

CalCOFI – A 56-year old Ocean Observing System

Results from Recent Observations

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CalCOFI - The Organization

The California Oceanic Cooperative Fisheries Investigation (CalCOFI) is a unique partnership of the California Department of Fish and Game, the NOAA Fisheries Service and the Scripps Institution of Oceanography. The organization was formed in 1949 to study the ecological aspects of the collapse of the sardine populations off California. Today its focus has shifted to the study of the marine environment off the coast of California and the management of its living resources. The organization hosts an annual conference, publishes data reports and a scientific journal and maintains a publicly accessible data server (www.calcofi.org).

CalCOFI - The Field Program

Since 1949, CalCOFI has organized cruises to measure the physical and chemical properties of the California Current System and census populations of organisms from phytoplankton to marine birds. This is the foremost observational oceanography program in the U.S. Currently, two to three week cruises are conducted quarterly. Scripps and NOAA provide equally in terms of ship time, personnel, and other cruise-related costs. On each cruise a grid of 66 stations off Southern California is occupied (Fig. 1). At each station a whole suite of physical and chemical measurements are made to characterize the environment and map the distribution and abundance of phytoplankton, zooplankton and fish eggs and larvae.

Observations

- Meteorological observations
- Temperature, salinity, oxygen
- Water masses and currents
- Concentrations of plant nutrients
- Primary production
- Biomass of phytoplankton and zooplankton
- Phytoplankton and zooplankton biodiversity
- Distribution and abundance of fish eggs, larvae, marine birds and mammals

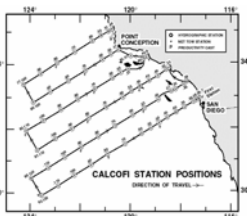


Fig. 1. The standard CalCOFI station pattern. All 66 stations are occupied on most cruises. During the winter and spring cruises the pattern is extended north for observations of hydrographic properties and distributions of fish eggs.

Hydrography: Standard data products of each cruise are fields of hydrographic properties: temperature, salinity, dynamic height (proxy for surface currents) and biological properties (Fig. 2). For example, in January 2005 the California Current was located in the offshore regions of the CalCOFI study area (Fig. 2A). Upwelling was not observed and consequently phytoplankton biomass was still moderate along the coast.

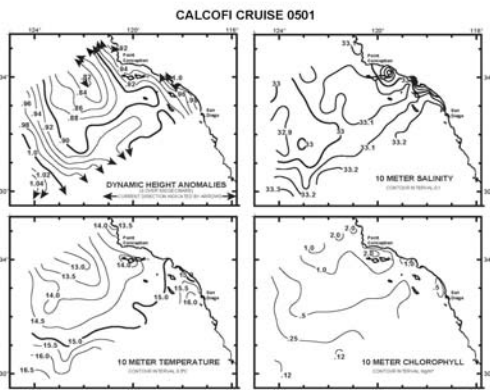


Fig. 2. Spatial patterns for a CalCOFI cruise in January 2005, including upper-ocean geostrophic flow estimated from the 0500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll a.

Hydrographic Time Series

Time series of hydrographic properties are used to ascertain the state of the physical system. Mixed Layer (ML) temperature (Fig. 3 A) reflects changes in ocean climate such as ENSO events (see the dramatic rise of SST anomalies during the 1998 El Niño) or changes in the sign of the Pacific Decadal Oscillation (PDO) as occurred in 1998.

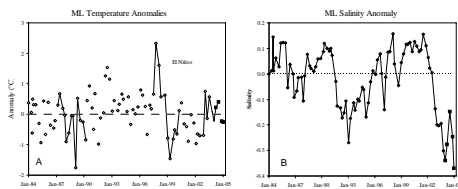


Fig. 3. A. Temperature anomalies for the Mixed Layer (ML) at the 66 standard CalCOFI stations calculated from observation made on the quarterly CalCOFI cruises. Anomalies are calculated relative to the time period 1985 to 2004. ENSO events are indicated with solid lines; data from the most recent cruises are solid symbols. Prominent in the time series are the effects of the 1997/8 El Niño and the following La Niña. The 2002/3 El Niño is only weakly expressed. B. Anomalies similar to A for ML salinity. Note the very low anomalies observed since 2003.

Hydrographic Time Series - Continued:

Time Mixed layer salinity has recently dropped dramatically in the CalCOFI area (Fig. 3B) to levels not observed since the 1970's. The anomalies still tend to be strongest at the offshore stations (Fig. 4A), where conditions since 2003 have not changed much, but these have intensified over the last year at the inshore stations (Fig. 4B, C). Associated with the change in water masses, particularly at the offshore stations, was a shallowing of the seasonal thermocline and the nutricline. It is possible that this phenomenon is caused by a spin-up of the Central Gyre of the North Pacific. In contrast to the salinity data that suggest a massive change in the upper 100 to 150 m of the system (Fig. 13), climatologies of other water column properties do not show such large anomalies over the last two to three years, with the exception of silicate.

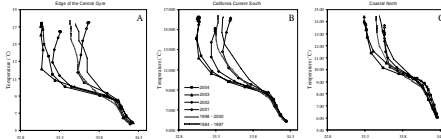


Fig. 5 – TS lines for three representative areas of the CalCOFI region. A. The edge of the central gyre (Line 90-93, Stations 100 – 120). B. The California Current region (Line 83-90, Stations 70-90) and C. the coastal areas in the north (Line 77-80, Stations 60 and inshore). Each data point represents the average TS characteristic of one standard depth level for the specified time period, e.g. the year 2002.

Nutrient Time Series

Concentrations of inorganic plant nutrients – nitrate, phosphate and silicate – and the depth of the nutricline are affected by changing ocean climate as well. With the exception of silicate, however, the changes of these parameters over the years have been small. Silicate anomalies over the last two years are the lowest on record (Fig. 6A). These large negative silicate anomalies coincide with the large negative salinity anomalies, suggesting that these are related to transport of subarctic waters into the CalCOFI area and its effect on the system. These changes in silicate concentrations likely affect diatom growth, which can become limited by the availability of silicate if its concentration falls below 1 μM . Prior to 2003 only 2% of all stations with ML nitrate concentrations larger than 0.3 μM had silicate concentrations < 1.2 μM , after 2003 22% of all stations belonged to that category. This implies that the likelihood that diatom growth was limited by the availability of silicate increased by an order of magnitude.

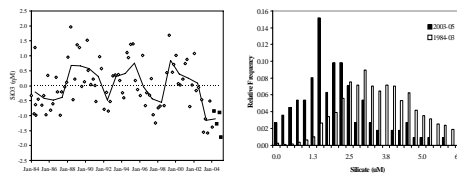


Fig. 6. A. CalCOFI region anomalies for mixed layer silicate. Symbols represent averages of individual cruises. Annual averages are represented by solid lines. B. Normalized ML Silicate concentration frequencies for CalCOFI stations with nitrate concentrations larger than 0.3 μM . Solid bars are frequencies for the time period July 2003 to January 2005. Open bars are for the time period 1985 to spring 2003. Note the dramatic shift in the frequency distribution, suggesting that likelihood that diatom growth is limited by the availability of silicate increased by an order of magnitude!

The Ecosystem – Phytoplankton and Zooplankton

The state of the ecosystem is monitored using proxies: concentrations of Chl a and the displacement volume of zooplankton caught in a 505 mm are used to monitor phytoplankton and zooplankton biomass. Understanding the response of different trophic levels to changing ocean climate is one of the objectives of CalCOFI and associated programs such as the California Current Long Term Ecosystem Research (LTER) project. Time series of Chl a concentrations and Zooplankton biomass are apparently unrelated. Whereas Chl a has been increasing over the last 20 years, varying little with ENSO events or changes in the PDO (Fig. 7A), zooplankton biomass has had periods of dramatic decline (early 1980's until 1997) and recovery (post 1998) and is significantly affected by ENSO cycles. The effect of global warming on zooplankton biomass in the California Current System is still unresolved.

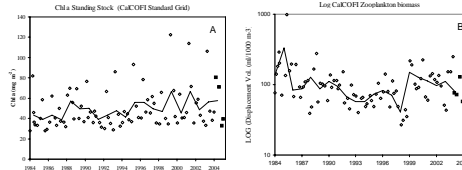


Fig. 7. CalCOFI cruise mean anomalies for (A) concentrations of mixed layer Chl a and (B) macrozooplankton displacement volumes. Symbols represent averages for the CalCOFI area and lines are annual averages.

Denitrification in the Santa Barbara Basin

Oxygen concentrations in the Santa Barbara Basin often reach suboxic levels (Fig. 8A) initiating denitrification (the use of nitrate by bacteria as an electron donor and its conversion into di-nitrogen). Over the last two years concentrations of nitrate in the SBB dropped below 1 μM which had not previously been observed (Fig. 8B). This dramatic drawdown of nitrate is likely due to increased fluxes of carbon to the bottom of the basin because of unusually long productive periods during the spring.

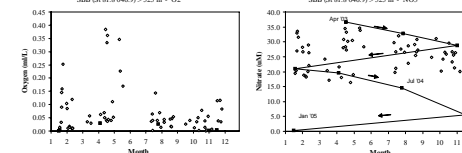


Fig. 8. Oxygen (A) and nitrate (B) concentrations at the bottom of the Santa Barbara Basin plotted against the month of the year. Data shown cover the years 1985 to 2005. Since April 2003, when the basin last flushed concentrations of nitrate have dropped from 37 μM to undetectable levels.

The Ecosystem – Small Pelagic Fish

Spawning biomass of Pacific Sardine, Northern Anchovy and Jack Mackerel are monitored by surveying the distribution and abundance of their eggs. The spawning habitat of these populations encompasses the whole California Current System (Fig. 9).

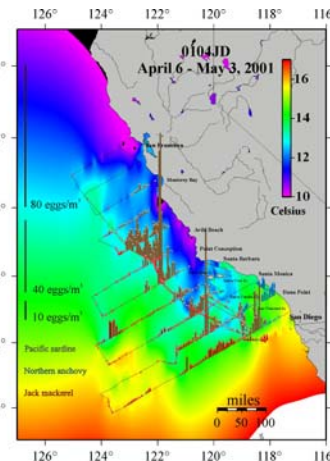


Fig. 9. Sea surface temperature and the distribution and abundance of Pacific Sardine, Northern Anchovy and Jack Mackerel eggs off Southern and Central California in the spring of 2001 (Courtesy of NOAA's Southwest Fisheries Science Center, Richard Charter).

Populations of small pelagic fish off California have varied dramatically over the years. The cycles of sardine abundance are probably best known. Indeed, the crash of the sardine populations in the late 1940's provided the motivation for the establishment of the CalCOFI program. Currently sardines are abundant off California, sustaining a fishery. Currently, however, sardines may be on the decline. The abundance of sardines is inversely related to the abundance of anchovies (Fig. 10). The distributions of the two populations overlap, however, their centers of distribution are quite distinct. Anchovies spawn close to shore, Sardines on the shelf and Jack Mackerel in the offshore areas (Fig. 11). Over the last two years the distribution center of sardines has shifted significantly to the north.



Fig. 10. The abundance of Pacific Sardine, Northern Anchovy and Jack Mackerel eggs between Monterey and San Diego. Note the inverse relationship between sardine and anchovy eggs.

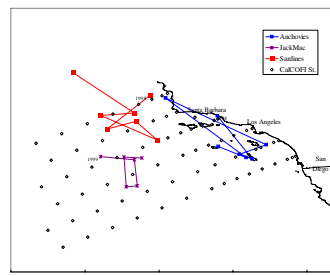


Fig. 11. The geographical centers of Pacific Sardine, Northern Anchovy and Jack Mackerel populations between Monterey and San Diego. The three species have well defined distribution centers. Sardine distributions have shifted north in recent years (incl. 2005, not shown).

ACKNOWLEDGMENTS

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