Marine Ecosystems of the North Pacific Ocean 2003-2008

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California Current

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highlights

- The timing, duration and intensity of coastal upwelling have been highly variable, with significant intra-seasonal oscillations. Upwelling was delayed in 2005 in the northern California Current System (CCS) resulting in discernable, pan-trophic disruptions in productivity, breeding, and species distributions. Intense upwelling has prevailed in 2006-2008.

- Long-term ocean time series have revealed trends toward lower dissolved oxygen content in the upper pycnocline, from southern California to Line-P. These trends are consistent with predictions from global climate models driven under global warming scenarios. The hypoxic boundary has shoaled in parts of the CCS, possibly leading to habitat compression for some species. Increased occurrence of continental shelf hypoxia has been observed off Oregon, with lethal consequences for coastal benthic species.

- Satellite and *in situ* data on primary productivity has revealed a tendency towards increased surface chlorophyll$_a$ concentrations throughout most of the CCS. However, dinoflagellates became more dominant in Monterey Bay in 2004 and 2005 leading to ecosystem changes at higher trophic levels.

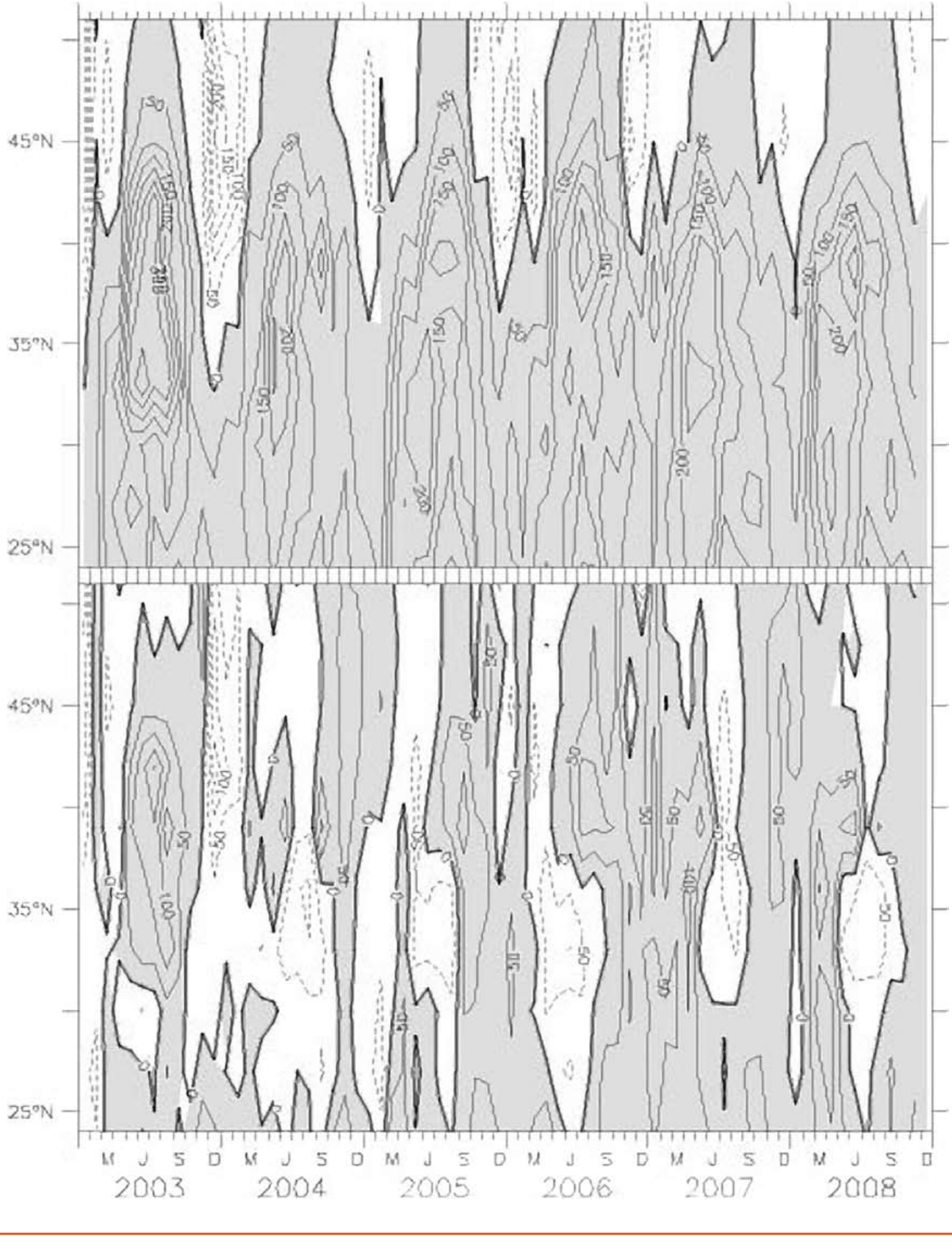
- Despite strengthened upwelling from 2003 to 2008 and cooler waters, the mesozooplankton (copepod) community off Oregon was comprised of many subtropical species up to 2008. In 2008, however, this community was dominated by species with "boreal", Subarctic zoogeographic affinities. Changes in *Neocalanus* phenology have been observed off British Columbia, with narrower and more short-lived peaks of abundance. The peak was significantly delayed in 2008.

- Rockfish production remained relatively low throughout the focus period. From Vancouver Island to Oregon, average marine survival of coho salmon was among the lowest observed since records began in the early 1970s. Sardine and herring recruitment and abundance have declined. Humboldt squid have continued their post-1998 range expansion into the northern CCS.

- Physical and biological data for the CCS have shown increasing ecosystem variability. Seabirds and marine mammals have shown dramatic responses including complete breeding failures (for the first time in 35 years) for Cassin's auklets off central California in 2005-2006 that were related to changes in upwelling phenology and corresponding changes in euphausiid populations. Cetacean populations have shown variable distributions, and the abundances of humpback whale is increasing.

Introduction

The California Current System (CCS) extends 3000 km from Baja California Sur to the northern tip of Vancouver Island, and is composed of several distinct circulation features. The California Current is a year-round equatorward flow extending from the shelfbreak to ~1000 km offshore, with strongest speeds at the surface and extending to at least 500 m depth (Hickey 1998). It carries cooler, fresher, nutrient-rich water equatorward. A narrow, weaker surface poleward flow along the coast is known as the California Countercurrent south of Pt. Conception, and the Davidson Current north of Pt. Conception. Another narrow but deeper poleward flow, the California Undercurrent, extends the length of the coast along the continental slope. Maximum current speed is usually from summer to early fall for the California Current and California Undercurrent, and in winter for the California Countercurrent/Davidson Current. The CCS is largely a wind-driven system, with little freshwater input except at the Columbia River. Three major estuaries, San Francisco Bay, the Columbia River, and Puget Sound contribute significantly to local economies. Coastal upwelling, El Niño, and decadal-scale climate forcing result in highly variable productivity of the region and consequently, for many fisheries (Bakun 1993; Aquarone and Adams 2009). Several long-term observing programs provide time series of physical, biological, chemical and fisheries variables within the CCS (Peña and Bograd 2007). These include: CalCOFI (Hewitt 1988; Bograd et al. 2003; http://www.calcofi.org), Line P (Freeland 2007; http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/linepdata/default_e.htm), and U.S. GLOBEC Northeast Pacific Program (Batchelder et al. 2002; http://globec.coas.oregonstate.edu). Fishery resources include invertebrate populations, especially in nearshore waters, groundfish populations along the continental shelf, and migratory pelagic species such as salmon (*Oncorhynchus* spp.), Pacific sardine (*Sardinops caeruleus*), Pacific hake (*Merluccius productus*), and Pacific herring (*Clupea harengus*) at the northern end of the CCS. At the southern end, the northern anchovy (*Engraulis mordax*) and market squid (*Loligo opalescens*) are important. The CCS also supports large and diverse seabird and marine mammal populations. This chapter contains a review of the status and trends of the CCS from 2003-2008, hereafter the *focus period*.



[Figure CC-1] Monthly upwelling index (top) and upwelling index anomaly (bottom) for January 2003–December 2008. Shaded areas denote positive (upwelling-favourable) values in upper panel, and positive anomalies (generally greater than normal upwelling) in lower panel. Anomalies are relative to 1948–1967 monthly means. Units are in m³·s⁻¹ per 100 km of coastline.

2.0 Atmosphere

2.1 Climate indices

(Di Lorenzo, McKinnell, Peterson, Sydeman)

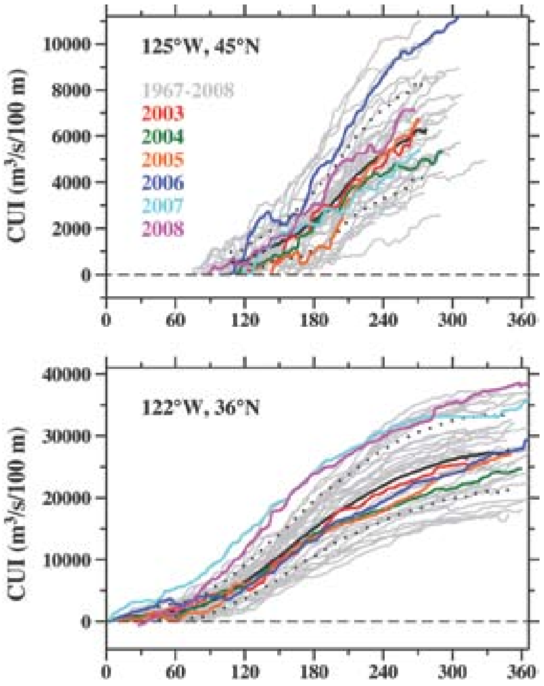
The wintertime North Pacific index (NPI) has increased during the focus period, indicating a trend toward higher than average sea level pressures from less intense and/or fewer winter storms in the subarctic North Pacific. The California Current region tends to have cooler surface ocean temperatures when the NPI is high. The Northern Oscillation index (NOI) has tended from negative to positive, indicating strengthening of the North Pacific High with relatively strong coastal upwelling, especially in 2007-2008. Correspondingly, the North Pacific Gyre Oscillation (NPGO) became positive in the past two years, while the Pacific Decadal Oscillation (PDO) became negative in the fall of 2007. The PDO has been in a generally positive state since 1977, with the exception of the periods 1999-2002 and 2006-2008. The Multivariate ENSO Index (MEI) has had relatively strong negative values in 2007-2008, reflecting La Niña conditions.

2.2 Coastal upwelling

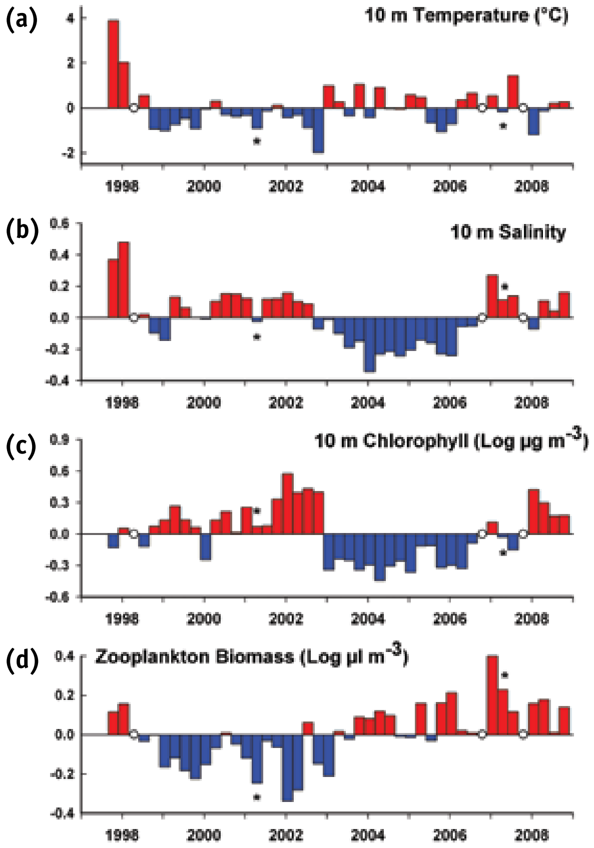
(Bograd, Durazo, Lavaniegos)

The intensity of coastal upwelling in the CCS was generally high during the focus period (Fig. CC-1). A strong upwelling season in 2003 was followed by strong winter downwelling in the northern CCS. The 2005 and 2006 upwelling seasons were unusual in terms of their initiation, duration and intensity. With the exception of a brief period of weaker than normal upwelling in the summers of 2007 and 2008, west coast upwelling index anomalies have been positive since the late summer of 2006. Wind patterns in early 2009 reflect anomalously strong high pressure over the Northeast Pacific and very high upwelling. At the southern end of the CCS, coastal upwelling off Punta Baja (30°N, 119°W) and Punta Eugenia (27°N, 116°W) has increased since April 2005.

The focus period was highly unusual in terms of the timing and duration (i.e., phenology) of coastal upwelling particularly in the northern CCS (Fig. CC-2). The phenology of coastal upwelling plays a particularly critical role in the region (Barth et al. 2007; Bograd et al. 2009). For example, the start of the upwelling season was significantly delayed in 2005 (Schwing et al. 2006) resulting in unusual coastal conditions (Kosro et al. 2006; Pierce et al. 2006) and ecosystem changes from primary production (Thomas and Brickley 2006) to zooplankton (Mackas et al. 2006) to fish, birds, and mammals (Brodeur et al. 2006; Sydeman et al. 2006; Wiese et al. 2006), respectively. In contrast, the upwelling season has begun either early or on time from 2006-2008 with particularly strong upwelling in the northern CCS in 2006 and in the central CCS in 2007-2008 (Fig. CC-2).



[Figure CC-2] Cumulative upwelling indices (CUI) vs. day of year for 1967-2008 at 125°W, 45°N (top) and 122°W, 36°N (bottom). CUI is computed by integrating the daily-averaged upwelling index from January 1 to December 31. Only the periods of positive CUI are plotted.



[Figure CC-3] Main physical and biological indicators of change in the Baja California pelagic ecosystem from quarterly IMECOCAL cruises between October 1997 and October 2008. Anomalies of the four variables calculated as deviations from the seasonal long-term means taken over the entire sample grid. Temperature and salinities at 10 m were taken from CTD profiles; chlorophyll concentrations are from water samples taken at 10 m; zooplankton biomass was measured as displacement volumes from standard oblique bongo net-tows (0-200 m). Biological variables were log-transformed. Open circles along the x-axis are missing cruises and asterisks indicate only data from the northern transects.

3.0 Oceanography

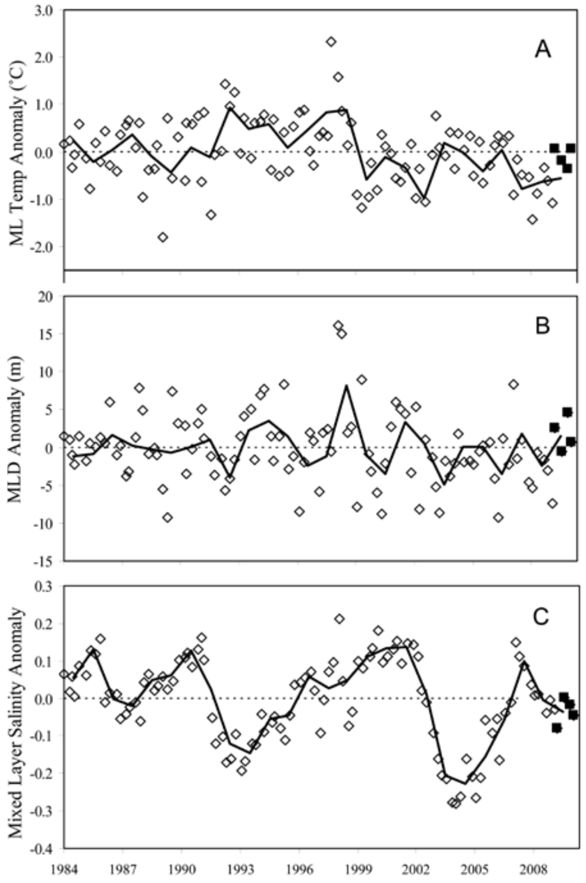
3.1 Hydrography

(Bograd, Chavez, Crawford, Di Lorenzo, Durazo, Goericke, Koslow, Peterson, Suntsov, Whitney)

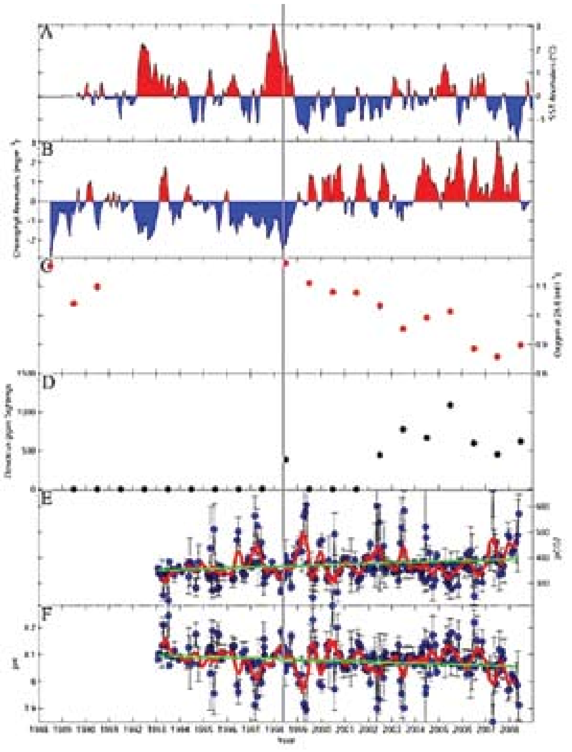
3.1.1 Temperature and salinity

Oceanographic time series off southern California and the Baja California Peninsula, Mexico are among the longest and richest in the world (Bograd et al. 2003; Peña and Bograd 2007). Field studies were initiated in the late 1940s to explain the collapse of the California sardine fishery and have continued under the auspices of the California Cooperative Oceanic and Fisheries Investigations (CalCOFI); since 1997 in Mexico, as the Investigaciones Mexicanas de la Corriente de California (IMECOCAL). These lengthy datasets allow the recent observations to be put into the context of interannual to decadal climate variability. Other time series of relatively shorter duration are also available.

Off Baja California, a period of relatively cool, saline near-surface waters extended between El Niños of 1997-1998 and 2002-2003, possibly a result of intensified coastal upwelling (Fig. CC-3). The period 2003-2006 was characterized by very fresh near-surface waters, while the El Niño events of 2002-2003 and 2006-2007 were characterized by much weaker temperature and salinity anomalies that those of the 1997-1998 event. Off southern California, mixed layer temperatures have been relatively cool (Fig. CC-4a). Mixed layer depth has not shown a consistent pattern but it has been ~5 m shallower than average during the past five years (Fig. CC-4b). Salinity in the mixed layer, on the other hand, has considerable low-frequency variability with a 5-10 year period that is correlated with the NPGO rather than the PDO (Di Lorenzo et al. 2008) (Fig. CC-4c). This is similar to the salinity variations observed off Baja California (Fig. CC-3).

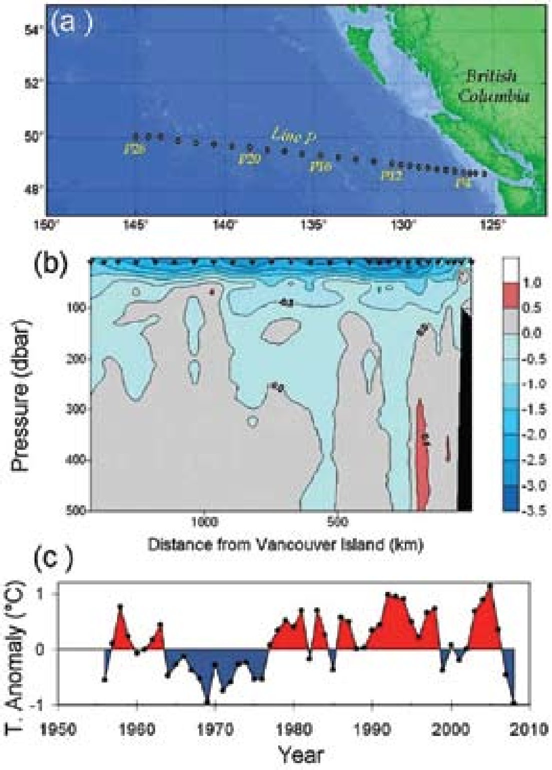


[Figure CC-4] Anomalies of (A) mixed layer temperature, (B) mixed layer depth, and (C) mixed layer salinity off Southern California (CalCOFI standard grid). Data from the last four CalCOFI cruises are plotted as solid squares, data from previous cruises are plotted as open diamonds. The solid lines represent the annual averages and the dotted lines, the climatological mean, which in the case of anomalies is zero.

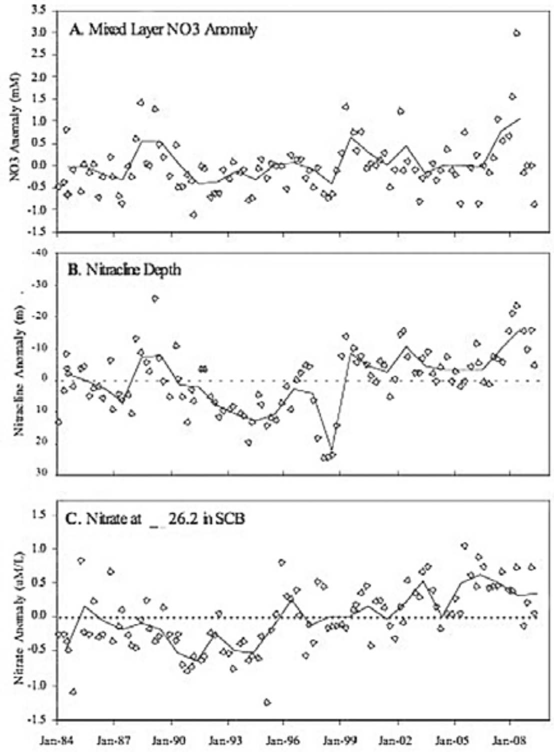


[Figure CC-5] Time series of SST, surface chlorophyll$_a$, oxygen on the 26.8 isopycnal surface, ROV sightings of the Humboldt squid (*Dosidicus gigas*), surface pCO$_2$ and pH measured in Monterey Bay and the California Current. The sharp regime shift, indicated by the vertical line, to cooler and more productive waters is evident in the SST and chlorophyll time series. The oxygen time series is incomplete but suggests that a decrease in oxygen started after the shift. A similar shift can be seen in the sightings of the Humboldt squid. The human-driven increases in pCO$_2$ and acidity (pH decrease) are evident in the lower panels. These changes are similar to those measured in the open-ocean Atlantic and Pacific but are slightly faster, presumably due to the regime shift.

A time series from Monterey Bay consists of a 20 year record of measurements taken on a cross-shore transect from inner Monterey Bay to offshore in the California Current. SST anomalies were similar to patterns observed by IMECOCAL and CalCOFI, with warmer conditions in 2005-2006 and cooler conditions thereafter (Fig. CC-5a,b). At the northern end of the CCS, the winters of 2007-2008 and 2008-2009 had stronger than normal westerly winds, bringing cool ocean waters from the Gulf of Alaska to the British Columbia coast (Crawford and Irvine 2009). Temperatures off British Columbia and along Line P were the coldest in several decades (Fig. CC-6). Deep waters in the Strait of Georgia have also been below normal in recent years (not shown).



[Figure CC-6] Annual average temperature anomalies along Line-P at 10-50 m. (from Crawford and Irvine 2009).



[Figure CC-7] Anomalies of (A) mixed layer nitrate concentrations, (B) nitracline depth (the depth where concentrations of nitrate reach values of 1 µM, and (C) nitrate concentration in the Southern California Bight at the 26.2 σ_θ isopycnal. Data presented as described for Fig. CC-4.

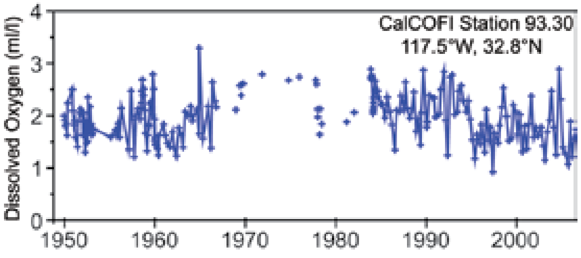
3.1.2 Dissolved inorganic nutrients and oxygen

Nutrient concentrations in the euphotic zone are a potential control on overall system productivity. Nitrate is the macronutrient often limiting phytoplankton biomass. In the southern CCS, concentrations of nitrate in the mixed layer (Fig. CC-7a) and the thermocline (Fig. CC-7b,c) have been above the long-term average since 1999. During the recent La Niña period, nitrate concentrations increased above the 1999-2008 average, likely driven by a shallowing of the nitracline depth (Fig. CC-7b).

Mean dissolved oxygen concentrations in the southern CCS have declined since the late 1980s (Fig. CC-8) resulting in substantial shoaling of the hypoxic boundary (Bograd et al. 2008). Potential mechanisms include isopycnal deepening driven by large-scale wind forcing and declining oxygen concentrations within the California Undercurrent source waters that are transported into the Southern California Bight. The decrease since 1984 was generally <10% at 50 to 100 m, but ranged from 10 to 30% at 200 to 300 m. The oxygen declines in the southern CCS are consistent with observations from several regions of the western and eastern Subarctic North Pacific, including off the Canadian west coast, where rates of oxygen decline have also exceeded 1% y^{-1} at 200-300 m (Fig. CC-9; Crawford and Irvine 2009).

3.1.3 Hypoxia and anoxia

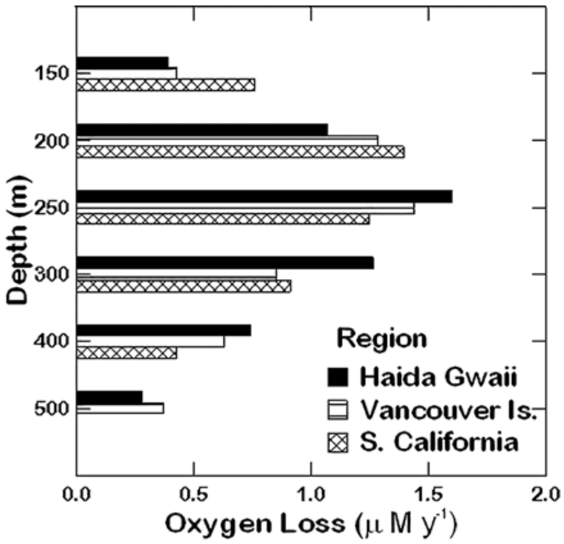
Some of the primary production in the surface layer of the California Current sinks and decays at depth so if production is higher (see Section 4), the increased decay of organic matter reduces subsurface oxygen, increases CO_2 and lowers pH. This process is clearly detectable at Monterey Bay (Fig. CC-5c). A repercussion of changes in ocean climate that enhances surface productivity is that continental shelf ecosystems off western North America, including important fishery species (e.g., Dungeness crab, rockfish), are now experiencing sporadic but nevertheless lethal anoxic conditions. These “dead zones” have long been known to occur beneath the extremely productive



[Figure CC-8] Dissolved oxygen concentrations ($ml \cdot l^{-1}$) at 200 m depth at a station off the coast of San Diego, CA (CalCOFI Station 93.30).

upwelling systems off Peru and Namibia, but are a new phenomenon in the CCS (Grantham et al. 2004; Barth et al. 2007; Chan et al. 2008). These changes in ocean climate reverberate through oceanic food webs leading to increases and redistributions of important predators like the Humboldt squid (*Dosidicus gigas*; Gilly et al. 2006; Field et al. 2007; Fig. CC-5d and see Section 4.3.4). Another repercussion of enhanced production is that the water being upwelled to the surface is more acidic, with as-yet unknown ecological consequences (see Section 3.1.4).

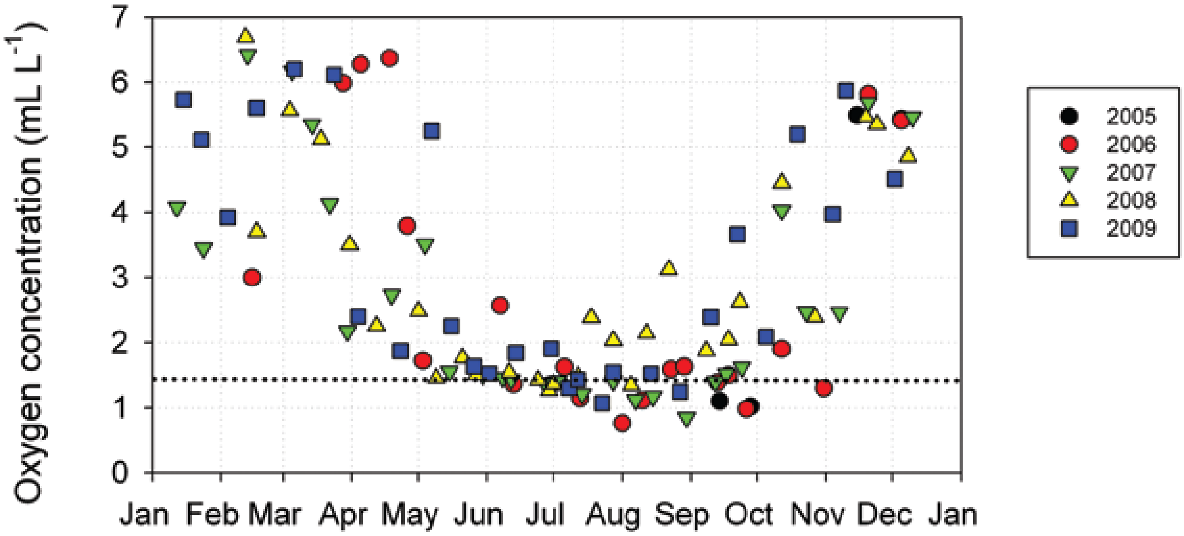
In the northern CCS, severe inner-shelf hypoxia and novel shoaling of water-column anoxia is related to enhanced upwelling, primary production and respiration. Demersal fish and benthic invertebrate communities off Oregon can be strongly affected by seasonally persistent anoxia and severe hypoxia. In August 2006, for example, surveys found no rockfish on rocky reefs and a near-complete mortality of macroscopic benthic invertebrates during one of the more severe anoxic events (Chan et al. 2008). Oxygen concentrations have been measured regularly along the Newport Hydrographic Line since September 2005. During the strong summer upwelling in 2006, water very low in oxygen was upwelled onto the shelf (Fig. CC-10). Oxygen concentrations were low in 2007 as well, another year of relatively strong upwelling off Oregon. Despite higher than average upwelling in 2008, oxygen concentrations fell below the hypoxic level on only two occasions.



[Figure CC-9] Rates of oxygen loss at three stations along the Pacific coast of North America (west coast of Haida Gwaii, west coast of Vancouver Is., and southern California). Redrawn from Crawford and Irvine (2009).

3.1.4 Ocean acidification

The slow and steady uptake of atmospheric CO_2 by the oceans has been observed in Monterey Bay (Fig. CC-5e) and in the open ocean time series off Hawaii and Bermuda. That it can be clearly detected in Monterey Bay is a surprise given the large high-frequency changes in pCO_2 due to coastal upwelling and biological production. The uptake of CO_2 by the oceans is lessening the atmospheric CO_2 problem but, in turn, the acidity of the oceans is slowly increasing (Fig. CC-5f) with potentially negative effects on some biota. In 2008, strong upwelling increased subsurface pCO_2 at Monterey Bay faster than what was seen in the atmosphere.



[Figure CC-10] Dissolved oxygen concentrations (ml·l^{-1}) at 50 m depth at Newport Hydrographic Line station NH-05.

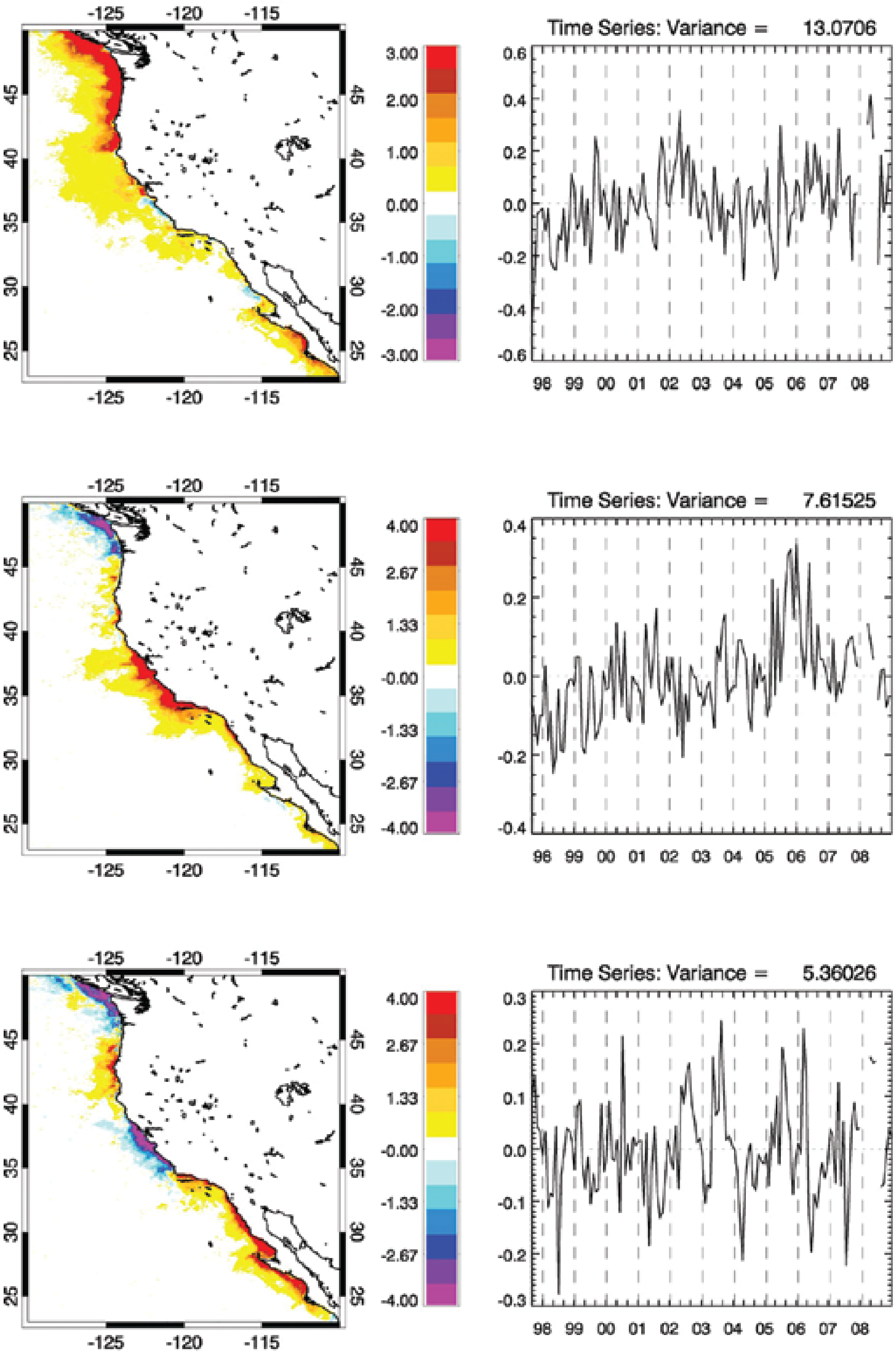
4.0 Biology

4.1 Phytoplankton *(Thomas, Kahru, Mitchell, Chavez, Durazo, Goericke, Koslow, Lavaniegos, Suntsov)*

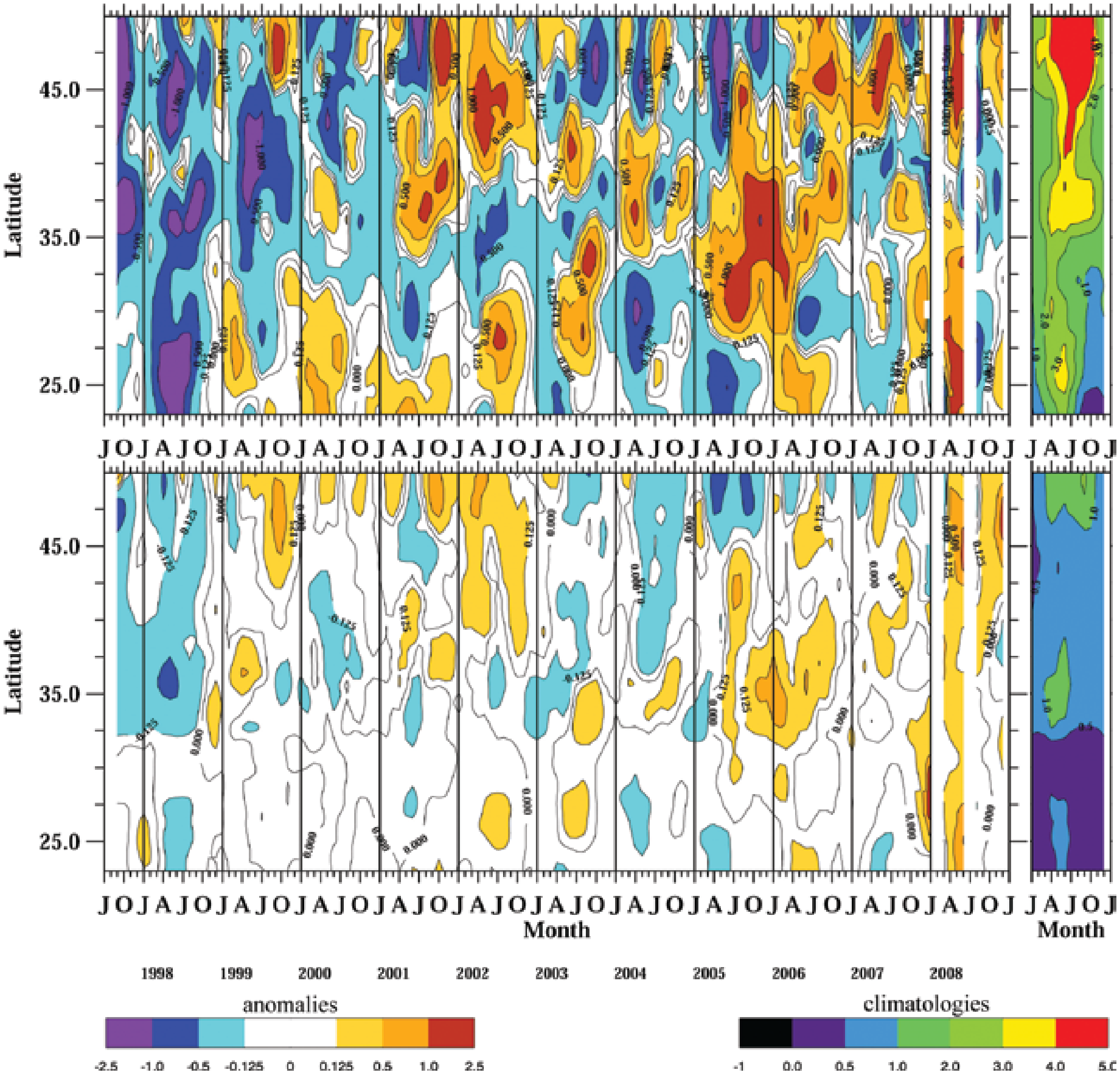
4.1.1 Surface chlorophyll interannual variability

The dominant spatial patterns of surface chlorophyll and their temporal variation can be identified by Empirical Orthogonal Function (EOF) decomposition of the non-seasonal time series (Fig. CC-11). The first mode (EOF1 = 13% of the non-seasonal variance) shows a strong coherence (higher values of EOF1 = higher chlorophyll concentrations) that extends 200-300 km offshore from the Vancouver Island to Cape Mendocino (40°N). South of this, the association with this pattern is weaker and constrained closer to shore with a narrow region of negative values off central California and Baja California. The time series of EOF1 was generally weak in 2003-2004, indicating that this spatial pattern (generally coast-wide chlorophyll concentrations) was not dominant. It was followed in early 2005 by a series of strong negative values that switched to strong positive values in mid-summer 2005 that lasted until fall. This period captures the change in upwelling phenology that occurred in 2005 when upwelling-favorable winds were delayed until mid-summer. The EOF1 pattern was weak through winter 2005-2006 but persistently positive through the rest of 2006, and again in summer 2007 and early 2008. The second mode (EOF2 = 7.6% of the non-seasonal variance) highlights out-of-phase variability in surface chlorophyll concentrations across the region. Negative values occur off British Columbia and Washington and positive values appear south of the Columbia River, strongest off central California. The strongest values of EOF2 were positive in 2005 extending into 2006, representing negative chlorophyll modal anomalies in the northern region and positive off central California.

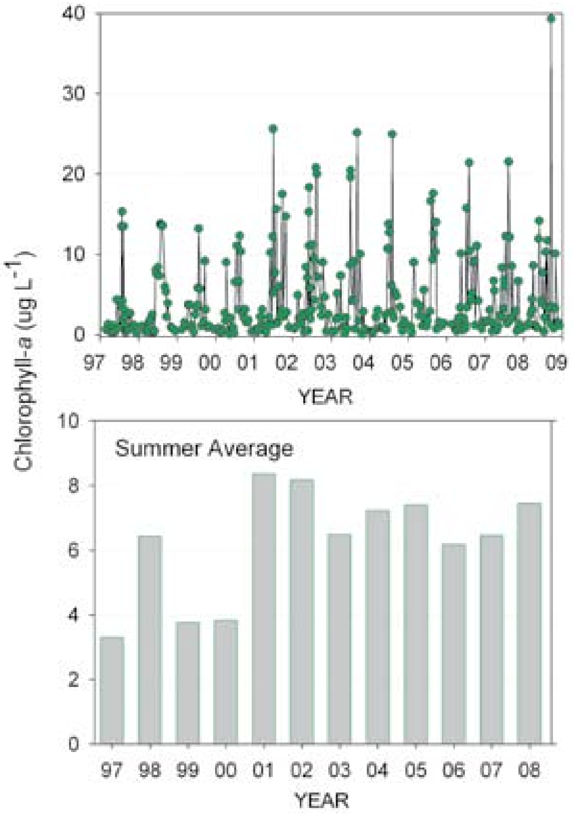
Mean surface chlorophyll concentration anomalies within two regions (0-50 km offshore, 100-200 km offshore; Fig. CC-12) describe variations within the coastal upwelling domain and the offshore region of enhanced upwelling-driven primary productivity, respectively. In the coastal upwelling domain, positive anomalies occurred from 30°-45°N in 2005, over much of the California Current region (except the Southern California Bight - northern Baja California region) in 2006, and remained strong north of 40°N in 2007, especially during early summer. Anomalies in 2008 were strongly positive from April-June throughout the region. These data reflect the latitudinal extent of anomalous upwelling in 2005, showing negative anomalies north of 40°N early in the year that remained negative throughout 2005 north of 48°N, but switched to strongly positive in July south of this. The strongest signals in the southern portion of the region were negative anomalies in 2004-2005 that switched to positive in the summer of 2006. In the offshore region,



[Figure CC-11] Dominant surface chlorophyll$_a$ spatial patterns and their temporal modulation in the California Current extracted by an EOF decomposition of the non-seasonal time series. Data are summarized from monthly composites of SeaWiFS satellite data, processed at 4 km resolution. Base period is 1998-2008.



[Figure CC-12] Surface chlorophyll$_a$ anomalies in the California Current as a function of time and latitude. Anomalies are averaged within two cross-shelf regions: 0-50 km offshore (top) and 100-200 km offshore (bottom). The monthly seasonal climatology for each cross-shelf region is shown at right.



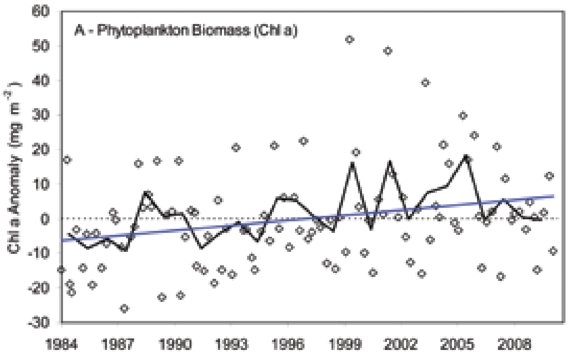
[Figure CC-13] Surface chlorophyll$_a$ time series (top) and summer average (bottom) at Newport Hydrographic Line station NH-05.

positive anomalies extended from 30-45°N in the summer of 2005 and persisted through winter and into summer 2006 in the region 30-40°N. Negative anomalies associated with the phenological shift in 2005 are evident north of 45°N, similar to those in the inshore region. Negative anomalies throughout summer 2004 in areas north of 35°N are less evident closer to shore, suggesting that the productive region was restricted to the coastal area that year. In 2008, anomalies in the offshore region were strongly positive and similar to those of the inshore region.

Surface chlorophyll concentrations in Monterey Bay have been anomalously high for several years (Kahru and Mitchell 2008; Kahru et al. 2009), consistent with the PDO shift that occurred in late 1998 (Peterson and Schwing 2003; Chavez et al. 2003; Fig. CC- 5b). Surface chlorophyll concentrations at a station on the Oregon continental shelf (NH-05, water depth 62 m) have also been high in recent years, with summer average values nearly double what they were in 1997-2000 (Fig. CC-13).

4.1.2 Chlorophyll at depth

Vertically-integrated chlorophyll$_a$ concentration in the mixed layer has an increasing trend and has been somewhat higher than average since 1999 (Fig. CC-14). This trend was observed at nearshore and offshore stations both north and south of Pt. Conception. The increasing trend in concentration of chlorophyll$_a$ is consistent with the long-term decline (since 1949) in Secchi depth in the coastal zone of the CalCOFI study region (Aksnes and Ohman 2009). Di Lorenzo et al. (2008) reported that the NPGO was correlated with salinity, nitrate concentration, and phytoplankton (chlorophyll concentration) within the CalCOFI domain.



[Figure CC-14] CalCOFI region averages for standing stocks of chlorophyll$_a$ integrated to the bottom of the euphotic zone, plotted against time. Data and symbol codes are the same as those in Fig. CC-4.

4.2 Zooplankton *(Peterson, Mackas, Durazo, Lavaniegos, Gaxiola-Castro, Goericke, Koslow, Suntsov)*

4.2.1 Regional time series

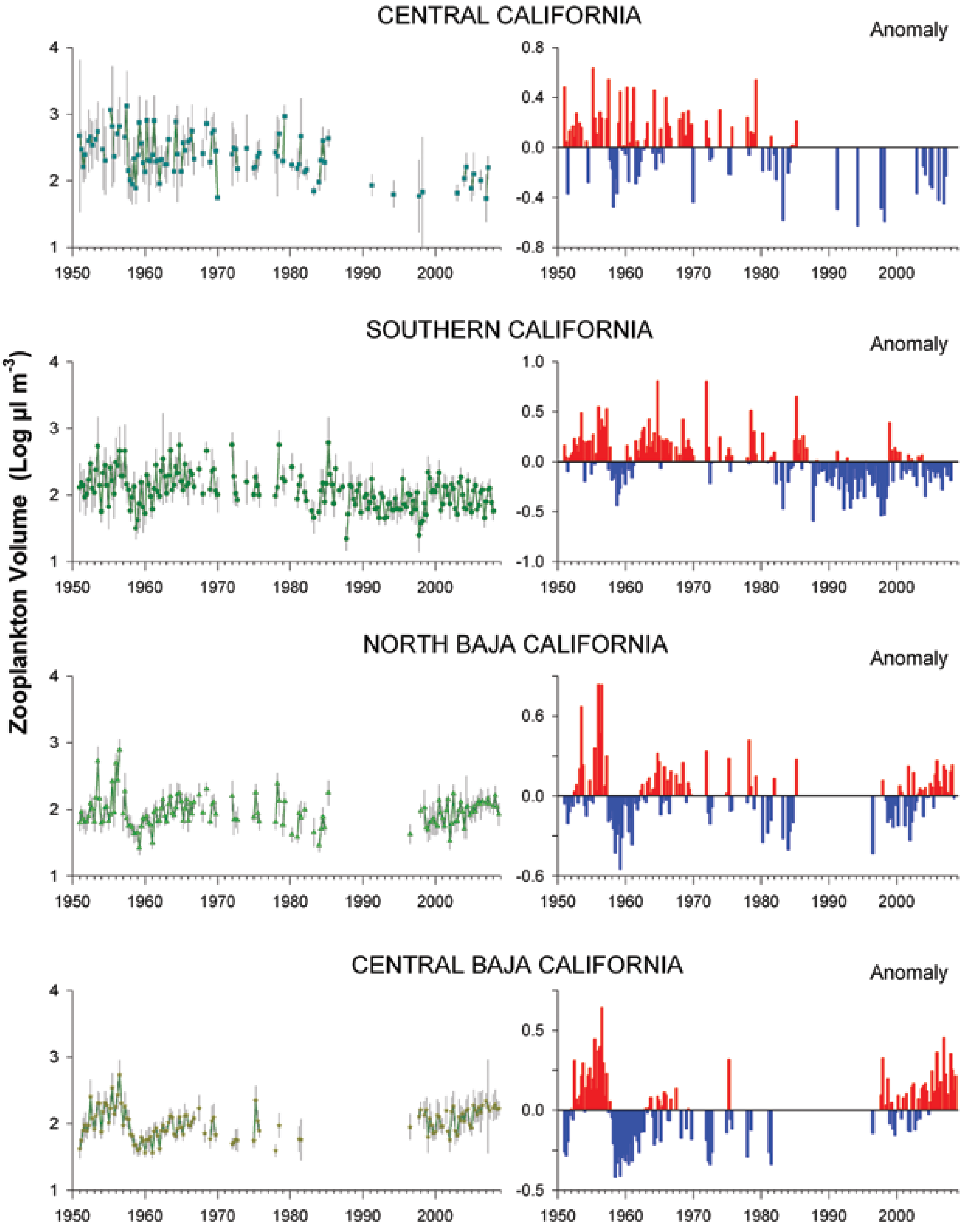
Off northern and central Baja California, zooplankton biovolume has an increasing trend from 2003-2008 (Fig. CC-3c,d). Zooplankton displacement volume off southern and central California has been low since about 1993; notably, the seasonal cycle of zooplankton biovolume, typical of earlier years in the time series, has been absent in recent years (Fig. CC-3a,b). Offshore curl-driven upwelling has apparently increased over time (Rykaczewski and Checkley 2008) and it promotes the production of relatively small zooplankton, which may not be sampled adequately by the coarse-meshed (505 µm) bongo nets used in the CalCOFI surveys. Nevertheless, the lack of a clear seasonal pulse in zooplankton biovolume in southern and central California in recent years is remarkable.

In the southern half of the CCS, the increasing trend in zooplankton appeared to be regional and more intense off central Baja California (Fig. CC-15; Baumgartner et al. 2008; Lavaniegos 2009). The increase was less intense in northern Baja California and was delayed after the recovery of low biomass during the 1999-2000 La Niña and the subarctic water intrusion (2002-2006). Unexpectedly, the trend was the opposite off southern California, which experienced a recovery in zooplankton biomass during La Niña only to diminish later with the freshening of the upper water column. The contrast is more remarkable considering that both northern Baja California and southern California regions are part of the recirculation that takes place in the Southern California Bight from summer to winter. The few data available from central California indicate negative anomalies in the last ten years.

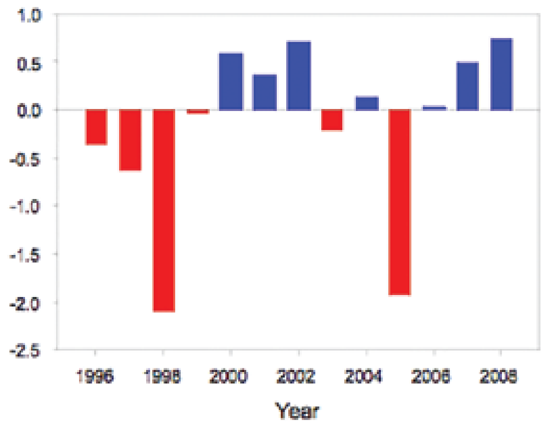
Biomass anomalies of the northern copepods (*Calanus marshallae, Pseudocalanus mimus, Acartia longiremis*) on the Oregon shelf were low in the warm years of 1998 and 2005, near average in 1996, 1997, 2000, and 2003, and above average during the colder years of 2000-2002 and 2007-2008 (Fig. CC-16). Note that extremely low biomass was observed both during the 1998 El Niño and during the 2005 "warm event". Copepod biomass began to recover in 2007 and reached values in 2008 that were similar to those observed in 2002. An index of copepod community composition was computed, based on an ordination of all samples (n=435) collected at Station NH-05 off Newport, OR, from 1996-present. When the PDO is in positive phase, a "southern" or "warm water" copepod community predominates, whereas a "northern" or "cold water" copepod community prevails in a negative PDO phase. Since the 2007 phase shift of the PDO, the northern copepod community has shown a consistently strong presence.

Zooplankton sampling off the southwestern coast of Vancouver Island has continued since 1979, and since 1990 (but with low sampling intensity and taxonomic resolution from 1991-1995) off northern Vancouver Island (Fig. CC-17). Sampling consists of vertical net hauls with black bongo nets (0.25 m² mouth area, 0.23 mm mesh aperture) from near-bottom to sea surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations (Mackas et al. 2001). Abundance and biomass are routinely estimated for more than 50 zooplankton taxa. Seasonal variability is intense and somewhat repeatable from year to year (Fig. CC-18). Year to year differences in abundance and species composition are calculated by averaging log-transformed anomalies within groups of species sharing similar ecological niches and zoogeographic ranges (1979-2005 baseline for southern Vancouver Island; 1990-2005 baseline for northern Vancouver Island).

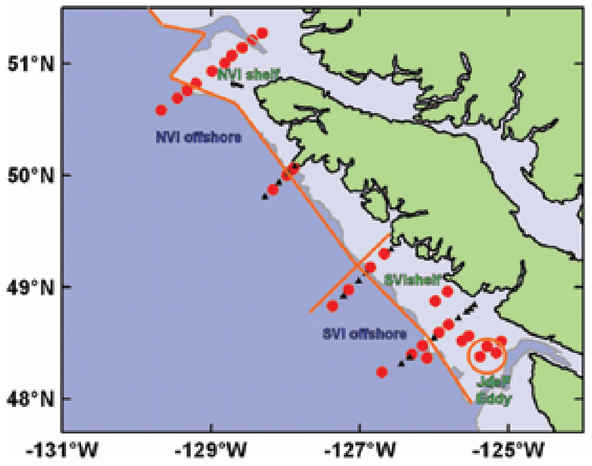
Sequences of warmer years were frequent during the past two decades. Warm ocean temperatures have direct effects on biota, but also cause changes in other important environmental factors such as increased vertical density stratification, resistance to wind-mixing and upwelling, reduced nutrient supply, reduced plankton productivity, and poleward shifts of anomalies in transport and migration. All of these push the zooplankton community toward reduced growth and survival of resident species, and increased abundance of their "warm-water" competitors and predators. These shifts in community composition are very evident in the southern Vancouver Island zooplankton anomaly time series (Fig. CC-19). Warm conditions prevailed in 2003-2005, leading to a higher abundance of "southern" origin copepod species and less abundant resident "northern" copepod species. Poleward/equatorward displacements were seen in other zooplankton groups, especially the chaetognaths. Cooler ocean conditions began to return in early 2006, but recovery of the boreal shelf copepods and northern chaetognaths and decline of the southern copepods and chaetognaths were delayed and more gradual. In 2007, the "cool ocean" community mix was confined primarily to the continental shelf. But in 2008, positive anomalies of cool-water (and negative anomalies of warm-water) zooplankton species groups were strong in all regions, leading to a zooplankton community similar in amount and composition to the beginning of our time series. The patterns of variation in the shorter northern Vancouver Island time series (Fig. CC-20) are qualitatively similar to those off southern Vancouver Island (bad for endemic species and good for southern species during warm years), but anomaly amplitudes off northern Vancouver Island are generally smaller. Zooplankton anomaly time series from further south in the CCS also show similar patterns of interannual-to-decadal variability (Mackas et al. 2006).



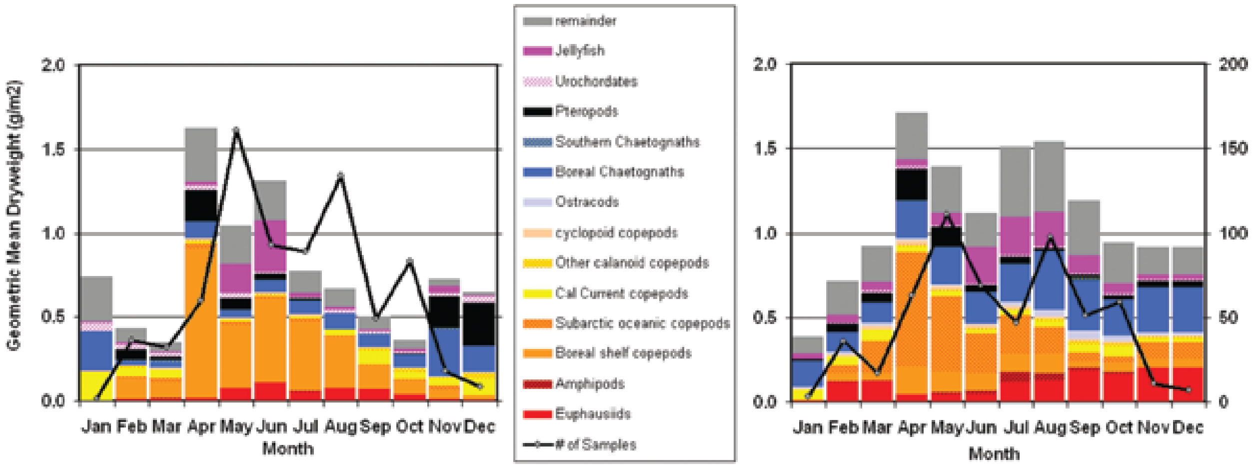
[Figure CC-15] Comparison of time series of zooplankton biomass in four regions of the CCS: central California (lines 60-70; 36°-38°N), southern California (lines 80-93; 32.5°-34.5°N), northern Baja California (lines 97-110; 30°-32°N), and central Baja California (lines 113-137, 25.5°-29.5°N). Left panels show the logarithm of quarterly values of mean biomass levels (with 95% confidence interval) over the corresponding lines. Right panels show the corresponding series of biomass anomalies obtained by removing the seasonal (quarterly) means from the values. All data are from nighttime samples. (CALCOFI data kindly provided by Mark Ohman and Paul Smith.)



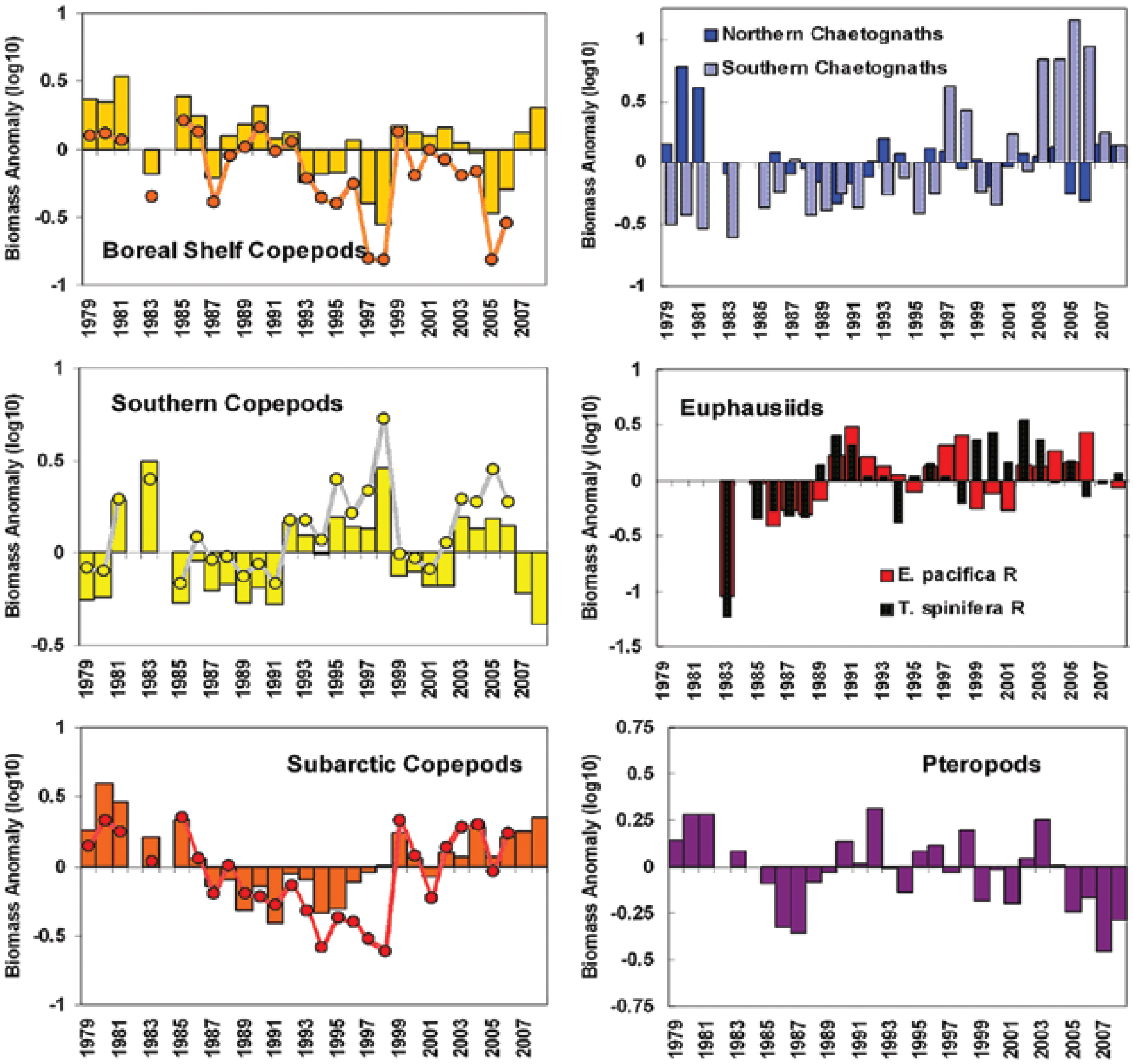
[Figure CC-16] Biomass anomalies of northern copepod species (*Calanus marshallae, Pseudocalanus mimus, Acartia longiremis*) based on bi-weekly sampling at Station NH-05 off Newport, OR (44.6°N). The anomalies are averaged monthly values for May through September for each year from 1996-2008.



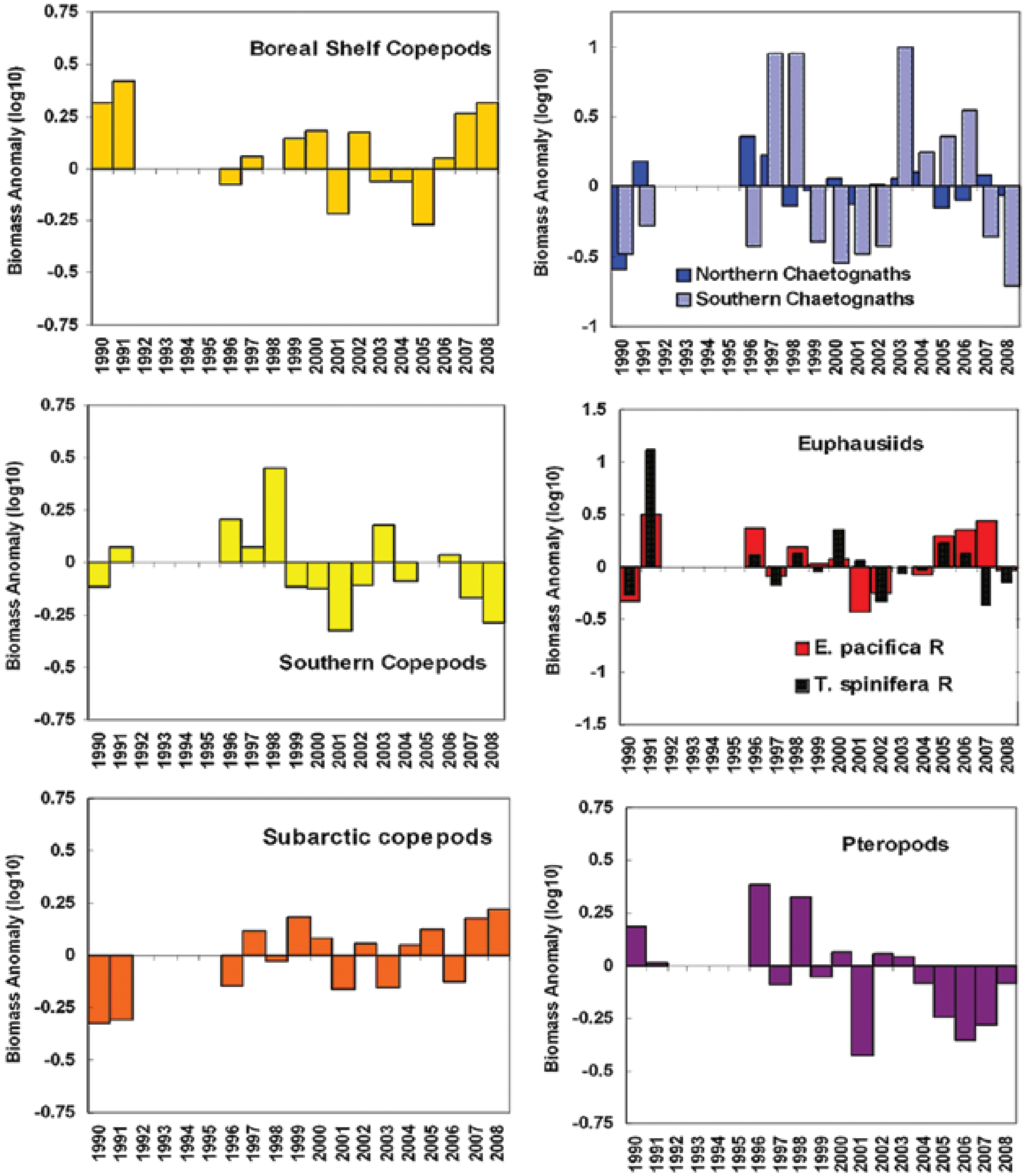
[Figure CC-17] Standard zooplankton sampling stations off the Vancouver Island continental margin (circles), and their spatial classification into statistical areas. Triangles show supplementary CTD stations.



[Figure CC-18] Average seasonal cycles (geometric mean of dry-weight biomass) for the southern Vancouver Island shelf and offshore regions shown in Fig. CC-17. Columns show cumulative amount within 14 summary taxonomic groups (1979-2005). Black lines show the number of samples included in each monthly and regional average.



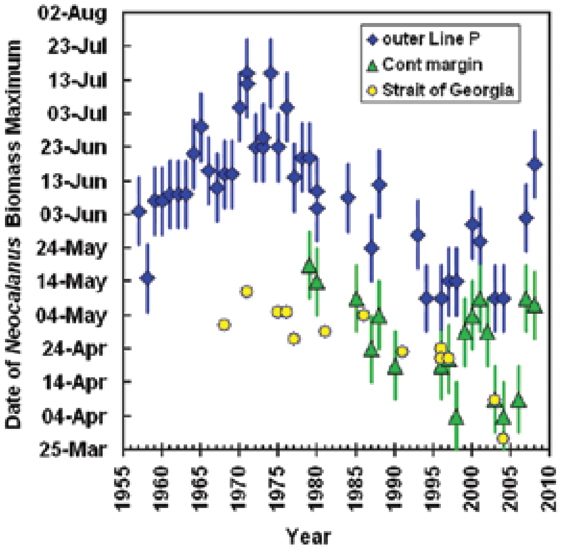
[Figure CC-19] Zooplankton anomaly time series for southern Vancouver Island. Column bars are species group anomalies referenced to the full 1979-2005 baseline period. The years 1982 and 1984 are omitted because there were too few samples. Circles and lines in the 3 left panels show for comparison the older anomalies (1979-1991 baseline). Euphausiid anomalies are reported only since 1983 (after a change in sampling method) and have been corrected for day vs. night effects on capture efficiency.



[Figure CC-20] Zooplankton anomaly time series for northern Vancouver Island. The years 1992-1995 are omitted because few samples were collected.

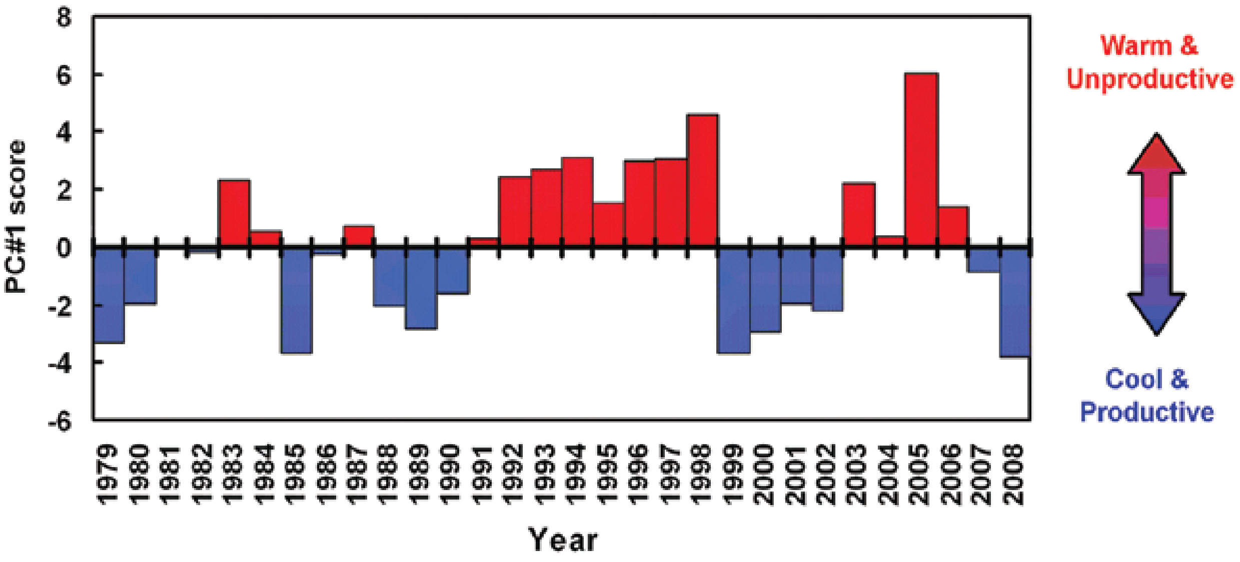
4.2.2 *Neocalanus* phenology off British Columbia

The biomass of the Subarctic oceanic copepods (*Neocalanus* spp.) has been increasing gradually off Vancouver Island since 1990. These large copepods make up most of the zooplankton biomass in the Alaska Gyre. They have an annual life cycle that includes a brief growing season from spring into early summer followed by emigration from the surface layer for a period of prolonged dormancy at depths from 400-1500 m. The annual biomass maximum, and maximum availability as food for upper ocean predators, is the 3-4 week period that precedes the start of this dormancy period. There is a very strong association between seasonal timing and ocean temperature (Mackas et al. 1998, 2007), with the annual biomass peak and onset of dormancy occurring early in the year if the upper ocean is warm in spring, and late if the water is cool. The years 2003-2006 were among the earliest recorded, both along the Vancouver Island continental margin, and in the Alaska Gyre (Fig. CC-21). Timing in 2007 was near the long-term average in both regions. Timing in 2008 was later than average (late June-early July) in the Alaska Gyre and near-average (mid-late May) along the continental margin.



[Figure CC-21] Time series of date of *Neocalanus plumchrus* biomass maximum for stations along Line-P.

The changes in zooplankton community composition in the past two decades appear to have had large effects on fish growth and survival (Mackas et al. 2007), probably because the "cool water" zooplankton are better fish food (larger individual body size and much higher energy content). Because much of the year to year variability of marine survival rate of harvested fish species occurs at early life stages (for salmon, in their first year after ocean entry), recent zooplankton anomalies provide a useful index of juvenile fish nutrition and a "leading indicator" for subsequent adult fish recruitment. Mackas et al. (2007) used multivariate ordination of the covariance among zooplankton composition and timing anomalies, local and large-scale indices of upper ocean temperature, and "success" of predator species (growth and marine survival of coho salmon on the west coast; sablefish recruitment; seabird reproductive success). They found that interannual variability of all of these series projected strongly onto a single component axis (loosely interpretable as a "cool-and-productive" to "warm-and-unproductive" gradient; Fig. CC-22). The years 1983, 1992-1998, and 2003-2006 all score as "warm and unproductive", however, data suggest that predator reproductive success and early marine survival of salmon may have been much better in 2008.



[Figure CC-22] Annual scores for zooplankton-temperature-predator Principal Component 1. Blue indicates cool temperature and favourable conditions for most of the endemic zooplankton and predators, red indicates warm and favourable for the southern zooplankton but unfavourable for endemic zooplankton and predators.

4.3 Fishes and Invertebrates

(Brodeur, Emmett, Field, Irvine, McKinnell, Peterson, Ralston, Schweigert, Tanasichuk)

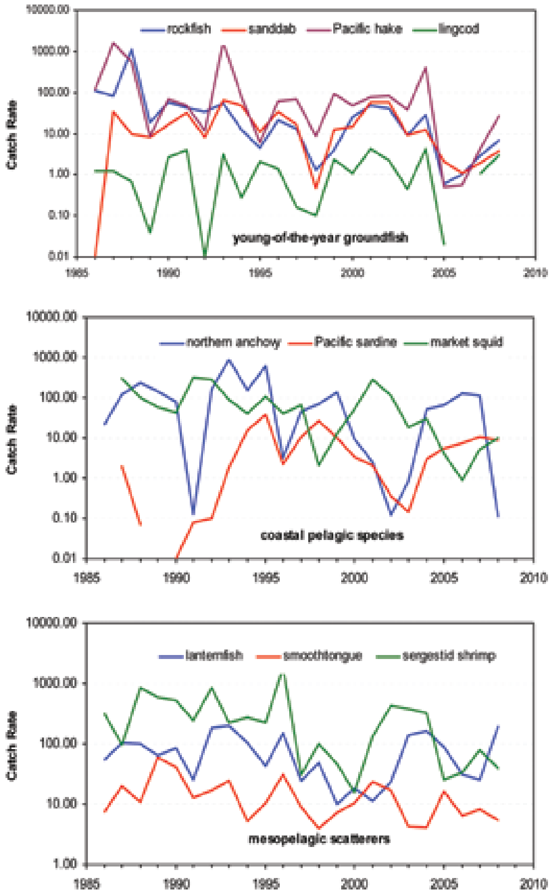
4.3.1 Larval fish abundance trends in the southern CCS

Based on CalCOFI data up to 2002, Hsieh et al. (2005, 2009) reported that the abundance of most oceanic fishes increased during warm phases of the PDO and declined during cool phases. These fishes are mostly mesopelagic and not commercially exploited making them a potential proxy for tracking environmental changes. Of the key coastal species, northern anchovy (*Engraulis mordax*) is often characterized as being favored during cool periods and Pacific sardine (*Sardinops sagax*) during warm periods (Chavez et al. 2003). However, for the past five years, a cool period, the abundance of sardine larvae has remained relatively high, but the abundance of anchovy and hake larvae has remained low (A. Koslow, Scripps Institution, pers. comm.), along with the larval abundance of jack mackerel (*Trachurus symmetricus*) and Pacific mackerel (*Scomber japonicus*). The larval abundance of *Leuroglossus stilbius, Stenobrachius leucopsarus, Tarletonbeania crenularis, Vinciguerra lucetia,* along with the coastal croakers, Sciaenidae spp. has also remained low during the past five years (Koslow and Suntsov, in prep.). The continuing recent declines in these oceanic species are inconsistent with the increased curl-driven upwelling offshore, which is hypothesized to lead to increased productivity (Rykaczewski and Checkley 2008). Their decline is, however, in agreement with the long-term decrease in zooplankton volume.

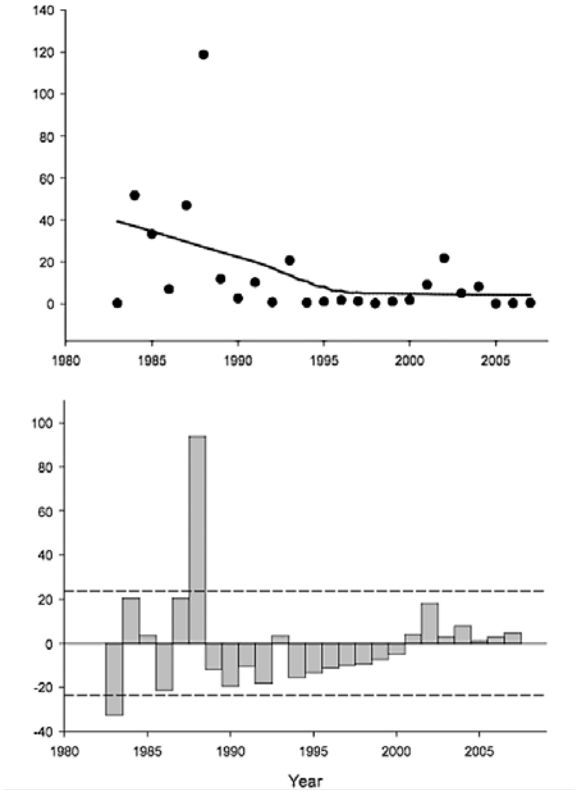
4.3.2 Forage fish and young of year predatory fish

The primary forage fishes in the CCS are Pacific sardine, northern anchovy, jack mackerel, chub (Pacific) mackerel, and Pacific herring (*Clupea pallasi*). Sardine, anchovy and mackerel are trans-boundary stocks, exploited primarily by U.S. and Mexican fleets. Sardines are taken for human consumption, bait, and aquaculture feed, while anchovy is generally reduced to fishmeal (Aquarone and Adams 2009). Market squid (*Loligo opalescens*) has become the most important fishery for the state of California in terms of revenue and landings. Landings of sardine and market squid to California ports have continued to increase, while those of Pacific herring, Pacific mackerel and jack mackerel have continued a dramatic decline in recent years (Sydeman and Thompson 2010). Primary groundfish resources in the CCS include sole, thornyheads, sablefish, rockfish, lingcod, flatfish, and Pacific hake.

A variety of epipelagic fish and invertebrate micronekton/nekton are sampled in the central CCS by a midwater trawl which is fished at a depth of 30 m with a 1-cm mesh cod-end.



[Figure CC-23] Long-term trends in abundance of 10 well-sampled taxa in NOAA's Southwest Fisheries Science Center (SWFSC) midwater trawl surveys, 1986-2008.



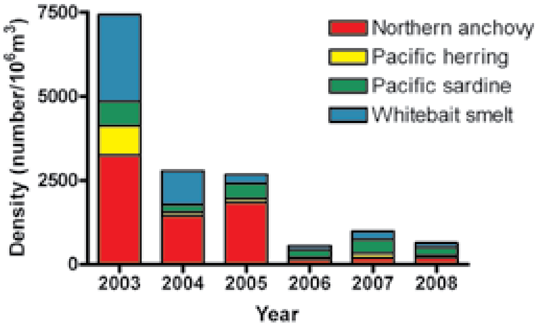
[Figure CC-24] Summed relative abundances (upper) and anomalies from long-term mean (lower) of 11 juvenile rockfish (*Sebastes* spp.) from the SWFSC midwater trawl surveys with a loess trend line indicated.

Catches of young of year (YOY) taken in replicate sweeps are available since 1986. Catches include rockfishes (*Sebastes* spp.), sanddabs (*Citharichthys* spp.), Pacific hake (*Merluccius productus*), and lingcod (*Ophiodon elongatus*). Likewise, catches of several important coastal pelagic species (northern anchovy, Pacific sardine, and market squid), as well as deep-scattering layer mesopelagic species (e.g., lanternfishes [*Myctophidae*], California smoothtongue [*Leuroglossus stilbius*], and sergestid shrimp) have been recorded routinely. Long-term trends in the average catch rates of 10 well-sampled taxa show significant interannual variability (Fig. CC-23). For example, YOY catch rates of Pacific hake have ranged over three orders of magnitude between 1986-2008. Among these taxa, lanternfish have been the least variable (CV = 0.76) and YOY rockfish have been the most variable (CV = 3.00). The composition of this forage fish community in 2005 and 2006 was most similar to that observed during the 1998 El Niño, with very low abundances of YOY groundfish and market squid, but with relatively high catch rates of anchovy and sardine. However, since 2006 the midwater trawl assemblage has trended back towards a species composition more characteristic of the cool, productive period of 2002. The relative abundance of juvenile rockfish (*Sebastes* spp.) observed in midwater trawl surveys varied among species but none increased over time (Sydeman and Thompson 2010). Abundances have been fairly stable since the mid-1990s, but have not reached the values observed in the mid-1980s (Fig. CC-24).

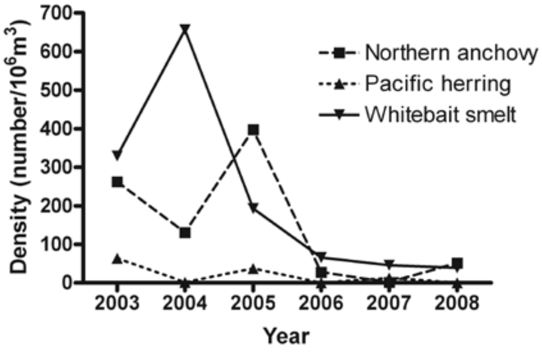
Surface trawls have been conducted bi-weekly from April-August off the mouth of the Columbia River at night since 1998 (Emmett et al. 2006). SST changed significantly over the recent time period with a cool, productive period from 1999-2002 changing to a warm, relatively unproductive period from 2003-2007. SST off the Columbia River was particularly warm during June-August of most years of the focus period. Temperatures were cooler in 2008, but since fish production lags ocean conditions by at least one year, the anticipated increase in productivity was not reflected in fish production.

Lower ocean productivity from 2003-2007 in the northern CCS was clearly reflected in the decreased abundance of forage fishes. Densities ranged from a high annual average of almost 7,500 per million m³ in 2003, to a low of only 554 per million m³ in 2006 (Fig. CC-25). The decline in forage fish densities appeared to be related to poor recruitment. The spring/summer sampling does not reflect the densities of larval or age-0 specimens of most forage fishes, however, the abundance of one-year-old or age-1 fishes is accurately reflected. Taking into consideration the one-year time lag, it appears that 2003, 2005-2007 were very poor spawning and recruitment years for Pacific herring and northern anchovy. The years 2004-2007 were also poor recruitment years for whitebait smelt (*Allosmerus elongatus*). Only 2003 was a good year for recruitment of whitebait smelt during the focus period (Fig. CC-26). Predatory fishes also showed a decline in densities, with highest annual average densities (200 per million m³) in 2004 and lowest densities in 2008 (<10 per million m³).

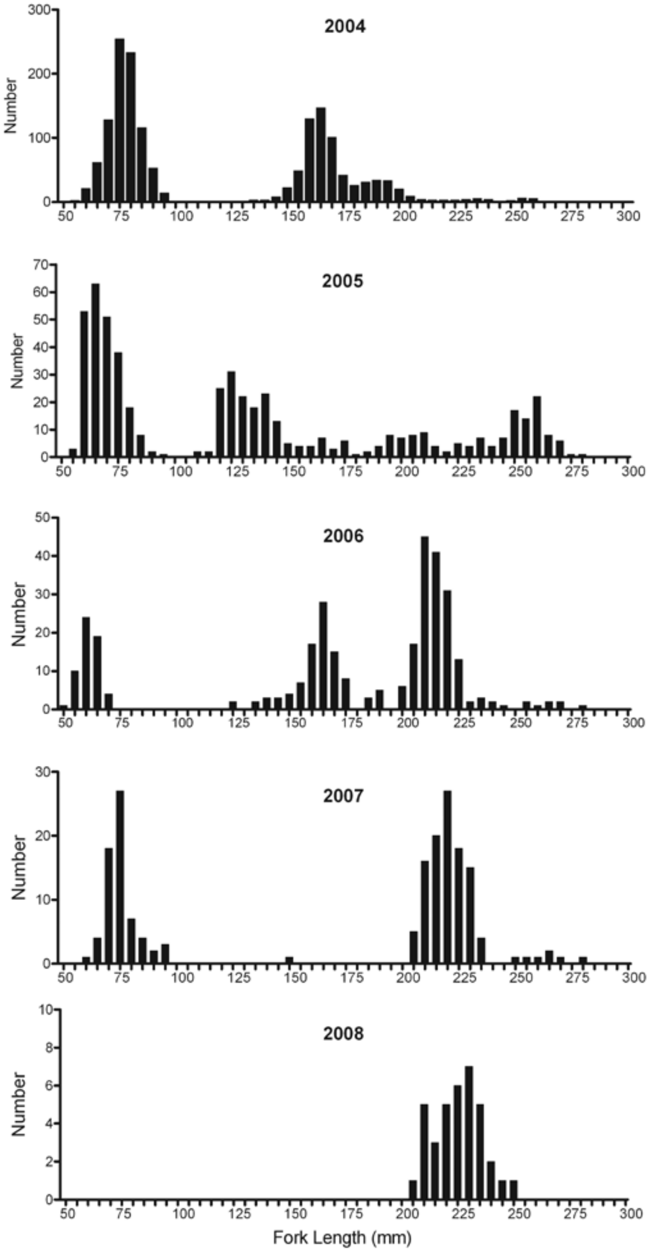
Pacific sardine had large changes in recruitment from 2004-2008 based on surface trawling for age-0 sardines off Oregon/Washington in September. The occurrence of a size mode of small individuals indicates that sardines spawned and recruited off Oregon in both 2004 and 2005, but poorly in 2006 and 2007, and not at all in 2008 (Fig. CC-27). Sardine biomass has continued to increase in British Columbia waters where the 2008 catch was the highest since the 1940s (Crawford and Irvine 2009). The return of sardines to Canadian waters over the past decade is likely due to the appearance of generally warmer waters.



[Figure CC-25] Average annual densities of key forage fishes caught off the Columbia River during bi-weekly night surface trawling during April-August.



[Figure CC-26] Average annual densities of one-year-old forage fishes caught off the Columbia River during bi-weekly night surface trawling during May-June.



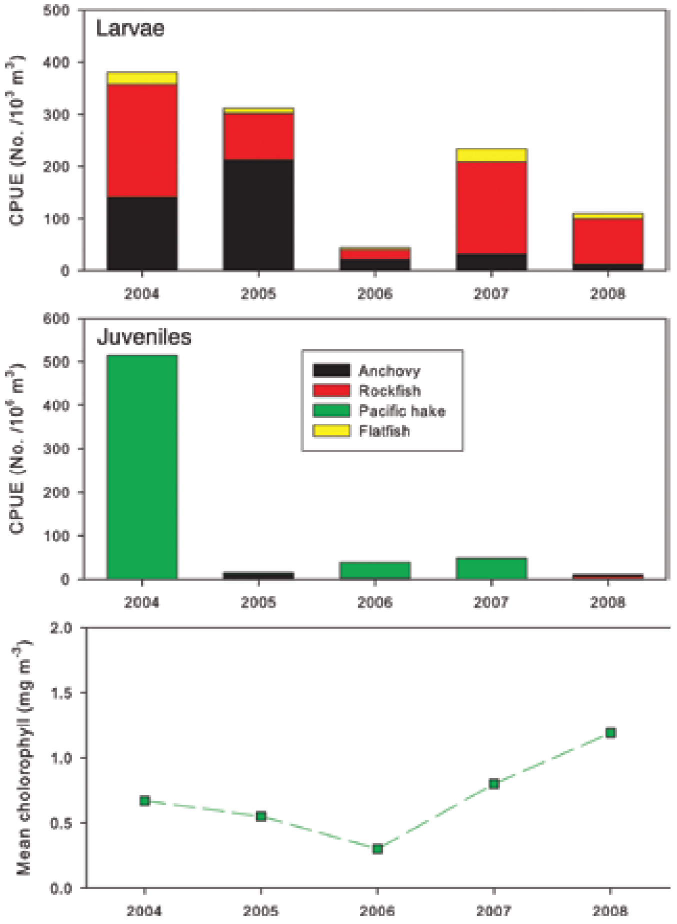
[Figure CC-27] Length frequency of Pacific sardine (*Sardinops sagax*) captured off northern Oregon/Washington in September.

Anchovy catches have been declining and rockfish catches have been increasing in the northern California Current surveys over the last 5 years (Fig. CC-28, Fig. CC-29). Many of these recruitment anomalies may have been triggered by unusual oceanographic events in 2004 and 2005 (Brodeur et al. 2006) coupled with a shift in the PDO that affected larval fish communities (Brodeur et al. 2008). Other ecosystem indicators such as jellyfish abundance in trawl surveys off Oregon and Washington do not show any consistent trends over the last 6 years, although jellyfish biomass was particularly high in June of 2004 and September of 2007 compared to the other cruises (Fig. CC-30).

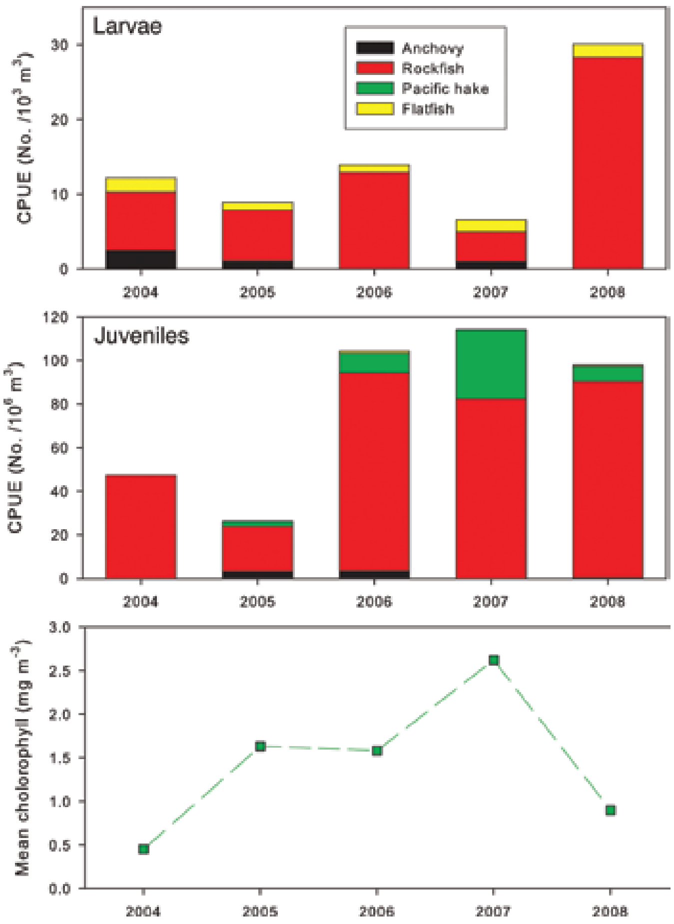
Herring abundance on the west coast of Vancouver Island is at an historically low level following a decade of poor recruitment (Crawford and Irvine 2009). Biomass has declined recently for all five major British Columbia stocks, with the Georgia Basin biomass declining nearly to the fishery-closure limit in 2008. Three other herring stocks in British Columbia were at or below the fishing limit, following weak recruitment of the 2003 and 2005 year-classes. Herring abundance in the Strait of Georgia has continued to decline since the near-historic high levels of 2002 (Fig. CC-31). Cooler ocean conditions since 2005, combined with a decrease in Pacific hake abundance, may result in improved herring recruitment and stock abundance over the short term (Crawford and Irvine 2009).

Euchalon (*Thaleichthys pacificus*) abundances off the west coast of Vancouver Island and in the Fraser River have declined since the mid-1990s. Anecdotal information suggests the decline has been coastwide throughout Washington and British Columbia (Crawford and Irvine 2009). Bottom trawl surveys off central Vancouver Island have found increasing biomass of smooth pink shrimp (*Pandalus jordani*) in 2008, up from very low levels found during the warmer period of 2004-2007 (Crawford and Irvine 2009). Biomass of British Columbia flatfish species also increased in 2008 after declines in 2006-2007 (Crawford and Irvine 2009).

Pacific hake showed unusual recruitment patterns off the northern California Current from 2003-2008. Pacific hake is not known to regularly spawn and recruit in the northern California Current off Oregon and Washington, however, relatively large densities of age-0 Pacific hake were first



[Figure CC-28] Annual average densities of dominant fish larvae (top) and pelagic juveniles (middle) from June Stock Assessment Improvement Plan (SAIP) surveys during 2004-2008. Also shown are the mean chlorophyll concentrations.

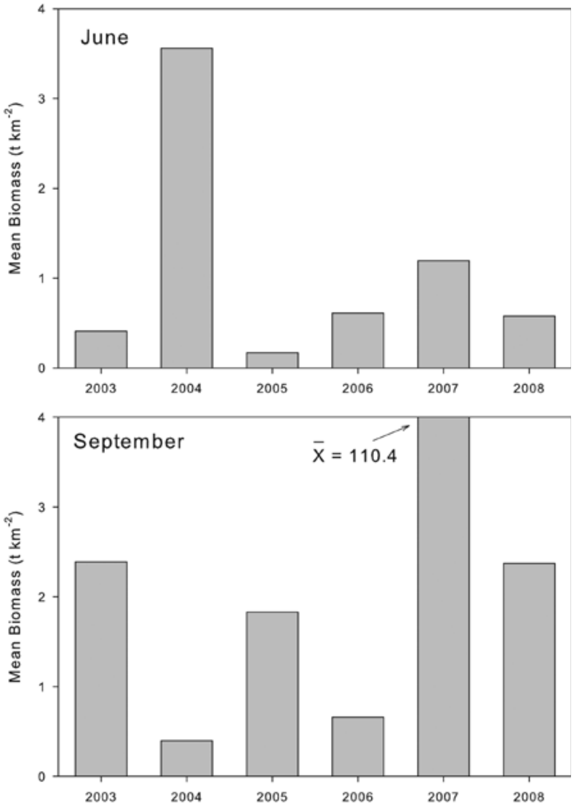


[Figure CC-29] Annual average densities of dominant fish larvae (top) and pelagic juveniles (middle) from September Stock Assessment Improvement Plan (SAIP) surveys during 2004-2008. Also shown are the mean chlorophyll concentrations.

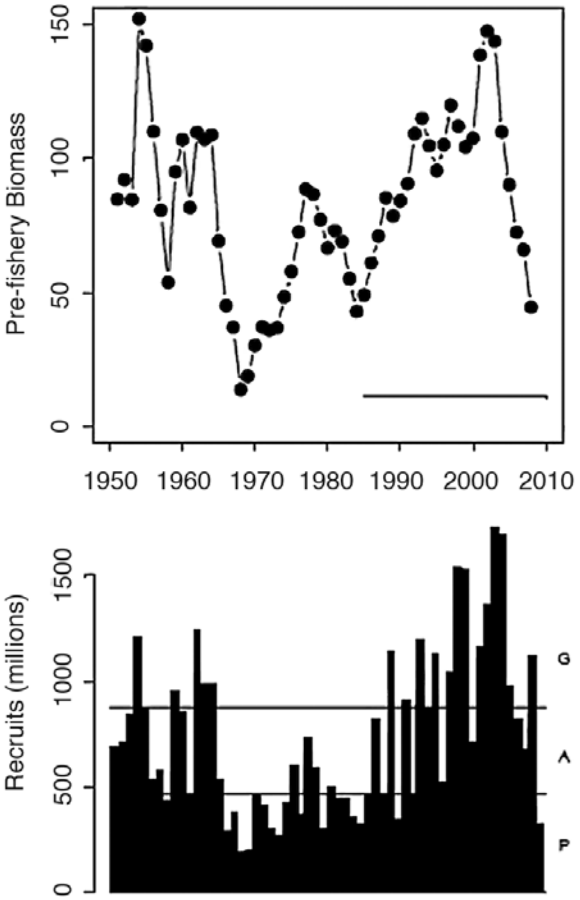
observed in 2004 and very large numbers were observed in 2006. Pelagic juvenile hake appear in high concentrations in large-scale summer micronekton surveys off Oregon and Washington in June (Fig. CC-28) and September (Fig. CC-29) during most years. Pacific hake is generally the most abundant pelagic predatory fish in the northern California Current, but was found in very low abundances (2.6 per million m^3) in 2008. These data and other information (Phillips et al. 2007) indicate that in recent years at least some Pacific hake do not appear to make their regular southerly spawning migrations to southern California, but perhaps spawn offshore off northern California or southern Oregon. Pacific hake numbers on the British Columbia continental shelf appeared to be low in 2008, continuing a trend that began developing around 2003-2004 (Crawford and Irvine 2009). On longer time scales, there has been a declining trend in pre-recruit (age-0) abundance and spawning biomass (Helser and Martell 2007; Sydeman and Elliott 2008; Sydeman and Thompson 2010).

4.3.3 Pacific salmon

Pacific salmon (*Oncorhynchus* spp.) are among the most culturally important and economically valuable commercially fished species in the CCS. Significant fluctuations in salmon abundances and marine survival have occurred throughout the CCS during the focus period, leading to a number of dramatic management actions. Exceptionally low adult returns to California Central Valley occurred in 2007-2008 that was traced to poor survival of the 2005 and 2006 cohorts. The chinook (*O. tshawytcha*)



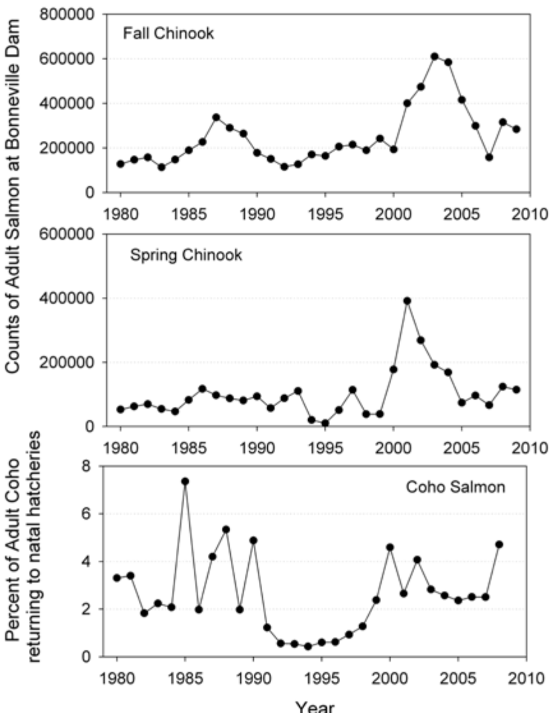
[Figure CC-30] Annual average biomass of large jellyfish in June (top) and September (bottom) from pelagic fish mesoscale surveys off Washington and Oregon during the 2003-2008.



[Figure CC-31] Pre-recruitment biomass and number of recruits of herring in Strait of Georgia stocks. The boundaries for poor (P), average (A), and good (G) recruitment are shown. (From Crawford and Irvine 2009).

and coho (*O. kisutch*) salmon that emigrate from rivers from California to Oregon reside in coastal waters for a period of time before migrating up the coast. It is in these coastal waters that the greatest mortality occurs. A poor environment can lead to reduced early growth and ultimately poor survival and recruitment to the spawning stock (Beamish and Mahnken 2001; Beamish et al. 2004; Wells et al. 2008). Only 66,000 fall chinook returned to spawn in 2008, well below the minimum required to allow harvesting. The chinook salmon collapse may have been caused by climatic conditions that produced little food in the ocean (i.e., delayed upwelling in the ocean-entry year 2005) combined with a reliance on hatchery-reared salmon instead of wild salmon. The numbers of adult chinook salmon at Bonneville Dam, the lowest dam on the Columbia River, generally reflects the magnitude of salmon runs to this river. Fall Columbia River chinook salmon counts had a similar trend as fall Sacramento River chinook in California as well as forage fishes in the northern CCS, with decreasing productivity from 2003-2007, particularly for fall chinook salmon (Fig. CC-32). The numbers of chinook salmon jacks (chinook males that spend two summers at sea before maturing) migrating past Bonneville Dam are good indicators of chinook salmon marine survival for Columbia River stocks. These clearly show declining marine survival from 2003-2005, then increasing since 2006 for most runs. Sockeye salmon returns to Bonneville Dam in 2008 (2006 ocean entry year) were the third highest since 1938, a rare example of a positive surprise for California Current salmon.

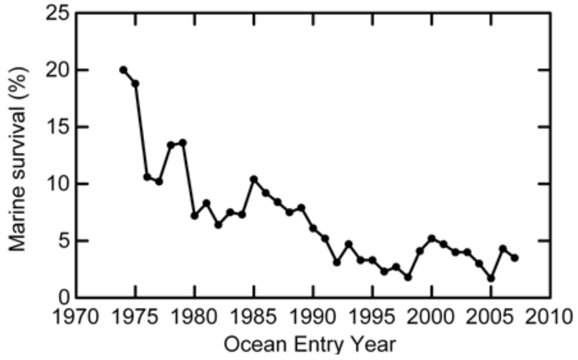
Estimates of coho salmon marine survival are made annually by the Pacific Fisheries Management Council (PFMC 2009). From 2003-2007 coho salmon marine survival was among the lowest on record, and similar to other salmon species (Fig. CC-33). There were regional differences, however, with Columbia River coho marine survival being higher



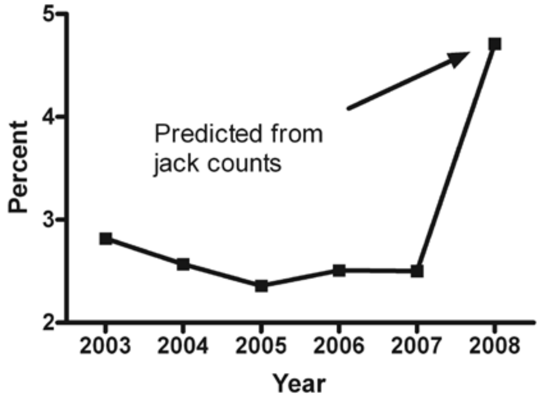
[Figure CC-32] Counts of adult spring and fall chinook salmon at Bonneville Dam, and survival of hatchery coho salmon returning to streams that enter the lower Columbia River. Note that the low returns in the 1990s was the period when coho salmon became listed as threatened under the U.S. Endangered Species Act.

than that observed in the mid-1990s. Predicted marine survival of coho salmon was higher for fish that migrated to sea in 2008 (Fig. CC-34). In 2008 and 2009, large numbers of sockeye salmon (*O. nerka*) returned to the Columbia River (Fig. CC-35). Preliminary analysis indicates that the large return in 2008 was due to good marine survival of fish migrating to sea in 2006.

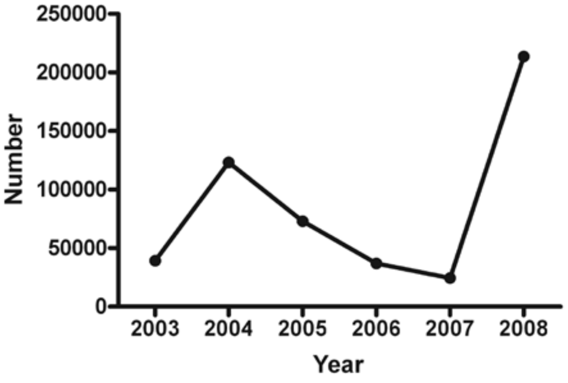
Although cooler oceans generally favour better survival for salmon, many British Columbia populations remain depressed because of low spawner numbers during 2003-2005 when conditions were less favorable (Crawford and Irvine 2009). Sockeye salmon returns were low coast-wide with the exception of Okanagan sockeye (Columbia River) that returned in record numbers in 2008 (Fig. CC-36). Coho salmon populations in southern British Columbia remain extremely depressed, while abundances of northern coho populations have improved. For chinook salmon, the situation is somewhat reversed. Northern populations continued to decline while the status of southern chinook is highly variable (Crawford and Irvine 2009).



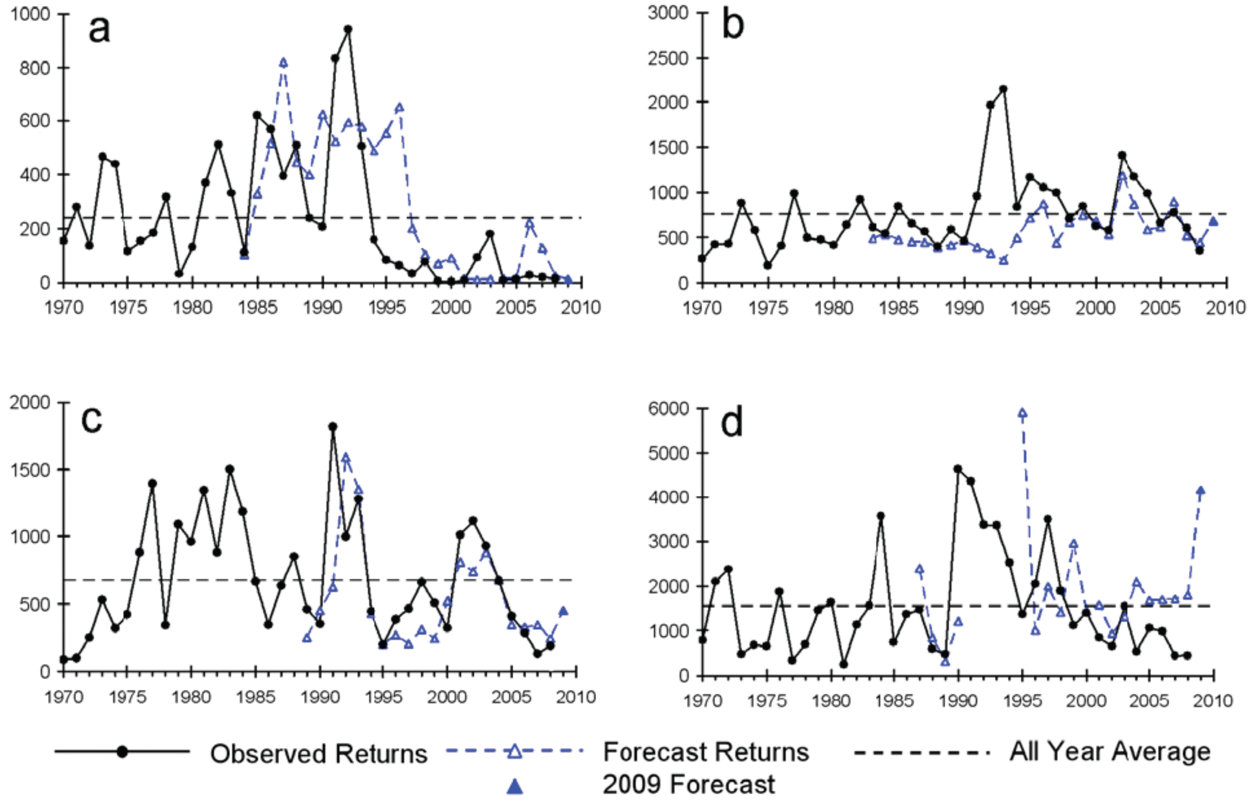
[Figure CC-33] Average marine survival of up to 45 coho salmon (*O. kisutch*) stocks in the northern California Current region by year of ocean entry. The lowest marine survival in the time series occurred when smolts went to sea in 2005.



[Figure CC-34] Oregon Production Index (OPI) for coho salmon (*O. kisutch*) marine survival during the focus period, 2003-2007 and a forecast for the 2008 release.

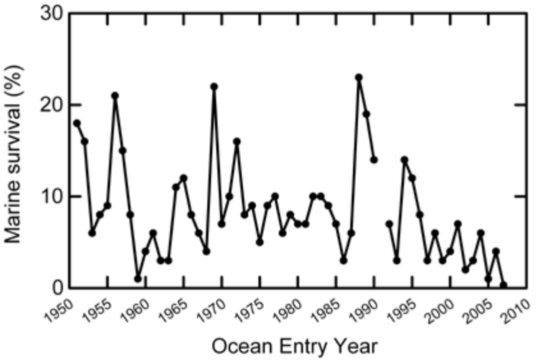


[Figure CC-35] Total numbers of sockeye salmon (*O.nerka*) migrating upstream past the Bonneville Dam on the Columbia River. (Data from Fish Passage Center website (http://www.fpc.org/fpc_homepage.html).



[Figure CC-36] Trends in the total returns (thousands of fish) and forecasts for British Columbia sockeye salmon index stocks: (a) Nass, (b) Rivers and Smith's Inlet, (c) Barkley Sound, (d) Fraser River (From Crawford and Irvine, 2009 – Fig. 14).

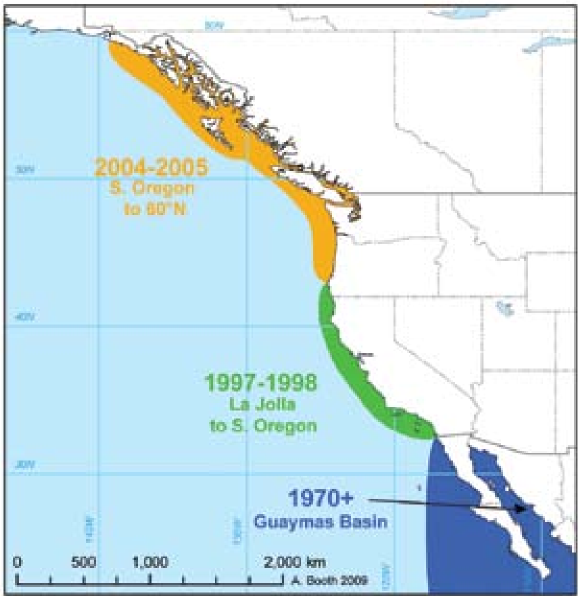
Sockeye salmon returns to the Fraser River in 2007 and 2008 (2005 and 2006 ocean entry years) were lower than expected and returns in 2009 were even worse. Marine survival of sockeye salmon from Chilko Lake (Fraser River drainage) was lower in 2003-2008 than during any equivalent period of this record (Fig. CC-37). The persistently low survivals in recent years resemble a shorter period of low survival that occurred in the late 1950s and early 1960s. These periods share a particularly disastrous ocean entry years for marine survival (1959 and 2005). The collapse of the Fraser River sockeye returns in 2009 was not a widespread event.



[Figure CC-37] Percentage of sockeye salmon smolts leaving Chilko Lake (Fraser River system) that return as adults, from 1951-2007. The worst survival on record occurred during the last year.

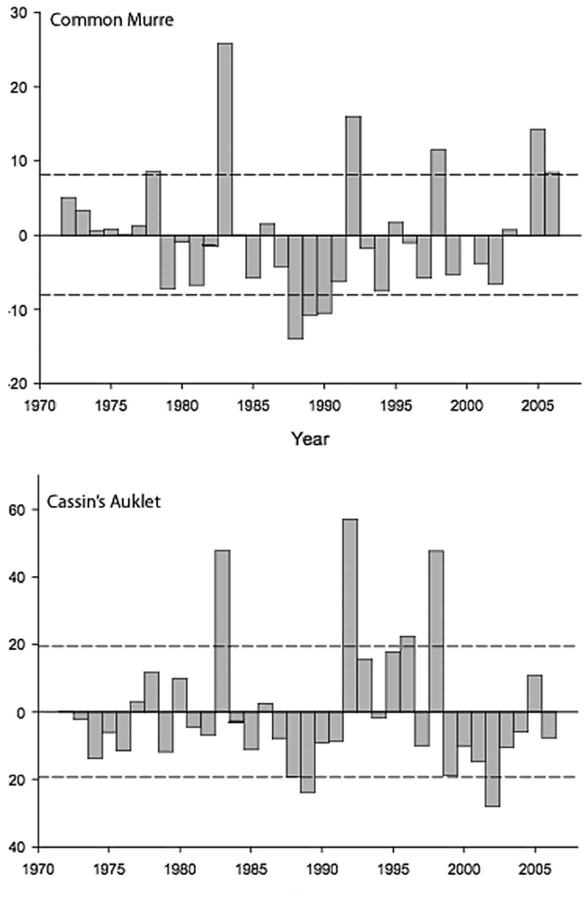
4.3.4 Humboldt squid

Prior to the 1997-98 El Niño, the Humboldt squid was an infrequent visitor to the U.S. waters of the CCS, yet since 2003 these animals have been regularly encountered in large numbers throughout the CCS in both the U.S. and Canada, and as far north as Southeast Alaska (Wing 2006; Zeidberg and Robison 2007; Field et al. 2007; Fig. CC-38). Although mature adults of both sexes have been encountered throughout the focus period, and demonstrated to have viable gametes as well as showing evidence of previous mating activity, zooplankton collections have provided no evidence that these squid are spawning in the northern waters of the CCS. Based on a qualitative interpretation of trends in catch rates from various fisheries and surveys throughout the CCS from 2003 to present, Humboldt squid appear to move north along southern and central California during late spring and early summer, showing up in surveys and commercial fisheries off Oregon, Washington and British Columbia during the late summer and early fall (particularly in the Pacific hake fishery, where Humboldt squid are frequently encountered as bycatch). They are then observed again off of California during late fall and early winter, suggesting a return migration of this population.



[Figure CC-38] Map showing the range expansion of Humboldt squid (*Dosidicus gigas*) in the eastern North Pacific.

The primary drivers of this apparent range expansion remain uncertain. It is possible that the large numbers of Humboldt squid observed since 2003, and particularly during 2005-2006, may have reflected changing ocean conditions (Gilly et al. 2006; Markaida 2006; Bograd et al. 2008). This period was characterized by unusually low upwelling, high stratification, and anomalous phenology, all of which contributed to the low productivity seen throughout many trophic levels (zooplankton, juvenile rockfish, salmon and seabird production) during those years. Although the impacts of the range expansion are not understood, a range of responses is plausible. Of some concern is the observation that many commercially important species, such as Pacific hake, Pacific sardine and several species of semi-pelagic rockfish are important prey of these animals (Field et al. 2007). Stock assessments for Pacific hake and sardine in particular have shown biomass declines over recent years. Although this could be a result of a wide range of factors, including non-causative covariation with the abundance of Humboldt squid, the poleward expansion of Humboldt squid has also been reported in the southern hemisphere where it appears to be affecting Chilean hake and other fisheries (Alarcón-Muñoz et al. 2008).



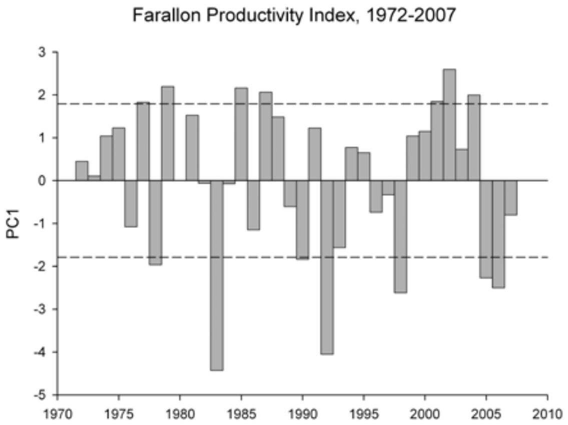
[Figure CC-39] Anomalies (day of year) of annual mean egg-laying dates for common murres (top) and Cassin's auklets (bottom) breeding on the Farallon Islands, California. Average day of year of egg-laying by murres is 134 (May 14) and by Cassin's auklet is 107 (17 April).

4.4 Marine birds and mammals

(Sydeman, Munger, Barlow, Calambokidis, Hildebrand, Lowry, Manzano-Sarabia)

4.4.1 Marine birds

There have been dramatic phenological changes in the reproductive cycles of CCS seabirds in recent years, presumably influenced by the changes in coastal upwelling (see section 2.2; Schroeder et al. 2009). Cassin's auklets did not show a change in their average annual egg laying date but the common murres were late laying eggs in 2005 and 2006 (Fig. CC-39; Sydeman and Thompson 2010). Trends and variability in reproductive success also varied by species. Reproductive success was substantially decreased for ashy storm-petrels and western gulls, while Brandt's cormorants had increasing reproductive success (Sydeman and Thompson 2010). Common murres, Cassin's auklets, rhinoceros auklets, pelagic cormorants, and pigeon guillemots have shown no overall change in reproductive success since the early 1970s. Common murres had somewhat consistent variation, with the exception of outliers, while Cassin's auklets had increasing variation in reproductive success measurements (Sydeman and Thompson 2010). Cassin's auklets were particularly affected by the unusually late upwelling in 2005, with nearly complete reproductive failure that year (Sydeman et al. 2006).

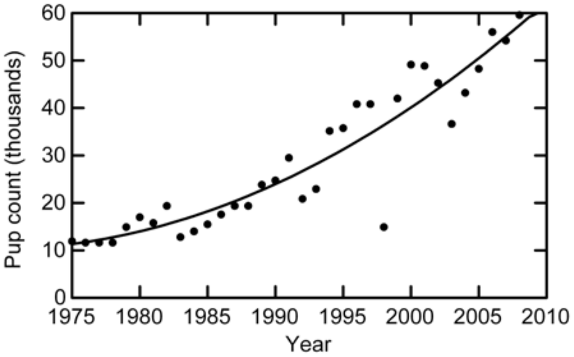


[Figure CC-40] The multivariate Farallon Productivity Index (Sydeman et al. 2001), based on the productivity of 6 seabird species: Cassin's auklet, common murre, Brandt's cormorant, pelagic cormorant, pigeon guillemot, and western gull.

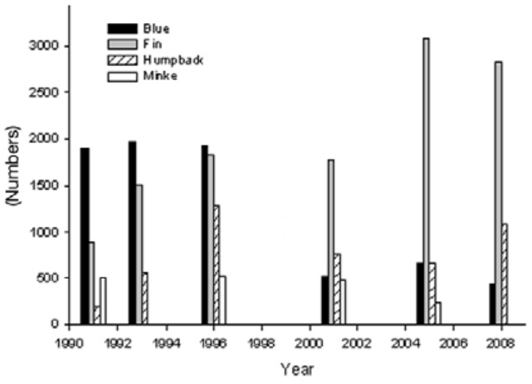
The multivariate *Farallon Productivity Index* (Fig. CC-40; Sydeman et al. 2001, Sydeman and Thompson 2010) reveals the same patterns of variability, with overall community failure during the El Niño years of 1983, 1992, and 1998 (all < -1 s.d.), a period of reasonably high productivity from 1999-2003 (> 1 s.d.), very poor productivity in 2005 and 2006 (< -1 s.d.), and poor productivity in 2007. The changes observed in seabird communities and population parameters in the CCS are consistent with predicted responses to climate change: (i) mean egg-laying dates for one species (murres) became earlier through time; (ii) species preferring colder waters (i.e., shearwaters and auklets) became less abundant; and (iii) productivity of some species declined and this was related to changes in the abundance/availability of their prey (zooplankton and forage fish). There was also an increase in variance in the productivity for one species (Cassin's auklet). The years 2005 and 2006 were particularly interesting with major declines in seabird productivity related to changes in their prey base (see Section 4.3.2). The years 2007 and especially 2008 (Warzybok and Bradley 2008) were more productive years, with recovery of seabird productivity to near average levels.

4.4.2 Pinnipeds

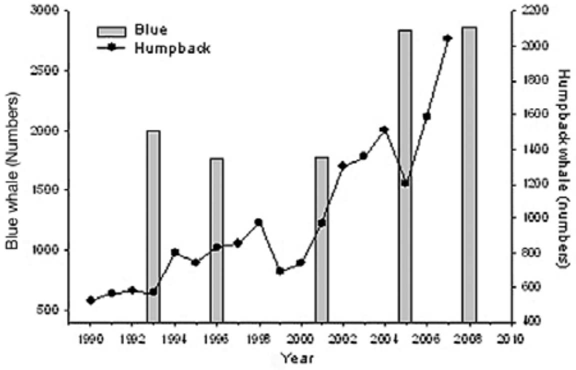
The breeding biology of California sea lion (*Zalophus californianus*) has been monitored on California's Channel Islands since the mid 1970s (Lowry and Maravilla-Chavez 2005). A trend for increasing numbers of pups counted during the 1970s, 1980s, 1990s, continued during the 2000s (Fig. CC-41). There was a substantial decline in pup counts during the weak El Niño of 2003, followed by increases in 2006 and 2008. The decline during this El Niño was similar to the drop-off during the 1992-1993 El Niño, but it was not as severe as the decline during the 1997-1998 El Niño.



[Figure CC-41] Counts of California sea lion pups (*Zalophus californianus*) on the Channel Islands, California, 1975-2008. The quadratic trend line was estimated from the data.



[Figure CC-42] Summer/fall baleen whale feeding populations in the California Current, 1991-2005. Data from Barlow and Forney (2007) and Barlow (in press).



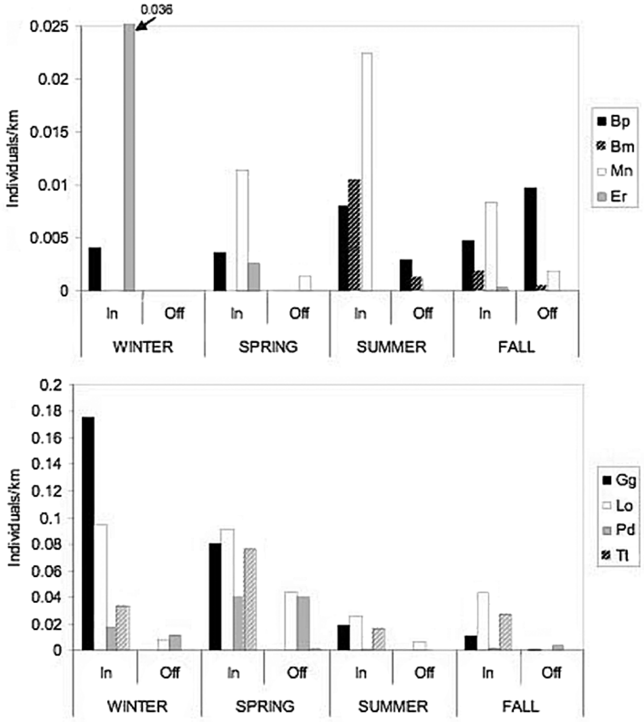
[Figure CC-43] Blue and humpback whale abundances in the California Current from sighting-resighting photo-identification surveys. Data from Calambokis et al. (2007) and Calambokidis (2009).

4.4.3 Cetaceans

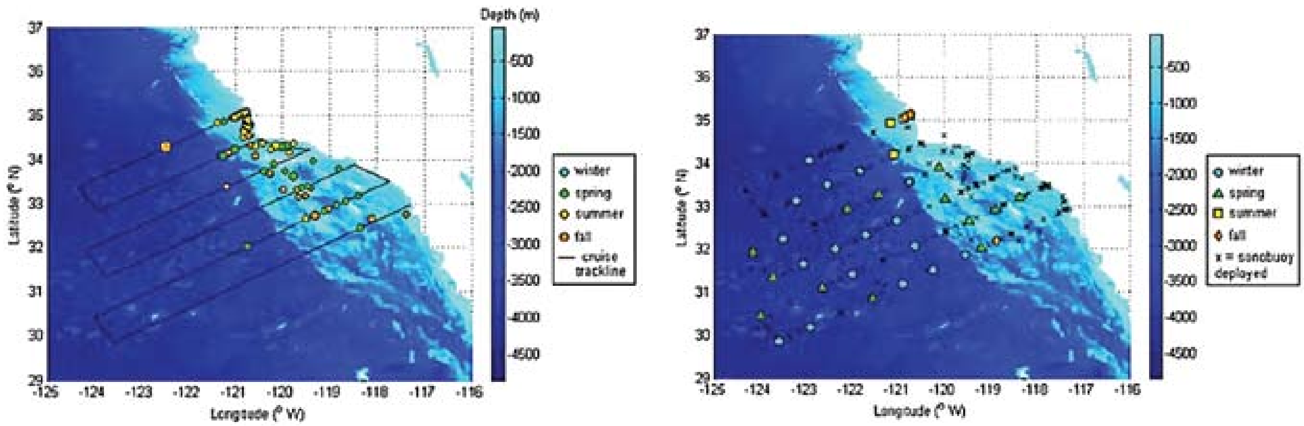
Systematic line transect surveys of cetaceans during the summer and fall throughout the California Current were conducted in 1991, 1993, 1996, 2001, and 2005 (Barlow and Forney 2007). These surveys provide information on the seasonal abundance of feeding whale populations. Ecosystem-scale feeding population surveys are supplemented with detailed photographic studies of individually identifiable whales (Calambokidis et al. 2007; Calambokidis 2009) to provide information on year-round whale abundance for humpback and blue whales.

Summer/fall feeding populations of fin whales have been increasing, with numbers exceeding 2800 individuals in 2008 (Fig. CC-42). Blue whales feeding in the California Current were much less abundant in 2001 and 2005 than during earlier survey years, but evidence suggest this reflects a re-distribution to more northerly feeding areas rather than a real decline in abundance (Calambokidis 2009). Estimated numbers of summer/fall feeding humpback and minke whales from line-transect surveys have been variable. Overall, the population of humpback whales in the California Current has been increasing at roughly 8% per year (Fig. CC-43; Calambokidis 2009). During 2005, there was an apparent decrease in abundance, but in 2006-2007 the population increases resumed. Blue whales have also increased in recent years, with approximately 2,800 estimated during the focus period.

The seasonal and spatial distribution patterns of cetaceans in the Southern California Bight were assessed using combined visual and acoustic surveys conducted during 18 quarterly CalCOFI cruises from summer 2004 through fall 2008 (Soldevilla et al. 2006). The most frequently sighted odontocete species were common dolphin (*Delphinus* spp.) (n=347 sightings), Dall's porpoise (*Phocoenoides dalli*) (n=58), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) (n=57), Risso's dolphin (*Grampus griseus*) (n=27), bottlenose dolphin (*Tursiops truncatus*) (n=23), and sperm whale (*Physeter macrocephalus*) (n=24). The most frequently sighted baleen whale species were humpback (*Megaptera novaeangliae*) (n=74 sightings), fin (*Balaenoptera physalus*) (n=69), gray (*Eschrichtius robustus*) (n=41), and blue whale (*Balaenoptera musculus*) (n=39). Some species distributions varied seasonally and spatially (Fig. CC-44). Gray whale and Dall's porpoise were sighted primarily in winter and spring, whereas blue whale was only detected in summer and fall. Species detected predominantly inshore (depth <2000 m) included gray whale, Risso's dolphin, bottlenose dolphin, and long-beaked common dolphin (*D. capensis*). Species detected both inshore and offshore included Dall's porpoise, Pacific white-sided dolphin, short-beaked common dolphin (*D. delphis*), and blue whale. Fin whales were only detected inshore in spring, whereas during other seasons they were detected both inshore and offshore.

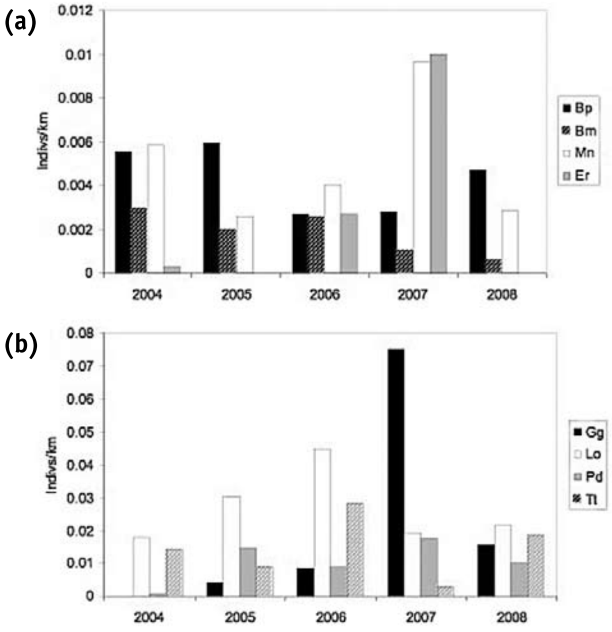


[Figure CC-44] Seasonal distribution of selected species from visual data in the Southern California Bight, 2004-2008. In = inshore of 2000 m, Off = offshore of 2000 m. (Top) Bp = fin whale, Bm = blue whale, Mn = humpback whale, Er = gray whale. (Bottom) Gg = Risso's dolphin, Lo = Pacific white-sided dolphin, Pd = Dall's porpoise, Tt = bottlenose dolphin.



[Figure CC-45] Humpback whale visual detections (left) and acoustic detections (right) from 2004-2008.

For some species the seasonal distribution of visual sightings varied markedly from acoustic detections. Humpback whales were visually detected in spring through fall primarily inshore, whereas they were acoustically detected offshore in winter and spring (Fig. CC-45). These contrasting patterns suggest that the probability of detecting animals visually or acoustically varies depending on their seasonal distribution and behavioural state, e.g. foraging, migrating, and social or reproductive interaction. In 2007 and 2008, the number of blue whale seen per km decreased from the number seen in 2004-2006 (Fig. CC-46). In 2007 there was also a slight decrease in Pacific white-sided dolphin per km and an increase in Risso's dolphin (Fig. CC-46b) and humpback whale (Fig. CC-46a).



[Figure CC-46] Annual number of individuals sighted per km of trackline in the Southern California Bight, 2004-2008. (a) Bp = fin whale, Bm = blue whale, Mn = humpback whale, Er = gray whale. (b) Gg = Risso's dolphin, Lo = Pacific white-sided dolphin, Pd = Dall's porpoise, Tt = bottlenose dolphin.

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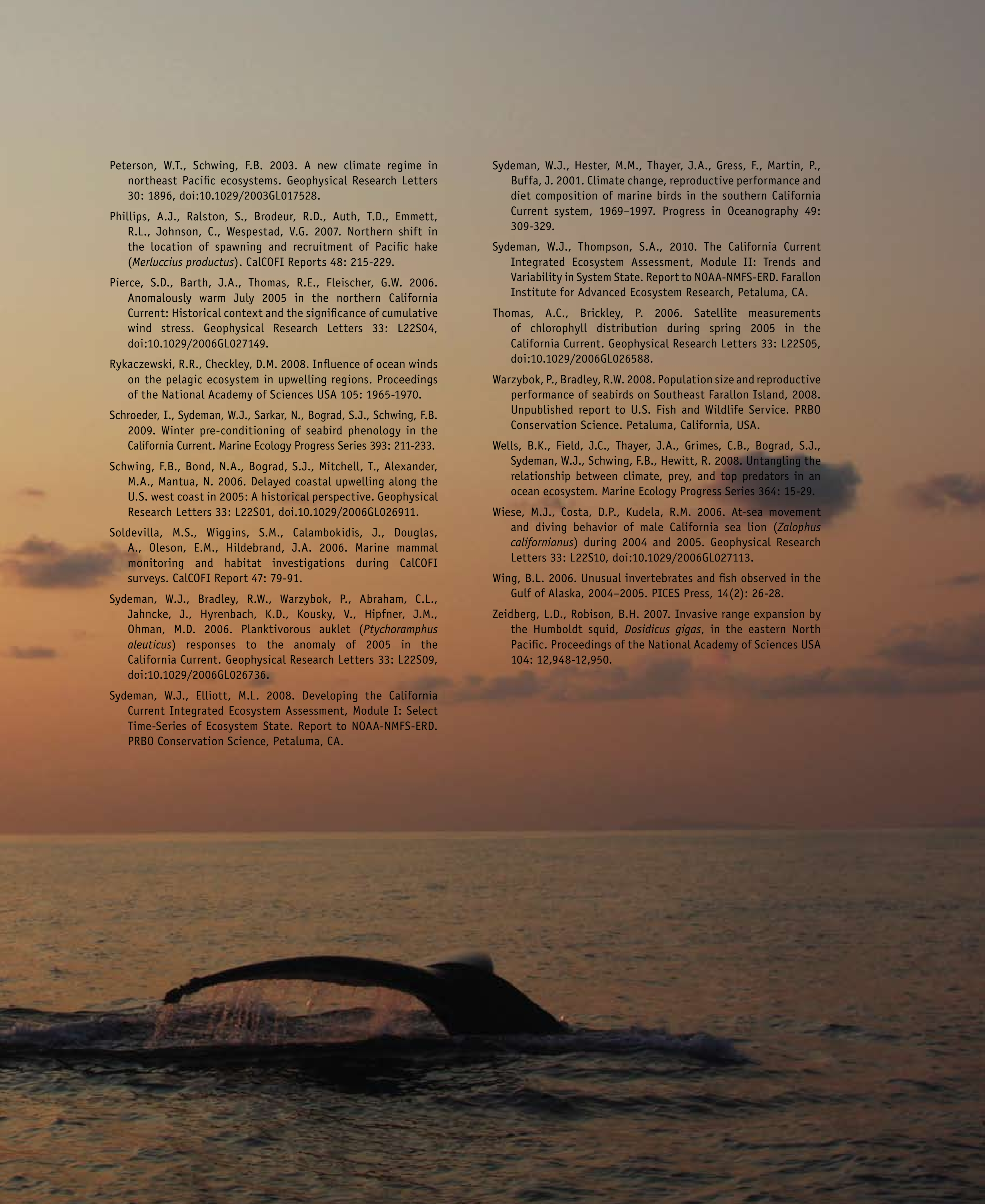

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