years following 2001. The smaller hydromedusa, *Aequorea* spp., was found in most years but was numerically dominant only in 1999 and 2000. The next most abundant species, *Aurelia labiata*, occurred in relatively low abundances in this region. By September, *C. fusce-*

[24]See Suchman et al. 2012 for collection methods.

scens dominates the catches in all years except 2010, reaching maximum biomass in 2007. Abundances of these large medusae overall were the lowest for both monthly periods during the El Niño of 2010, and have only rebounded slightly in 2011 (fig. 29). However, surveys on the shelf in both these years witnessed particularly high densities of salps of offshore origin, especially in the fall of 2010 and spring of 2011.

Central/Northern California. In contrast to the trends observed off Oregon and Washington, the abundance of *C. fuscescens* captured during late-spring midwater trawl surveys between Point Reyes and Monterey Bay appears to have increased by at least a rough factor of two to five from the mid-2000s to 2010–11 (fig. 30). The largest catches of *C. fuscescens* consistently occur within the Gulf of the Farallones. It is likely that the increase in density of *C. fuscescens* in this region is substantially larger, as it is exceedingly difficult to quantify the abundance of *C. fuscescens* at high densities with the current sampling protocols. In contrast, catches of *Aurelia* spp. are more variable, and total abundance of *Aurelia* spp. rarely exceeds that of *C. fuscescens*. The largest catches of *Aurelia* spp. typically occur inside Monterey Bay, predominantly in the "upwelling shadow" (Graham and Largier 1997) in the northern part of the bay.

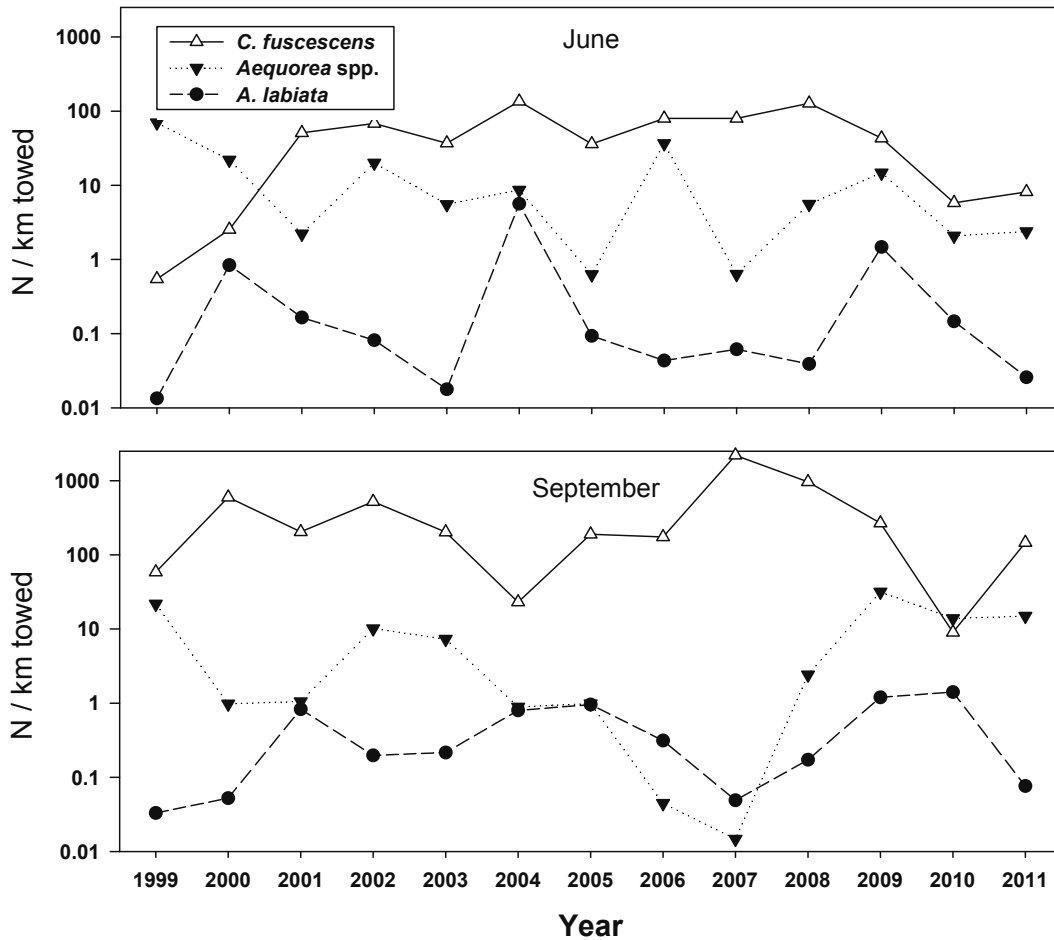Trends in the abundance of *C. fuscescens* encountered

Figure 29. Catches of the three dominant species of jellyfish in pelagic surveys off the coast of Oregon and Washington in June and September, from 1999 to 2011.

during the midwater trawl survey are consistent with changes in abundance observed during the SWFSC salmon surveys conducted in early summer, in which the *C. fuscescens* were two to five times more abundant (at least) in 2010–11 (mean catches of 116–255 individuals per 10^6 m³) than in 2007 (57 individuals per 10^6 m³). In contrast, *Aurelia* spp. declined from rather high abundance in 2007 (426 individuals per 10^6 m³) to very low abundances in 2010–11 (0.5 to 4.9 individuals per 10^6 m³).

Quantitative counts of other gelatinous taxa during the midwater trawl survey had been discontinued after 2001 but were resumed in 2012 upon recognizing the unusual abundance of gelatinous taxa during the 2012 midwater trawl survey. The abundance of *Thetys vagina* in the historical "core region" of the survey (roughly Point Reyes to Point Pinos) remained well within the range of previously observed "outbursts" (fig. 30). In contrast, the numerical abundance (and by a greater margin, the volume) of other salps and pyrosomes far exceeded previously recorded values (fig. 30). Catches of salps and pyrosomes were even higher in southern parts of the survey (fig. 30).

Southern California. The spring 2012 CalCOFI cruise also encountered unusual numbers and volumes of diverse gelatinous taxa—a pattern noted as exceedingly unusual by NOAA staff who have participated in Cal-COFI surveys for over 25 years. Gelatinous zooplankton were most abundant north of Point Conception and in offshore waters, coincident with the region where high concentrations of sardine eggs were observed (fig. 22).

Seabirds and Marine Mammals

At-sea density of seabirds off southern California[25]. Based on analysis of data on seabird abundance at sea, seabirds in the CalCOFI region have declined (Hyrenbach and Veit 2003) and their distribution has shifted

[25]Surveys of marine birds have been conducted in conjunction with seasonal CalCOFI/CCE-LTER cruises since May 1987. Observations are collected by experienced observers, who identify and count seabirds within a 300 m wide strip transect while the ship is underway at speeds >5 k (see Yen et al. 2006 for details). Relative abundance is expressed as density of birds at sea (birds km⁻²).
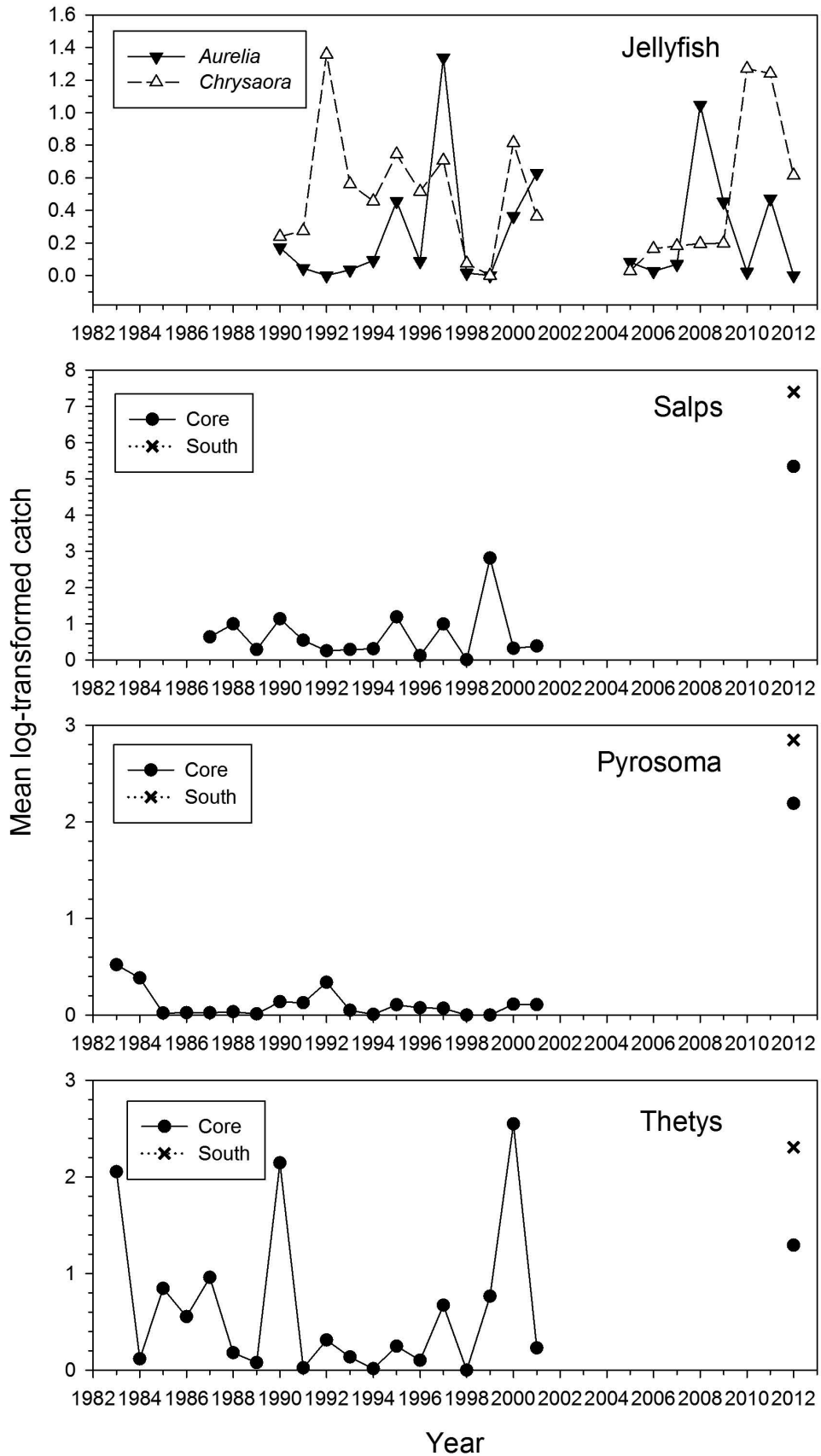
Figure 30.   Catches of gelatinous plankton from the core and southern regions of the SWFSC/FED midwater trawl survey.
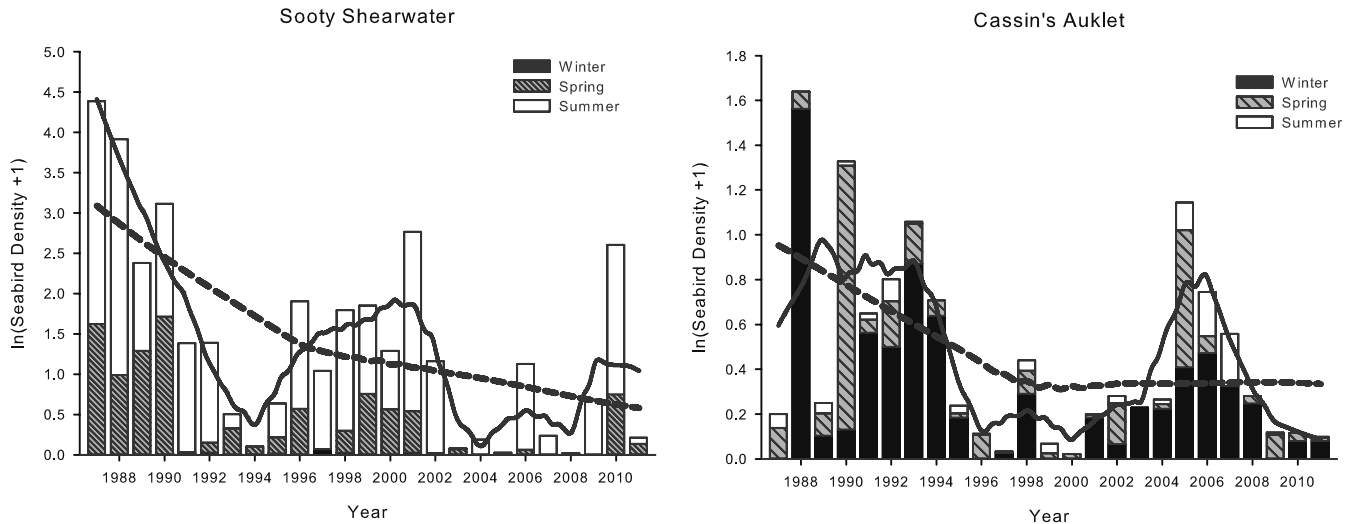
Figure 31.   Patterns of change in the abundance (expressed as at-sea density) of sooty shearwaters (*Puffinus griesus*; upper panel) and Cassin's auklets (*Ptychoramphus aleuticus*; lower panel) over three seasons: winter, spring, and summer. Lines indicate LOESS fits with sampling proportions of 0.8 (dashed line) or 0.2 (solid lines).

towards the coast over the past 25 years, and these trends in abundance and distribution have persisted through summer 2011. Two species provide representative examples of these patterns: (a) sooty shearwaters (*Puffinus griesus*), which are migrants from the southern hemisphere and are most abundant in the California Current during the spring and summer (i.e., during the austral winter), and (b) Cassin's auklets (*Ptychoramphus aleuticus*), which are resident in the California Current year-round, but are most abundant in the CalCOFI region in winter.

Shearwater density has declined in a log-linear fashion since surveys began in the late 1980s, with each successive peak in abundance (i.e., 1990, 2001, 2010) lower than the preceding one (fig. 31a). Trends (declines) in abundance were similar in both spring and summer. Shearwater density in 2011 was greatly reduced from the preceding year and is comparable to levels observed during previous troughs in at-sea densities, suggesting that foraging conditions were not as favorable as last year for these migrants (fig. 31a).

Following an apparent decline from high densities of auklets observed in the late 1980s, the abundance of auklets observed off southern California appears to be relatively stable or perhaps declining slowly, based on slight declines in peak densities observed during winter in the 1990s and 2000s (fig. 31b). Recent unusual increases in density in spring 2005 and summer 2005–07 are likely to reflect large-scale colony abandonment from the Farallon Islands, and/or non-breeding by auklets in those years (Sydeman et al. 2006). The density of auklets was little different in 2011 from 2010, and densities of auklets off southern California during Spring 2011 were very low (fig. 31b).

Breeding success of seabirds at Southeast Farallon

Island.   Breeding success of seabirds during the 2011 breeding season at Southeast Farallon Island (SEFI) was average for most species (fig. 32) (Warzybok et al. 2011). Among the piscivorus seabirds, productivity of common murres (*Uria aalge*), rhinoceros auklets (*Cerorhinca monocerata*), pelagic cormorants (*Phalacrocorax pelagicus*), and pigeon guillemots (*Cepphus columba*) declined from high values observed in 2010 to values very near the long-term means observed for each species (fig. 32). Less favorable ocean conditions and a decline in abundance of forage fishes, particularly juvenile rockfish, from the previous year likely contributed to the lower productivity for these seabirds when compared to the previous year. Cassin's auklets (*Ptychoramphus aleuticus*), which feed primarily on euphausiids, exhibited exceptionally high productivity (fig. 32). The average number of chicks fledged per breeding pair was the second highest on record, and reflected a high rate of successful double brooding. Brandt's cormorants (*Phalacrocorax penicillatus*) experienced near complete breeding failure in 2011, marking the fourth consecutive year of very low reproductive success, and western gulls (*Larus occidentalis*) had their poorest year on record, surpassing the record low productivity observed during 2010 (fig. 32).

Breeding success and diets of seabirds at Castle Rock. Common murres nesting at Castle Rock National Wildlife Refuge[26] show a somewhat different pattern of reproductive success over the past several years than has been observed at SEFI (fig. 33, upper panel). Breeding success in 2011 was the second highest observed in this

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[26]The proportion of nests that successfully fledged young is based on a subset of approximately 75 nests that were monitored every other day. Diet observations occurred for an average of 80 hours each year while common murre chicks were present.
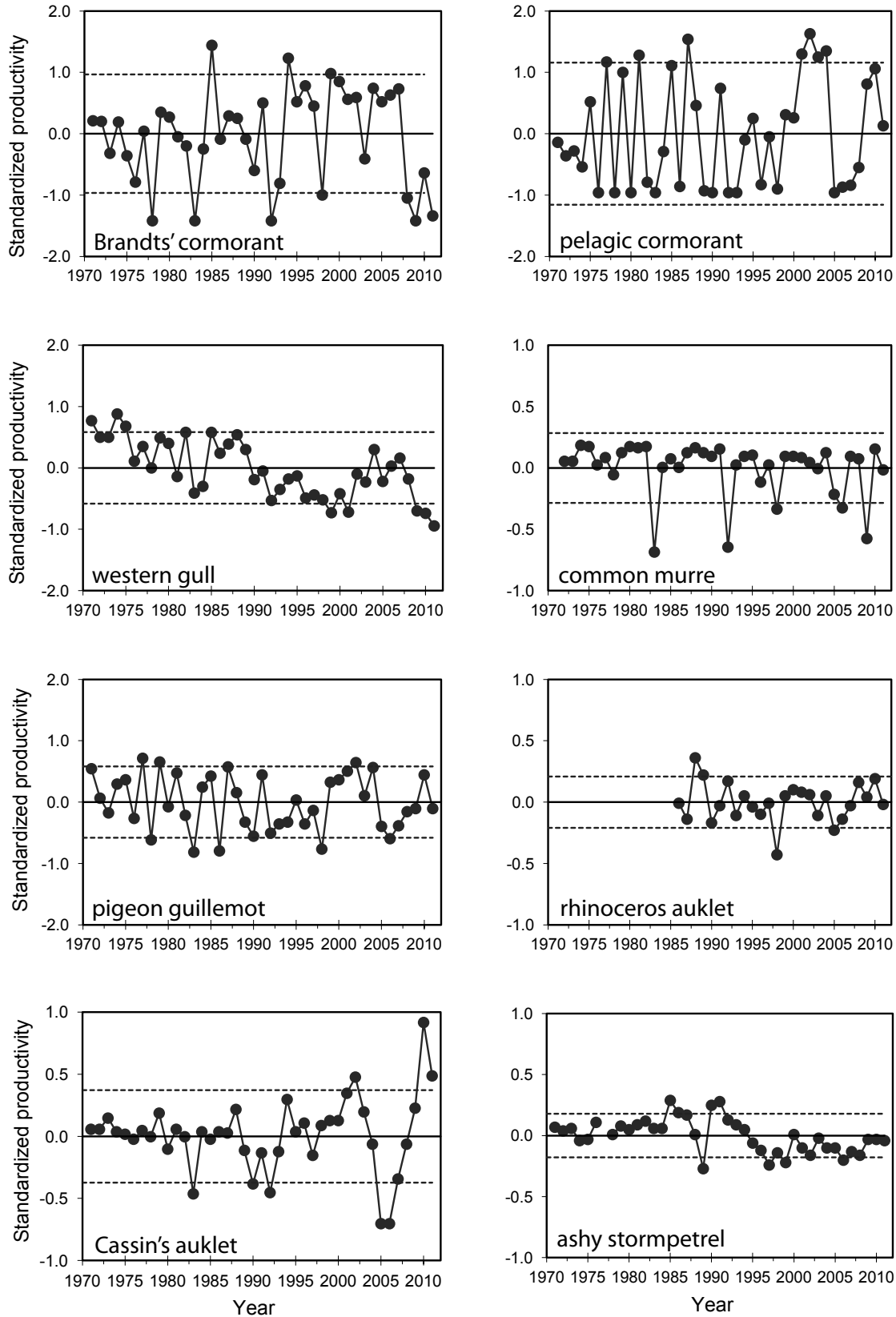
Figure 32.   Productivity anomalies of productivity (annual productivity – long term mean) for 8 species of seabirds breeding on SE Farallon Island, 1971–2011. Dashed lines represent 80% confidence intervals for the long term means. Species are Brandts' cormorant (*Phalacrocorax penicillatus*), western gull (*Larus occidentalis*), pigeon guillemot (*Cepphus columba*), Cassin's auklet (*Ptychoramphus aleuticus*), pelagic cormorant (*Phalacrocorax pelagicus*), common murre (*Uria aalge*), rhinocerous auklet (*Cerorhinca monocerata*), and ashy storm petrel (*Oceanodroma homochroa*).
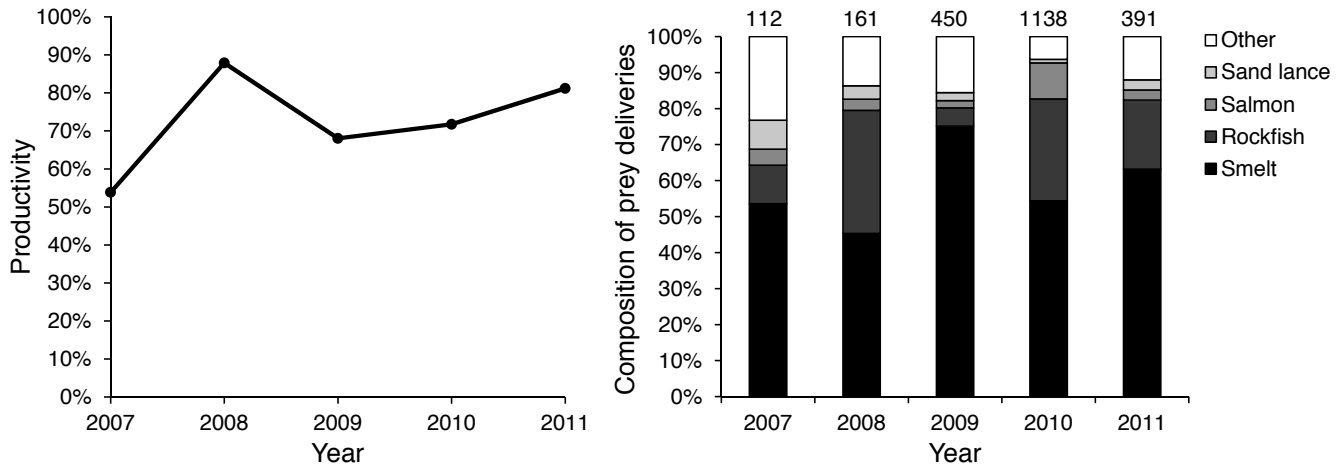
Figure 33.   Upper panel: Percentage of common murre (*Uria aalge*) nests that successfully fledged young (upper panel) between 2007 and 2011 at Castle Rock National Wildlife Refuge, Del Norte County, California. These data do not include the success of second clutches which are rare. Lower panel: composition of prey delivered to common murre chicks and between 2007 and 2011 at Castle Rock National Wildlife Refuge, Del Norte County, California. Numbers above each bar indicate the total number of identified prey deliveries for each year.

short time series and continues a trend towards increasing productivity since 2009. Replacement clutches are rarely observed in this colony: in 2010, 4 of 7 replacement clutches successfully fledged, but no replacement clutches were observed in 2011.

In 2011, a total of 16 prey types were delivered to murre chicks, and prey composition was generally similar to other years, with smelt (Osmeridae) being the predominant prey fed to chicks (fig. 33, lower panel). Unlike other years, however, 2011 was the first year that shrimp[27] were seen (2% of prey deliveries). The proportion of rockfish in deliveries declined from 2010 into 2011.

Breeding success and diets of seabirds at Yaquina Head, Oregon.   Reproductive success of common murres at Yaquina Head Outstanding Natural Area (YHONA)[28] was very low in 2011 (0.22 chicks fledged pair[-1]), which was less than half that observed over the previous 4 years of the time series (mean 0.69 ± 0.05 [SE] chicks fledged pair[-1]). While much of this decline can be attributed to greatly increased predation rates on eggs and chicks (3 to 10 times higher than in 2007–10), prey deliveries to chicks indicate that foraging conditions for murres also appeared to be suboptimal (fig. 34). In particular, flatfishes (Bothidae or Pleuronectidae), which are suboptimal prey, were unusually common among deliveries

to chicks during 2011, in contrast to the dominance of smelt (Osmeridae) and Pacific sand lance (*Ammodytes hexapterus*) in previous years. Pacific sand lance (*Ammodytes hexapterus*), which are usually associated with cool, productive conditions, increased in murres' diets in 2011, but remained quite low relative to productive years like 2008. The proportion of juvenile rockfishes in prey deliveries also declined from 2010 to 2011. The dramatic increase in predator disturbance in 2011 observed at YHONA was further corroborated by reports of predators (e.g., bald eagles) causing extensive reproductive loss at other seabird colonies on the northern Oregon coast, and may reflect regional-scale factors affecting predators' distribution or their prey resources.

Productivity of California sea lions at San Miguel Island[29].   California sea lions (*Zalophus californianus*) are permanent residents of the CCS—they breed in the California Channel Islands and forage throughout the CCS in coastal and offshore habitats—and have been shown to respond to changes in the CCS on different temporal and spatial scales (Melin et al. 2010). Two indices provide measures of foraging conditions for California sea lions at different times of the year: pup production (an indicator of prey available to pregnant females from October to the following June) and pup weight at four months of age (an indicator of prey available to lactating females from June to October). Pup production reflects conditions encountered in the females range in coastal

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[27]It is impossible to identify shrimp unambiguously to low taxonomic level using current methods for observing prey deliveries. Shrimp prey were identified as being from the broad taxonomic group Caridea, which includes pandalid shrimps such as the pink shrimp (*Pandalus jordani*).

[28]The proportion of breeding pairs that successfully fledged young was calculated as a mean among 10 to 12 plots each containing 7 to 25 breeding pairs that were monitored every 1 to 3 days. Murre chicks that remained on the colony ≥ 15 days were considered successfully reared to fledging age. Diet data were collected on 2 to 5 days per week during the chick-rearing period. Single prey items carried in the bill of adult murres were digitally photographed for identification. Each year, diet samples from 36 to 585 (median = 146) adult murres were identified.

[29]San Miguel Island, California (34.03˚N, 120.4˚W) is one of the largest colonies of California sea lions, representing about 45% of the U. S. breeding population. The number of pups born is estimated from the total number of dead (cumulative) and live pups (survivors) counted by the end of July in each year. Mean weight of pups at 4 months of age is based on data collected for 200 to 500 pups adjusted to a standard 1 October weighing date. This research was conducted under NMFS Permit 16087 issued to the National Marine Mammal Laboratory.
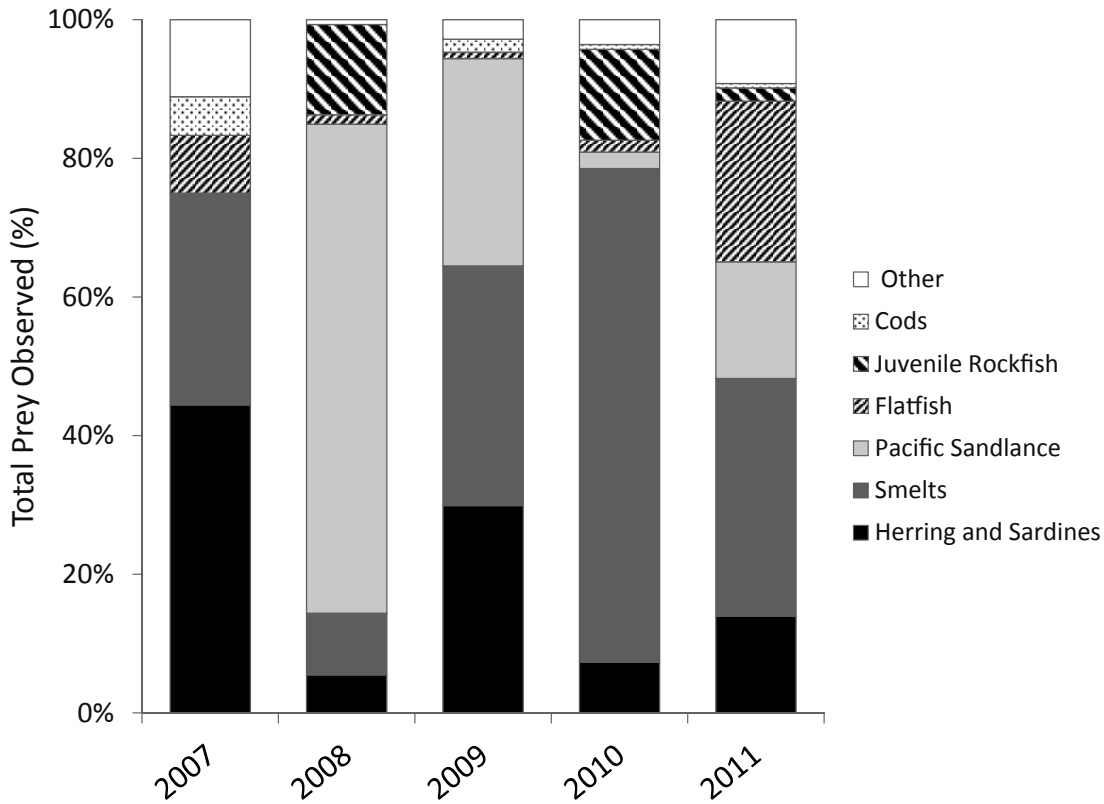
Figure 34.   Composition of prey delivered to common murre (*Uria aalge*) chicks between 2007 and 2011 at Yaquina Head Outstanding Natural Area, Oregon.

waters throughout the southern part of the CCS (south of Monterey Bay), while pup weight is an indicator of conditions females encounter during 2 to 5 day foraging trips away from their pup (Melin et al. 2010).

In 2011, the estimated pup production by California sea lions at San Miguel Island (SMI) was the highest ever recorded and was 28% higher than mean production (fig. 35, upper panel). After the substantial decline in production in 2010 associated with the 2009–10 El Niño, the increase in 2011 suggests that pregnant females experienced particularly good foraging conditions from fall 2011 through early summer 2011.

In contrast to pup production, mean weights of 4-month-old pups on SMI were significantly lower in 2011 compared to the long-term mean (fig. 35, lower panel), suggesting that adult female sea lions encountered poor foraging conditions during summer 2011. Mean pup weights in 2011 were similar to mean weights in 2009, when a collapse in the seasonal upwelling patterns off the central California coast caused unusually high pup mortality and dramatically reduced the condition of 4-month-old pups (Melin et al. 2010).

DISCUSSION

During 2011 and early 2012, the evolution of the state of the California Current reflected mixed, and sometimes seemingly contradictory, basin-scale and local forcing. Although La Niña conditions persisted across the California Current System (CCS) during much of 2011 and into 2012, the strength of cool anomalies and associated conditions was variable over time and space. Climate conditions, as represented by the MEI and PDO, displayed a modest relaxation towards neutral conditions in early-to-mid 2011. However, whereas the MEI suggests that subsequent recovery towards La Niña conditions was less robust than that observed in early 2010 following the 2009–10 El Niño (Bjorkstedt et al. 2011), the PDO indicated a strong return to La Niña, reaching some of the strongest negative (cool) anomalies in the recent record. The NPGO remained consistently but moderately positive, while exhibiting substantial variability and possibly a mild decline in strength throughout 2011 and into early 2012. The persistence of cool, but more moderate, conditions indicated by basin-wide indices was corroborated through field observations at several moorings and from several ongoing hydrographic surveys. In 2010, several of these surveys had encountered the coldest average conditions in the observational record (Bjorkstedt et al. 2011); 2011 observations were much closer to long-term mean conditions and in some cases, tended to the warm side in coastal regions of the northern CCS.
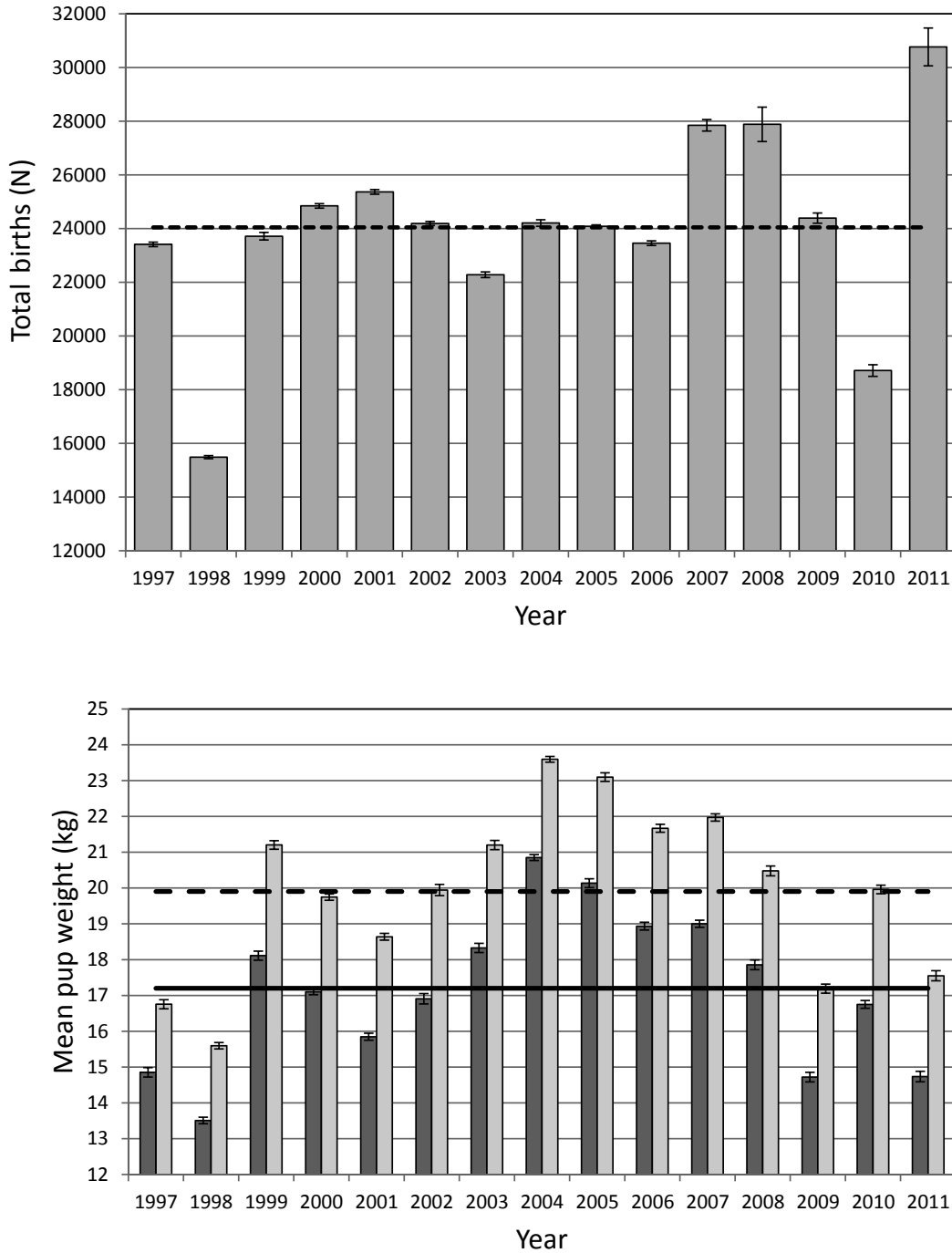
Figure 35.   Upper panel: Estimated number of California sea lion pup births (± 1 standard deviation) at San Miguel Island, California. Dashed line indicates mean over time series. Lower panel: Mean weights (±1 standard deviation) of 4 month old female (dark grey) and male (light grey) California sea lion pups at San Miguel Island, California. Lines indicate means for females (solid line) and males (dashed line) over the time series.

Within the broader climate context, available information indicates latitudinal variability in the timing and strength of local forcing, particularly with respect to the evolution of upwelling intensity along the coast. Ecosystem responses at lower trophic levels reflect these dynamics in both time and space. For example, in 2011, upwelling strengthened in the southern part of the CCS

relatively early but was generally near the climatological mean, except in the very southern part of the CCS. Correspondingly, concentrations of chl *a* and mesozooplankton (e.g., copepods) were elevated off Baja California for much of 2011, while biological metrics (e.g., chl *a* concentrations and zooplankton displacement volume) off southern California were close to long-term

means, despite the generally cool conditions.

In contrast, upwelling was relatively weak throughout early 2011 from central California north, only picking up strength in June and July before dropping off rapidly in late summer through early fall. Ecosystem consequences of this pattern are most apparent at the base of the food chain. For example, concentrations of chl *a* in Monterey Bay remained low through the spring and summer while upwelling was weak. High concentrations of chl *a* concentrations (i.e., concentrations typically observed in spring and early summer) were achieved only in late summer, following the onset of sustained upwelling. A similar pattern appears to have played out off northern California, with weak upwelling leading to lower than normal chl *a* concentrations in spring and summer 2011, and a rapid decline in chl *a* concentrations following the early cessation of sustained upwelling. Further north, off Oregon, weak upwelling had a physical signature (i.e., moderate temperatures of deep waters on the shelf despite cool SSTs at coastal buoys and the PDO) and apparent ecological consequences, e.g., a substantial decline in abundance of juvenile fishes despite evidence of consistent larval production and copepod indices less strongly indicative of the prevailing cool conditions than might otherwise be expected based on the PDO.

Several higher level ecosystem indicators suggest that the effects of persistent cool, productive La Niña conditions propagated through the ecosystem across southern and central CCS during 2011 but also indicate that productivity in general was weaker than in the previous year and that not all levels of the coastal ecosystem benefitted equally. Reproductive success of seabird populations on Southeast Farallon Island declined across the board from 2010, yet most species either fared quite well (Cassin's auklets, which feed on krill) or maintained productivity at or above long-term mean levels (several piscivorous taxa). The performance of auklets was corroborated by their low at-sea densities in the CalCOFI region—a further indication that euphausiid stocks were sufficiently productive for auklets to remain near their breeding sites (cf. Sydeman et al. 2006). Growth rates of Chinook salmon off California during the early part of the year declined modestly from 2010 to 2011, although they remained greater than had been observed in previous years. Indices of reproductive success in California sea lions capture signals of year-to-year changes in ocean productivity: pup production increased from 2010 to 2011, presumably reflecting better foraging conditions for female sea lions from fall 2010 through spring 2011 than during the 2009–10 El Niño, yet pup growth declined from 2010 to 2011 as the strong La Niña conditions that developed in summer 2010 were not repeated in 2011. The decline in at-sea densities of shearwaters off southern California suggests that foraging conditions in spring and summer 2011 were not as favorable as in the previous year. Increased predation was the proximate driver of low productivity of common murres on Yaquina Head, but the inclusion of suboptimal prey in murres' diets corroborates other evidence of declines in ecosystem productivity, particularly of juvenile fishes, off Oregon.

In contrast to these general trends, common murres in northern California (Castle Rock) appeared to exhibit a modest increase in productivity, raising the question of which spatial or temporal differences in ecosystem structure or forage base might underlie latitudinal variability in reproductive success of seabirds. In this case, reproductive success of murres remained high despite a decline in juvenile rockfish abundance (a common indicator of seabird productivity off California, e.g., Wells et al. 2008), which suggests that murres may be taking advantage of alternate prey, such as unusually abundant shrimp, to maintain reproductive success. While it is not clear whether alternate prey can offset declines in availability of juvenile rockfish or other prey, this example illustrates how data on diet and insights from fisheries-dependent data can inform our view of the California Current.

We note that while the general responses of higher trophic levels are consistent with observed forcing dynamics, the preliminary evaluations presented in this report do not necessarily account well for several possible ecological mechanisms for the observed changes. For example, several of the metrics discussed in the preceding paragraph may include unquantified contributions of density-dependence on reproductive performance or mortality due to predation or other factors. Other time series (e.g., at-sea densities of sooty shearwater) may include the effects of latitudinal shifts (e.g., Sydeman et al. 2009) as well as population processes happening outside the CCS. Finally, in contrast to measures of per capita reproductive success for long-lived organisms, changes in short-lived species such as market squid may be indicators of changes in abundance over time and thus integrate population growth over multiyear trends rather than yielding independent estimates of annual recruitment success.

As has been the case in several recent reports from this series (Goericke et al. 2005, 2007; Peterson et al. 2006; McClatchie et al. 2008, 2009; Bjorkstedt et al. 2010, 2011), available data lead to a conclusion that regional structure is a consistent characteristic of the CCS (e.g., Thomas and Brickley 2006; Thomas et al. 2009; Bograd et al. 2009). Resolving the structure with respect to regions' spatial extent, the scale of transition zones between regions, and the underlying mechanisms remains difficult due to differences in the temporal, spatial, and taxonomic scales at which data are collected throughout the CCS.

Several aspects of the observations presented above argue strongly for the importance of maintaining and modestly expanding the resolution and extent of observations throughout the CCS and for promoting greater integration of available data into this (and other) summary reports. Reasons for doing so are several. Perhaps foremost, the California Current is likely to show particular sensitivity to the effects of climate change (Checkley and Barth 2009) and ocean acidification (Gruber et al. 2012). The time series of CalCOFI data continues to show trends in dissolved oxygen (cf. Bograd et al. 2008, and this report) and nutrient concentrations (this report) that lend empirical support to model-based predictions of changes in upwelling source water characteristics associated with climate change (Rykaczewski and Dunne 2010). Continued development of capacity for assessment of such changes and their consequences elsewhere along the coast should be a priority.

A second reason is to enhance our ability to provide rapid assessment of spatial variability in ecosystem state. Broadly distributed, comparable observations are essential for assessing such variability, and they also provide insight into the applicability and reliability of ecosystem indicators based on historical time series of spatially limited observations. Variability in reproductive success of common murres from Oregon to central California provide one example where expanding the scope of observations leads to a broader perspective, even as it raises further questions about the underlying mechanisms. In another example, the dynamics of copepod community structure off Oregon and northern California have been generally coherent over much of the time series available for comparison (Bjorkstedt et al. 2011), yet this pattern appears to have been disrupted in early 2012, possibly as a consequence of unusual circulation patterns. Such events, if undetected, compromise the potential for ecosystem indicators based on local observations, even those as successful as the copepod-based indices derived from the Newport Hydrographic line, to apply broadly along the coast. Likewise, survey designs that do not fully encompass at-sea distributions of seabirds and pelagic fishes hinder our ability to evaluate whether apparent trends in abundance are real or are due to changes in distribution. For some taxa, such as seabirds, synthesis of observations CCS with data from elsewhere in the Northeast Pacific has been informative (e.g., Sydeman et al. 2009). For others, such as pelagic fishes, coast-wide surveys have had some success and are expected to make increasing contributions to future syntheses. Smaller-scale, high-frequency survey programs have emerged as a successful strategy for assessing the dynamics of the California Current in regions and seasons where weather can severely constrain the effectiveness of large-scale surveys, and are particularly useful in resolving year-round dynamics (Bjorkstedt et al. 2010, 2011). Efforts to enhance and improve the resolution of more traditional oceanographic data streams should be complemented by expanding the spatial range of data on higher trophic levels (e.g., seabirds); as demonstrated in this report, such data have substantial potential to yield greater insight to regional structure.

Looking forward, the resurgence of La Niña conditions in late 2011 appears to have supported relatively high productivity going into early 2012. Throughout much of the CCS, upwelling in late fall 2011 and early winter 2012 appears to have had particularly strong effects in the central part of the CCS, with increased enrichment going into early 2012 compared to that going into early 2011. The scope and direction of ecosystem responses to forcing during winter 2011–12 is as yet unclear, particularly in the northern CCS, but preliminary evidence suggests that early 2012 has been relatively productive.

However, these same observations suggest that 2012 may prove to be a particularly unusual year. Upwelling during winter 2011–12 would be expected to set the stage for high productivity throughout much of the CCS (Logerwell et al. 2003; Schroeder et al. 2009; Black et al. 2010, 2011), yet ecosystem surveys in spring and summer 2012 have encountered unusually high concentrations and volumes of gelatinous zooplankton throughout much of the CCS, so the ultimate consequences of early enrichment are difficult to forecast. Preliminary observations also suggest that the cross-shelf distribution of several taxa may be different in 2012 from those in previous years marked by cool, productive conditions. These observations, coupled with the emergence of ENSO-neutral conditions going into summer 2012 and the forecast development of El Niño in late 2012, suggest that the ongoing evolution of the state of the California Current will be very interesting indeed.

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