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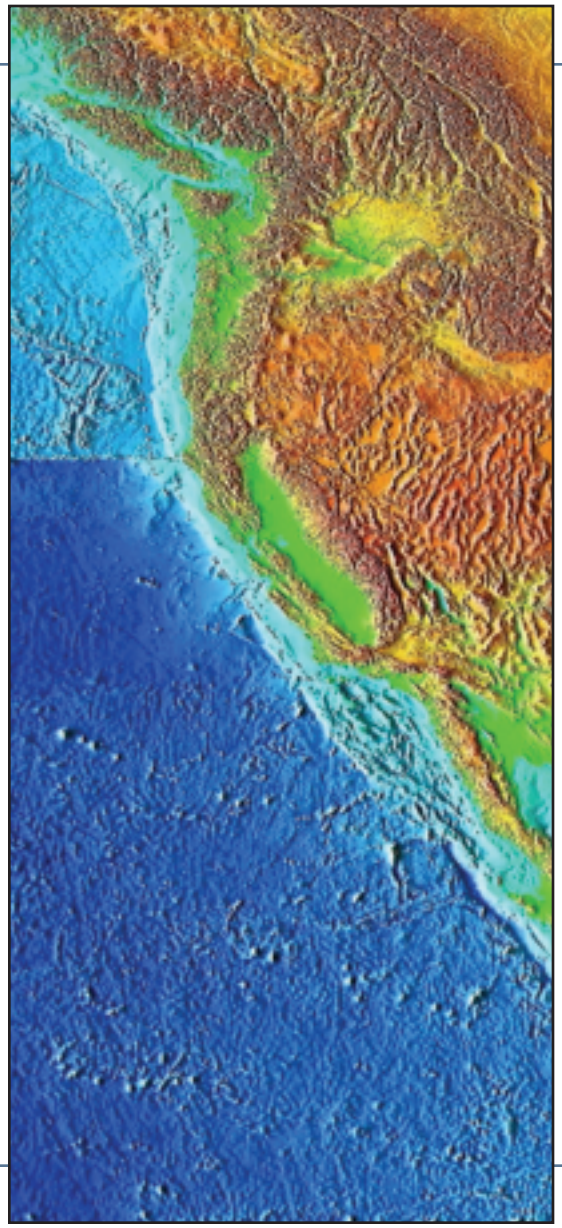
# California Current



# highlights

- The period from 1977 to 1999 was generally warmer than normal, with extensive re-distributions of plankton and nekton northwards along the continental shelf. This period appears to have concluded in 1999 after a significant coastwide El Niño event. La Niña conditions prevailed in the middle and northern parts of the California Current after 1999. A new climate regime, with generally cooler and more productive waters has been speculated.
- A large-scale intrusion of subarctic waters into the California Current in spring-summer 2002 affected water mass structure and biological productivity from Vancouver Island to southern California.
- A moderate El Niño developed in the equatorial Pacific in summer 2002, with modest impacts on the California Current evident by winter 2002-03. These impacts included depressed plankton abundances observed off southern California in February 2003, anomalously warm SSTs throughout much of California Current in late winter, and isolated warm anomalies at depth.
- Recent zooplankton data off Oregon suggest a return to cool-regime conditions after a brief interruption by the 2002-03 El Niño. Zooplankton abundances in the southern CCS have remained steady in recent years, and are still well below the values observed in earlier decades.
- Enhanced productivity associated with the subarctic intrusion was not strongly transferred to higher trophic levels. Certain fish stocks and, especially, seabirds have shown a response to environmental fluctuations at El Niño and longer timescales.

# background

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 proper is a year-round equatorward flow extending seaward from the shelfbreak to a distance of ~1000 km, with strongest speeds at the surface and extending to at least 500 m depth.[320] 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 poleward flow, the California Undercurrent, extends the length of the coast along the continental slope. Seasonal maxima in current speeds are usually in summer to early fall for the California Current and California Undercurrent, and in winter for the California Countercurrent/Davidson Current.

There is little freshwater input except at the Columbia River. The region is often strongly impacted by El Niño events, and also varies on interdecadal timescales.

Fishery resources include significant commercial invertebrate populations, especially in nearshore waters, important groundfish populations along the continental shelf, and large and highly migratory pelagic species such as Pacific salmon (6 *Oncorhynchus* species), Pacific sardine (*Sardinops caeruleus*), Pacific hake (*Merluccius productus*), and Pacific herring (*Clupea harengus*) at the northern end of the CCS and at the southern end, northern anchovy (*Engraulis mordax*) and squid (*Loligo opalescens*). There are also important populations of marine mammals and seabirds.

## Status and Trends*

### Hydrography

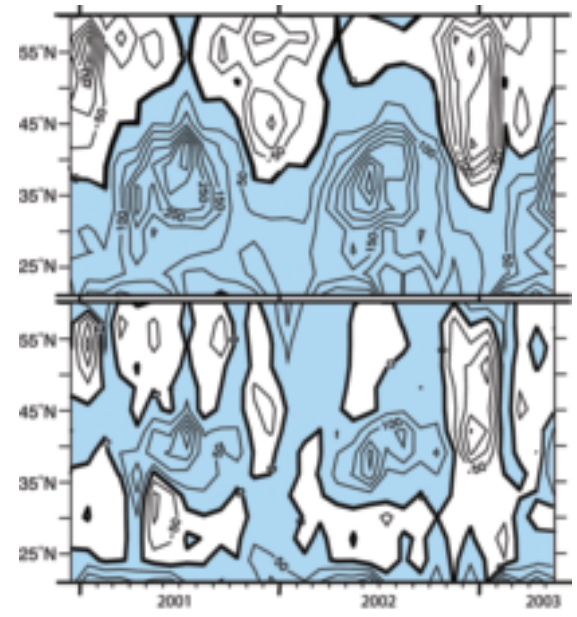
**British Columbia** Oceanographic and meteorological conditions reflected the development of the moderate El Niño late in 2002.[321] Cool sea surface temperatures (SST) and above average surface salinity that persisted since 1999 changed to warm SSTs by the end of 2002 consistent with the weak El Niño. Upwelling in 2001 and 2002 was near the 1990-1996 average. Sea surface height in 2002 remained below the 1990-1996 average and well below those experienced during the 1997-1998 El Niño.

**Washington** Hydrographic data from the Washington shelf indicated colder and fresher water on the mid- to outer shelf in summer 2002 compared to summer 2001, particularly at mid-depths (below 30 m). This region also experienced enhanced southward flow in spring 2002, as part of the anomalous subarctic influence in the CCS.

Columbia River outflow was extremely low in 2001, resulting in low surface salinities off the Washington coast. River outflow was slightly lower than normal in 2002 and 2003.

**Oregon** The northern portion of the CCS has been sampled seasonally by the Long-Term Observation Program (LTOP) of the U.S. GLOBEC/Northeast Pacific Program since 1997. Observations are made five times per year along the Newport Hydrographic (NH) Line at 44.65°N, and three times per year along a set of 4 or 5 east/west transects between 42°N and 45°N.

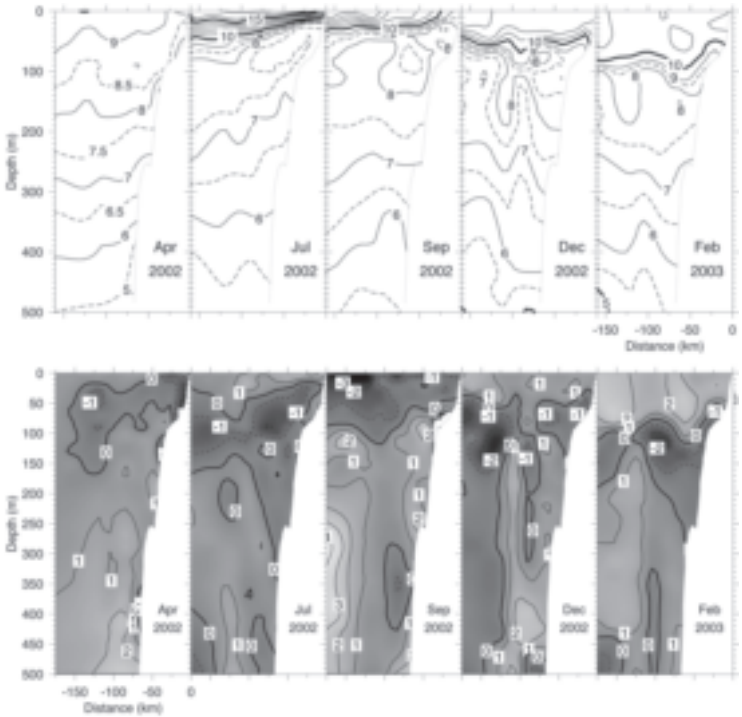
* More detailed reviews of recent physical and biological trends in the southern parts of the California Current can be found in CalCOFI Reports, published each fall; trends in the northern parts are available each year in the Fisheries & Oceans Canada *State of the Ocean* reports.




[Figure 123] Monthly upwelling index (top panel) and upwelling index anomaly (bottom panel) for January 2001 through May 2003. Shaded areas denote positive (upwelling) values in the top panel and positive anomalies (greater than normal upwelling) in bottom panel. Anomalies are relative to 1948-67 monthly means. Units are in $m^3s^{-1}$ per 100 km coastline.

The NH-line had been occupied regularly from 1961 to 1971, and long-term seasonal averages have been calculated from these historical data.[322] Water temperatures off central Oregon had been near normal during the extended La Niña of 1998-2001[323], except that waters over the continental slope tended to be above normal at depths of 30 to 100 m in summer.[323] By February 2002, the entire section was colder than normal, and steric height was lower than normal.[323]

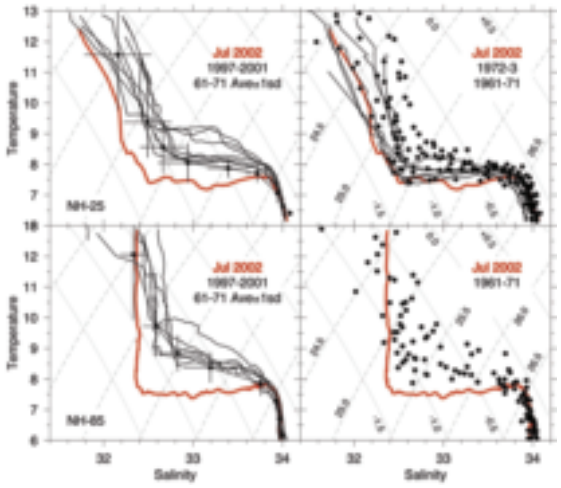
Temperature sections along the NH-Line in 2002/03 (Figure 124) showed some striking anomalies: very cold (< 7.5°C) subsurface waters over the outer shelf in July 2002, and complex inversions in fall and winter. The remarkably cold water over the outer shelf in July 2002 occurred in the upper halocline and was the coldest in this salinity range yet observed off Newport (Figure 125). This anomaly was part of the large-scale subarctic intrusion that also affected Vancouver Island[324] and southern California.[325] This water mass anomaly can be explained by enhanced southward advection that was detected by moorings[326] and satellite-tracked drifters[327] and in satellite altimeter data.[328] These anomalous conditions apparently resulted from large-scale atmospheric forcing in the northeast Pacific Ocean.[329] The cold halocline anomaly was already present off central Oregon in April 2002, and was still present in February 2003 when its peak amplitude occurred at a depth of 110 m, 100 km from shore (Figure 124).



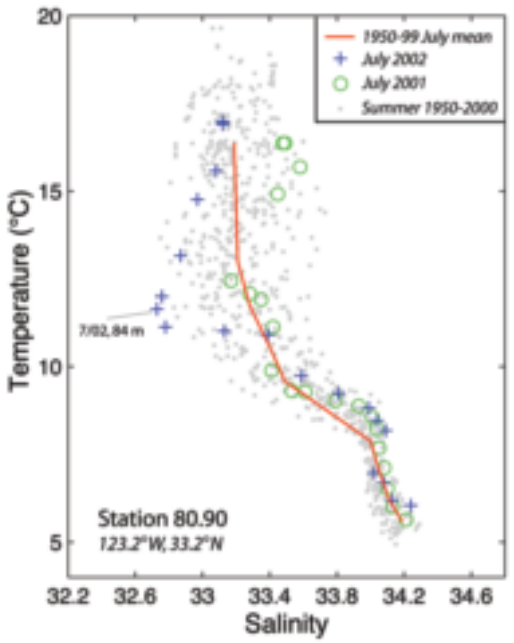

[Figure 124] (top panels) Temperature along the NH-line (44.65°N) for post-April 2002 sections. (bottom panels) Normalized temperature anomalies for NH-line. Positive (negative, dashed contours) anomalies indicate present values are warmer (colder) than the historical (1961-71) seasonal or monthly averages. Values greater than 1 (2,3) are significant at the 90% (95, 99%) level.

Chlorophyll concentrations in all three 2002 surveys (April, July, and September) were generally high, exceeding 4 mg $l^{-1}$ over most of the shelf in both April and July. Even at the end of September, most of the inner shelf region had values >4 mg $l^{-1}$. These high chlorophyll values apparently reflect the enhanced subarctic influence. [330]

Hydrographic observations made off Oregon in 2002-03 suggest that the recent El Niño had only a minor impact on the northern CCS, appearing as higher than normal surface temperatures in late winter and isolated warm anomalies at depths of 200–500 m. In contrast, the subarctic intrusion of cool fresh water has had a significant ecosystem impact, causing elevated nutrient concentrations, high chlorophyll concentrations, and even hypoxic waters over the inner shelf off Oregon.[330] The extent to which anomalous subarctic waters will continue to affect the CCS remains to be seen.




[Figure 125] T-S data for the shelfbreak station (NH-25, upper panels) and the offshore station (NH-85, lower panels) comparing July 2002 to recent summers (left) and to historical summer data (right). Curves represent CTD casts; dots represent discrete bottle samples.




[Figure 126] T-S plot for CalCOFI station 80.90. Historical summer data (June – September observations over the period 1950-2000; 48 occupations) are shown in gray; the 1950-99 July mean is shown in red; July 2002 and July 2001 bottle data are shown as blue crosses and green circles, respectively.[325]

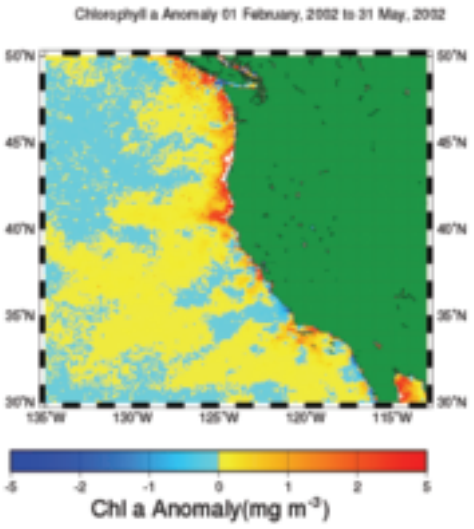
**Southern California** Both subarctic and tropical influences affected hydrographic conditions off southern California through 2002 and into 2003. Samples from San Diego to Monterey, and up to 700 km offshore, were collected by CalCOFI four times per year (usually January, April, July, October). The strong cool, fresh anomalies that peaked in July 2002 were confined spatially to a narrow ribbon in the upper pycnocline: at a density of $\sigma_t$ = 25.0 kg $m^{-3}$ and 150-350 km offshore, within and seaward of the main California Current core.[325] These were the largest T-S anomalies seen at this depth at several nominal CalCOFI stations (Figure 126). Strong upwelling in the spring-summer of 2001 and 2002 contributed to the southward advection of these anomalies within the CCS. Downwelling-favorable winds during winter 2002-03 and early spring 2003 contributed to an unusually strong coastal countercurrent along the southern and central California coast in winter 2003. A return to strong upwelling in late spring 2003 forced cool near-surface temperatures in the southern CCS. The cool, fresh upper-pycnocline anomalies were still observed at some offshore CalCOFI stations in February and April 2003. The 2002-03 El Niño contributed to short-term near-surface warming in the Southern California Bight.

**Baja California** Data from the southernmost part of the CCS were obtained from the Mexican IMECOCAL program, which samples historical CalCOFI lines quarterly off Baja California using standard CalCOFI protocols. Cruises were conducted in April, July, and October 2002, and January and April 2003. Water properties were near normal through 2002 (based on CalCOFI climatology). Slightly higher than usual temperatures and salinities were observed at depth off Baja California in October 2002 and January 2003, suggesting a strengthened California Undercurrent associated with the El Niño.

## Chemistry

There was a substantial increase in nutrients (nitrate, phosphate, silicate) in summer 2002 on the Newport line off Oregon compared to the period 1998-2001.[330] This was related to the anomalous southward advection of subarctic waters, combined with high upwelling in spring 2002.

Largest fluctuations in nutrient concentrations (nitrate, phosphate, silicate) in southern California were associated with the subarctic intrusion of 2002. The anomalous subarctic water mass was characterized by high concentrations of dissolved oxygen and inorganic nutrients, and had unusually high chlorophyll fluorescence.




[Figure 127] Chlorophyll-a anomaly for spring 2002 derived from 1998-2002 SeaWiFS ocean color data.

## Plankton

**Phytoplankton** Satellite-derived monthly mean chlorophyll concentrations in 2001-02 were >1.0 mg $m^{-3}$ larger than the previous 3-year average over the entire shelf region from British Columbia to at least as far as northern California.[331] These anomalies were most extensive in the northern CCS off the British Columbia and Washington coasts, but were strongest off southern Oregon (Figure 127). The anomalies persisted from late 2001 until fall 2002, corresponding to the period of the intrusion of subarctic waters and enhanced coastal upwelling. A major toxic domoic acid event occurred on the Washington coast in fall 2002, resulting in the closure of razor clam harvests through spring 2003. These events, caused by the diatom *Pseudonitzschia*, have become more frequent in recent years.

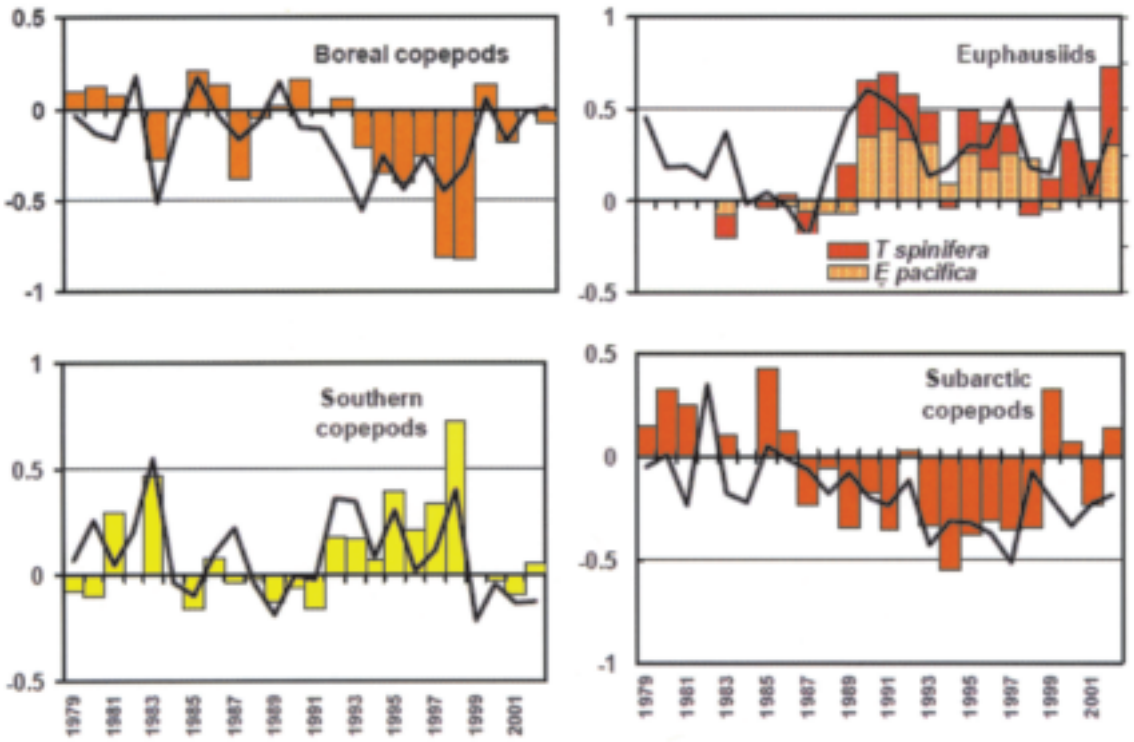
The substantial increase in upper-layer nutrients (see above) contributed to a 2-3 fold increase in primary production on the Oregon shelf in summer 2002 compared with the preceding five years.[330] Much of this production did not appear to be transfered to higher trophic levels, but instead sunk and resulted in increased water column and benthic respiration. Oxygen levels were supersaturated in the near-surface, but dropped to unusually low levels at depth. The result was a hypoxic zone covering over 700 km of the Oregon shelf observed in summer 2002.[330] An unusually high abundance of jellyfish may have kept copepod abundances relatively low during this time, helping to reduce the grazing pressure on the phytoplankton standing stock.

Vertically-integrated chlorophyll-a values from CalCOFI cruises in southern California through 2002-03 were within the range of past values.[332] The April 2002 phytoplankton species distribution was quite unusual, with *Pseudo-nitzschia australis*, a domoic acid producer, dominating the flora near Pt. Conception.[323] Elevated values of this species was observed again in April 2003 in the Santa Barbara Channel, although the overall floral composition was nearer to normal. The low integrated chlorophyll value observed in February 2003 may have been associated with a depressed nutricline as a result of the El Niño.

**Zooplankton** Shifts in zooplankton composition off British Columbia were dramatic during the 1990s, and particularly strong at the end of the 1980s and between 1998-1999 (Figure 128).

Through most of the 1990s, there was a strong shift toward a more "southerly" copepod community. This reversed abruptly in 1999 and since then, the biomass of most zooplankton taxa has been similar to the period before the 1990s.[318,321]

Zooplankton sampling has occurred in the shelf waters off Newport, Oregon on a bi-weekly basis since May 1996. These data, and historical samples from the area, have revealed a strong correlation between the PDO and copepod community structure.



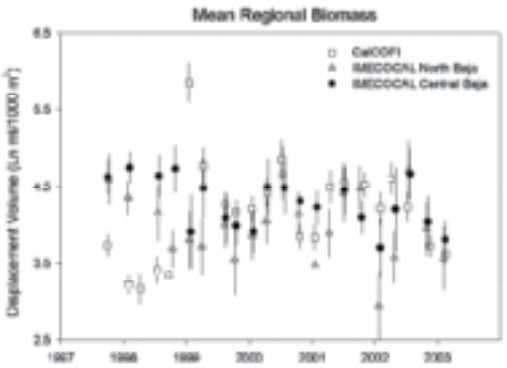

[Figure 128] Annual zooplankton anomalies (1979–2002) averaged across southern Vancouver Island statistical areas and within groups of ecologically similar species (coloured columns). Lines show fits to the zooplankton anomaly time series from stepwise regressions on 1985–1998 time series of environmental indices: large-scale (solid lines). Note the continuing "predictive" fit 1979–2002.[272 -updated]

A positive PDO, indicating a warm regime in the CCS, corresponds with anomalously high (low) biomass of warm water (cold water) species off Oregon. Cold water species predominate during the negative PDO phase. During the warm regime of the 1990s, the spring-summer biomass of subarctic species was anomalously low, while biomass of subtropical species was anomalously high. This situation reversed in early 1999, as cool temperatures and boreal subarctic species became dominant off the Oregon coast, a pattern that persisted through late summer 2002. The PDO changed sign to positive in August 2002 and remained positive through the winter of 2003/04, likely in conjunction with the 2002-03 El Niño event. The biomass anomalies of warm water zooplankton species increased during this period, but subarctic species returned to normal levels by June 2003.

One possible mechanism for this strong correlation between PDO and northern CCS zooplankton community structure is the strength and duration of coastal upwelling. The expectation is for an association between a positive PDO, weak upwelling, and a shorter upwelling season, while the opposite should be true during a negative PDO phase. The length of the growth season is clearly related to the sign of the PDO with a longer growth season characteristic of a negative PDO pattern. However, although upwelling is certainly stronger off central California during negative PDO phase, there is no evidence from the Bakun upwelling index of an increase in upwelling at latitudes of the Northern California Current (45°-51° N). Thus, the alternate hypothesis is offered that increases in biomass and production of cold water species during a cool regime in the northern California Current are due to increased advection of relatively eutrophic Gulf of

Alaska waters into the coastal branch of CCS, bringing with it "cold water" species. In constrast, increases in biomass of warm water species and decreases in production are a result of relatively oligotrophic waters moving into the coastal regions of the California Current from the offshore Transition Zone, bringing with it subtropical species.

Mean zooplankton biomass off southern California was markedly elevated in April 2002, a period of strong upwelling and the start of the subarctic intrusion into the CCS. Values later in the year, however, were below the monthly averages over the period 1984-2001.[332] The February 2003 value was the sixth lowest in the CalCOFI record, characteristic of declined productivity during peak El Niño influence.




[Figure 129] Mean macrozooplankton biomass in three regions of the southern California Current System: southern California (CalCOFI lines 80-93), northern Baja California (IMECOCAL lines 100-110), and central Baja California (IMECOCAL lines 113-133).

As off southern California, mean zooplankton values off Baja California were low in February 2003, the second consecutive winter with mean values lower than the historical mean (from 1951-84). The rest of the 2002 cruises had mean biomass values within the confidence interval of the period 1951-84. July 2002 had the largest biomass in the IMECOCAL series but it appeared to be typical for that time of year.

Tendencies in macrozooplankton biomass between southern CCS regions (Figure 129) showed that during February and April 2002, biomass was highest off southern California and lowest off northern Baja California, with values off central Baja California falling between. From July 2002 to February 2003 the three regions showed similar mean values. Considering previous years, these regions have been responding coherently from July 2000, with the exception of winter and spring 2001 and 2002, when low zooplankton volumes off northern Baja California were the rule.

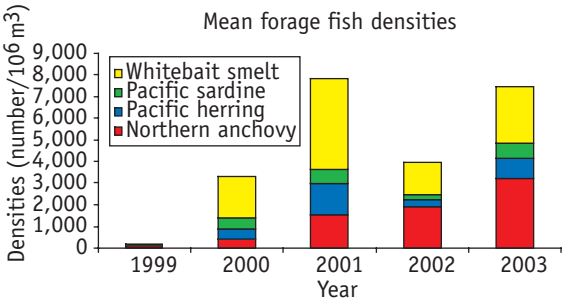
## Fish and Invertebrates

In British Columbia in 2002, the spawning biomass of Pacific herring increased to near the average for the past two decades. A long-term research program has shown that herring recruitment in this region tends to be below average when ocean temperatures are warm and the summer biomass of migratory predators (primarily hake and mackerel) is high. Ocean conditions were therefore more favourable for herring survival in 2000 and 2001. Growth conditions for Pacific salmon off Vancouver Island, for coho salmon (*O. kisutch*) in particular, exceeded those of prior years that have been studied since 1998.

The epipelagic and mesopelagic nekton communities of the northern California Current have been sampled by a number of methods over the past four decades.[333] Abundance trends of pelagic nekton from this region demonstrate large-scale ecosystem changes around the times of the proposed regime shifts of 1976 and 1989, and suggestions of a similar shift around 1998. The rapidity of the community composition changes point to fluctuations in migration of distribution patterns, rather than changes in recruitment. The strong El Niño events of 1983 and 1998 led to altered alongshore and cross-shore distributions of many pelagic nekton and micronektonic species.

Annual surveys conducted in the vicinity of the Columbia River since 1999 indicate that forage fish (whitebait smelt, Pacific herring, and northern anchovy) abundance has increased from very low levels in 1999. A decline in abundance in 2002 appears to be directly related to extremely low Columbia River flows in 2001; a year-class of both northern anchovy and whitebait smelt was lost (no 1 year old anchovy or whitebait smelt were found in 2002). The September 2003 survey found extremely large numbers of young-of-year anchovy; many more than seen prevously. There were also large numbers of young-of-year sardines off Oregon and Washington in September, likely a result of successful spawning off Oregon in 2003 (Figure 130).

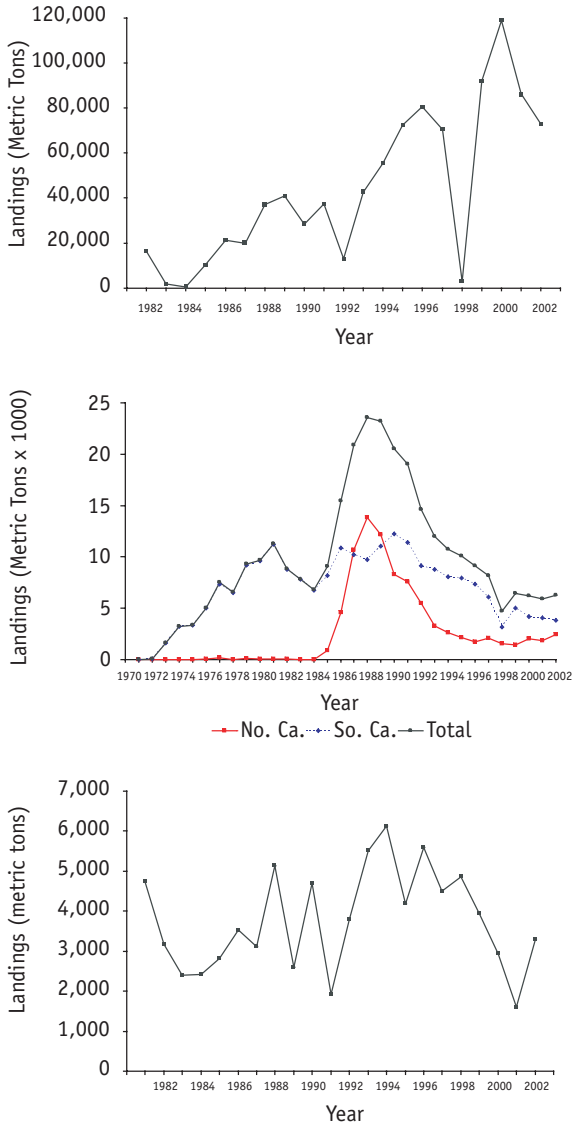
Commercial fisheries in California landed over 177,000 metric tons of fishes and invertebrates from California ocean waters in 2002, a decrease of 12% from 2001 and a 28% decrease from 2000.[334] The preliminary ex-vessel economic value of California commercial landings was US$104 million, slightly higher than in 2001 but a decrease of 22% from 2000.




[Figure 130] The mean density of forage fishes (whitebait smelt, Pacific herring, northern anchovy, and Pacific sardine) off N Oregon/S Washington from April to July.[335]

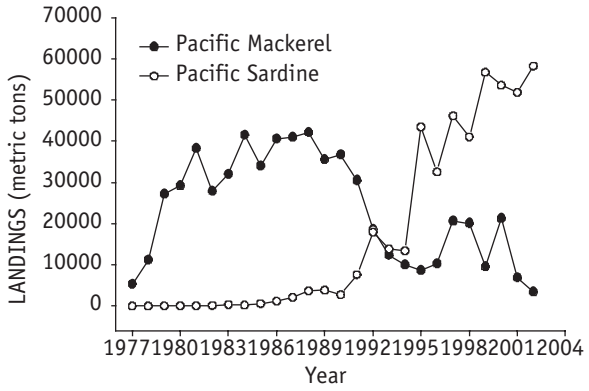
The top three valued fisheries in California in 2002 were invertebrates: market squid, dungeness crab, and sea urchin (Figure 131). Landings of squid (-15%) and dungeness crab (+105%) changed substantially in 2002, while demand for both species led to higher revenue, by 8% for squid and 49% for dungeness crab. Sea urchin revenue decreased by 13% from 2001, although landings increased slightly. The remainder of the top ten California commercial fisheries in 2002 were: chinook salmon (60% increase in value from 2001), swordfish (28% decrease in value from 2001), Pacific sardine, California spiny lobster, albacore, sablefish, and spot prawn. Further details of all important commercial and recreational California marine fisheries are available.[334,336].

Market squid was the largest fishery in California by volume (72.9 t) and ex-vessel value. Pacific sardine ranked second in landings (58.3 t), despite a closure for domoic acid, export bans, and a regional closure in northern California, Oregon and Washington due to attainment of the harvest guideline.




[Figure 131] Commercial landings of the top three valued California fisheries: (top) market squid, 1982-2002, (middle) red sea urchin for northern and southern fisheries, 1970-2002, and (bottom) dungeness crab, 1981-2002.[334]

Landings of Pacific mackerel, jack mackerel, and northern anchovy all declined substantially in 2002, by 51%, 72%, and 76%, respectively, from 2001. Long-term trends in California Pacific sardine and Pacific mackerel landings are shown in Figure 132.




[Figure 132] California commercial landings (metric tons) of Pacific sardine (*Sardinops caeruleus*) and Pacific mackerel (*Scomber japonicus*), 1977-2002.[334]

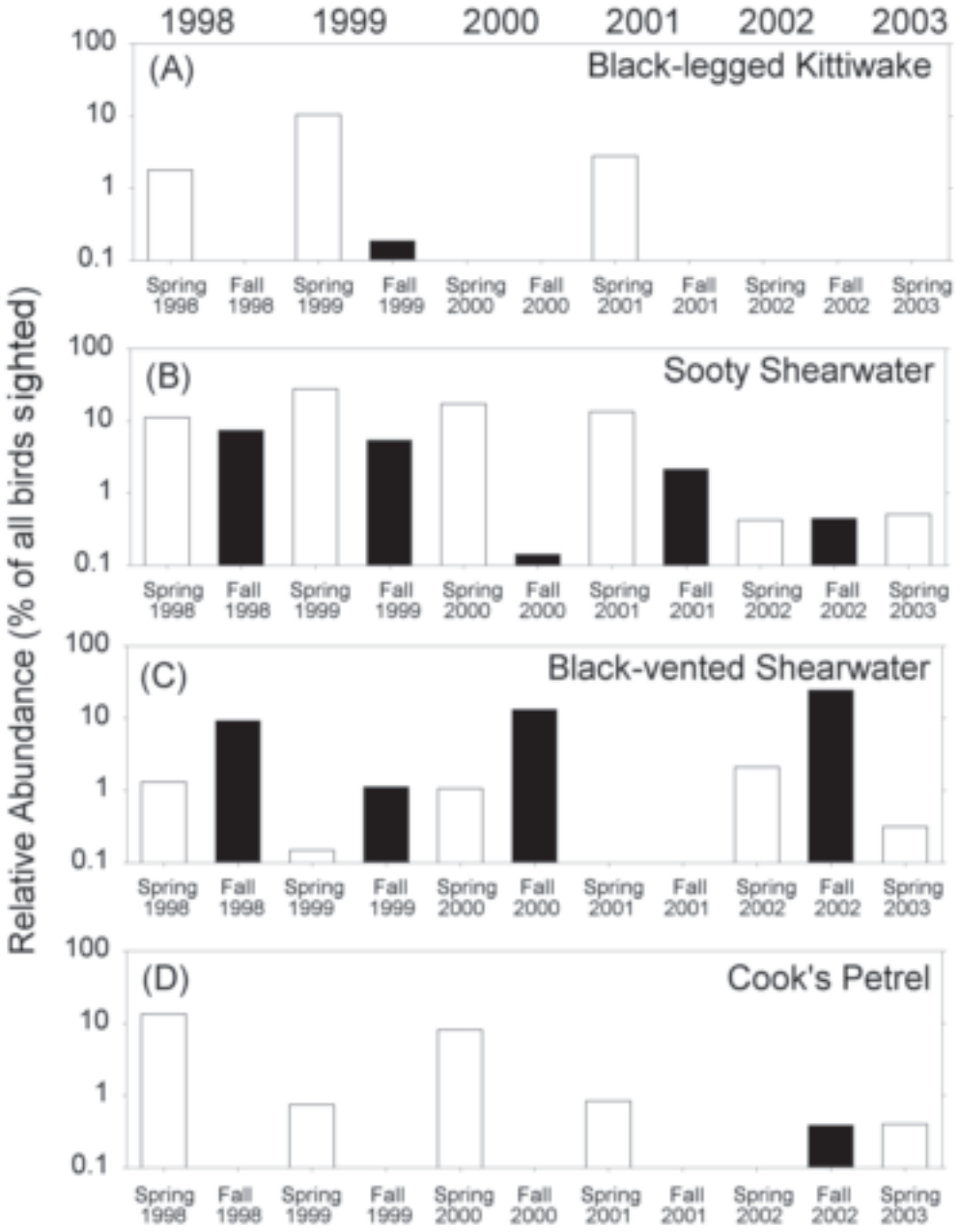
New federal and state regulations were imposed in 2002 to help rebuild overfished rockfish stocks, including bocaccio, canary, cowcod, yelloweye rockfishes, and lingcod. Management areas for California rockfish were closed for 4-8 months. In addition, the California Fish and Game Commission voted to adopt a series of marine protected areas within the Channel Islands National Marine Sanctuary.

The NMFS Santa Cruz Laboratory conducts an annual survey of pelagic juvenile rockfish abundance along the central California coast (lat. 36°30′ – 38°20′ N). This survey is designed to estimate the annual reproductive success of 10 species of rockfish (*Sebastes* spp.) by catching fish that are 80-140 days old during May-June. Recent results show that catches in the survey have increased markedly since the 1998 El Niño. Moreover, there appears to be a strong relationship between the survival of rockfish larvae spawned during the winter months and ocean conditions in the California Current indexed by the PDO. Because managers of the groundfish fishery on the U.S. west coast are struggling to rebuild a number of overfished rockfish stocks, these findings are a welcome sign that changing productivity conditions along the west coast may accelerate the recovery of these stocks.

For short-lived species like market squid, the affects of El Niño are dramatic but short-lived. Unfortunately, accurate estimates of biomass are not available for a variety of reasons. Only total catch or catch rate (catch per landing) provide an index of squid population response to environmental variability. Over the last 20 years annual catch has increased exponentially, but has been extremely low during and immediately after El Niños. However, usually within 2 to three generations (12 to 18 months), catch rates within the fishery are equivalent to the catch rates immediately prior to the El Niño. The moderate 2002-03 El Niño led to a significant reduction in market squid landings. It should be noted that little is known about market squid ecology and life history, so inferring relationships between the environment and the productivity of this species is still tenuous.

## Marine Birds and Mammals

**Seabirds** Observations of marine bird species provide information on the response of higher trophic level predators to interannual and longer-term oceanographic variability. CalCOFI cruises have provided the opportunity for systematic surveys of the distribution and abundance of marine birds and mammals in relation to oceanographic conditions off southern California since 1987. These observations have documented fluctuations in seabird community structure in response to changes in the physical and biological properties of the CCS.[323,332,337,338] To illustrate the response of marine bird communities to recent environmental variability in the CCS, data for four indicator species with different water mass preferences and biogeographic affinities are presented (Figure 133). Seabird communities have shifted from year to year in response to transient warming and cooling periods since the spring of 1998.




[Figure 133] Relative abundance of four indicator seabirds with an affinity for distinct water temperature and biogeographic domains (subtropical/warm-water taxa: black-vented shearwater, Cook's petrel; subarctic/cool-water taxa: black-legged kittiwake, sooty shearwater). Importance was computed by dividing the number of a given species by the total number of seabirds sighted during each cruise. White (black) histograms depict spring (fall) cruises.

In particular, short-term fluctuations indicative of the onset of El Niño conditions were apparent starting in the second half of 2002. By fall 2002, the avifauna was dominated by warm-water species indicators, like the black-vented shearwater (Figure 133c).

The northward incursions of subtropical species were particularly apparent during the spring of 2003, when a number of species that had not been seen in large numbers off California since the 1997-98 El Niño were observed. Locally breeding seabird populations in the Farallon Islands in central California (37°N) had increased reproductive success for all six species studied. Mean annual productivity was a record high in 2002, the fourth consecutive year of positive seabird anomalies for all species. Because seabird populations integrate the variability in oceanographic conditions during the breeding season, it is expected that productivity metrics respond strongly to interannual changes in ocean conditions and prey availability. The recent reproductive success of seabirds in the central and southern CCS supports the idea that a regime shift to conditions with enhanced upwelling and ocean productivity may have occurred following the 1997-98 El Niño.

Off British Columbia, Triangle Island (50°52'N 129°05'W) supports the world's largest population of Cassin's auklet (*Ptychoramphus aleuticus*; 1.1 million breeders) and a large population of rhinoceros auklet (*Cerorhinca monocerata*; 82,000 breeders) in addition to significant populations of tufted puffin (*Fratercula cirrhata* 52,000 breeders) and common murre (*Uria aalge*; 8,200). All share a common characteristic of a single egg clutch. The Cassin's auklet is a small (190g) primarily planktivorous, burrow nesting seabird which visits the colony only at night. The rhinoceros auklet (*Cerorhinca monocerata*) is a 550 g piscivorous, burrow nesting species which also visits the colony at night. The tufted puffin is a 750 g, piscivorous, burrow nester which visits the colony at multiple times throughout the day when feeding young. The common murre is a large (950g), piscivorous, cliff-nesting, diurnal species. In 2003, the fish eating rhinoceros auklet and tufted puffin hatched approximately 1 week later than in 2002. In contrast, common murres and Cassin's auklet exhibited similar timing to that reported for 2001. For the first time in the data series, common murre chicks were observed prior to mean hatching dates of tufted puffins.[318,321]

**Pinnipeds** Over 400 California sea lions (*Zalophus californianus*) died along the central California coast during May and June 1998, at the time of an observed bloom of the diatom *Pseudonitzschia australis* that was associated with the production of domoic acid.[339] This neurotoxin was detected in sea lion body fluids and in planktivorous fish in the region, but not in blue mussels collected during the domoic acid outbreak. These observations demonstrate the trophic transfer of domoic acid resulting in marine mammal mortality, but also reveals that monitoring of mussel toxicity alone does not necessarily provide adequate warning of domoic acid entering the food web.

Due to the rapid expansion of some California Current fisheries, in particular in California, there has been an increase in the number of incidental captures of marine mammals in fishing operations.[340] A major issue is therefore how to reduce this incidental capture of marine mammals. California sea lion and harbour seal populations appear to be growing, although fishing mortality has increased on sea lions. The Steller sea lion population along the west coast of North America (excluding Alaska) is estimated to be about 39,000 individuals, which is less than 50% of the 1956-1960 population estimate. This species is now listed in the United States as endangered.

**Cetaceans** The abundance of many whale species, including humpback and gray whales, is increasing and the latter was removed from the U.S. endangered species list in 1994.

PCB concentrations in wild killer whales in British Columbia are among the highest measured for cetaceans in the world, putting them at risk for toxic effects. Transient killer whales that migrate widely along the west coast of North America were the most heavily contaminated.[341]

Sea otter (*Enhydra lutris*) populations in the California Current system are expanding. In California, this population growth ceased during the 1997-1998 El Niño, possibly due to a reduction in food. The interaction of sea otters with commercially fished species, in particular invertebrates, is an important issue.

# critical factors causing change

The CCS was impacted by a rare and unusually strong intrusion of subarctic water during 2002.[342] The impact was observed from 49°N (Vancouver Island) to 33°N (southern California), a distance of over 1500 km. The intrusion was characterized by cold, fresh water mass in the upper halocline, with temperature and salinity anomalies more extreme than any seen previously in a historical record that extends for nearly 50 years in some locations. The subarctic anomaly brought high-nutrient waters into the coastal upwelling zone off Oregon and northern California and produced very high chlorophyll concentrations. The subarctic water mass was propagated through the CCS via strongly anomalous southward flow, which was detected by moorings, drifters, and satellite altimetry. It appears that large-scale wind forcing over the northeast Pacific in the winter-spring of 2001-02 set the conditions for the subarctic intrusion. Cool, fresh conditions were still apparent from Oregon to southern California in spring 2003, although not to the extent seen the previous year.

Following several consecutive years of weak-to-moderate La Niña conditions, an El Niño developed in the tropical Pacific in summer 2002. This was the first El Niño since the large 1997-98 event, but it was considerably weaker. The 2002-03 El Niño did not evolve as the typical El Niño pattern, with strong positive temperature anomalies never developing completely along the South American coast, followed by a rapid decline in spring 2003.

Two large-scale North Pacific climate indices, the Northern Oscillation Index[31] and the Pacific Decadal Oscillation[23], reversed sign in summer 2002 along with the development of the El Niño, indicating a switch to warmer conditions in the CCS for the first time since 1998. However, both indices again reversed sign by summer 2003, after the El Niño had dissipated. Most recent data suggest a return to cooler conditions in the CCS, perhaps reflecting the continuation of a new climate regime in the North Pacific which was hypothesized to have begun in 1998.[343,344,30]

The CCS was impacted by stronger than normal upwelling in spring-summer of 2001 and 2002 (Figure 123), continuing a pattern of strong upwelling and cool SSTs since the dissipation of the 1997-98 El Niño. Strongest upwelling was centered around 36-40°N. Strong downwelling prevailed north of Pt. Conception (34°N) during winter 2002-03, and persisted in the northern CCS at least through April 2003. Anomalously strong upwelling returned to the CCS by May 2003, as the large-scale indices were indicating a change from El Niño influences.

The number of vessels with recorded commercial landings in California declined 20% between 1995 and 1999, to 2690 vessels. The values of commercial invertebrates and groundfishes have also declined in recent years.

# issues

It appears that harmful algal bloom events (HABs) are increasing in intensity, frequency, duration, and geographical location; however the long term observations needed to substantiate such trends are often lacking. Examination of the past 40 years of paralytic shellfish poisoning (PSP) data for Puget Sound has revealed significant trends.

Occurrences of outbreaks of PSP within the Puget Sound basin of Washington State has increased both in intensity (i.e., levels of PSP reported) and spatially. Prior to 1978, PSP was largely confined to the northern basins of Puget Sound. In subsequent years the PSP outbreaks appeared to spread into the central or main basin of Puget Sound and within the last decade they have occurred in the southern basin. There has been a steady increase in the numbers of outbreaks, particularly those in excess of the US action level (80 ug STX equiv/100g). Annual and decadal averages of the highest levels measured have also increased over this time period. There is a strong correlation between human population growth in the Puget Sound basin and the maximum paralytic shellfish toxin levels per decade.[345]

One of the most important unresolved issues in CCS ecosystem dynamics is the relative impacts and interplay between low-frequency climate variability (e.g. the proposed climate regime shift of 1999) and transient interannual variability (e.g., the modest 2002-03 El Niño). In particular, the mechanisms responsible for large-scale climate shifts, and their biological implications, are not yet understood. This is a critical gap in understanding, since proposed regime shifts are observed to result in a pan-trophic biological response.[346] Continued and enhanced monitoring of the CCS is essential to address these questions.

A lot of activity is underway to design an integrated observing system for the entire CCS. Some of this activity is under the auspices of the Integrated Ocean Observing System (IOOS), and involves academic, state, and federal agencies in the U.S., as well as Canadian and Mexican institutions. There is an urgent need to design and fund an observing architecture that will monitor the physics, chemistry, and biology of the CCS synoptically and with sufficient frequency to capture important fluctuations on seasonal to interannual time scales.

Other major issues include lack of understanding of the interactions among environmental variability, recruitment fluctuations, and fishing pressure; over-harvest of low mobility species such as abalone and rockfishes; interactions between fisheries and marine mammal populations; and pollution/contaminants problems.

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