CalCOFI & CCE-LTER: 60 + Years of Ocean Observations

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CalCOFI & CCE-LTER - The Organizations

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).

The California Current Ecosystem Long Term Ecological Research program (CCE-LTER) (http://cce.lternet.edu/) is part of the NSF funded LTER network and was started in 2004. The program's objective is to study the mechanisms leading to temporal transitions between different states of the California Current ecosystem. It is an extension of the CalCOFI program and consists of four parts: 1. augmentations to the CalCOFI program to further characterize the biogeochemistry and ecology of the ecosystem, 2. series of process studies to characterize and quantify system processes, 3. a modeling program to integrate observations and test hypotheses and 4. an education and outreach program.

The Field Programs

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. 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 (Table 1) to characterize the environment and map the distribution and abundance of phytoplankton, zooplankton and fish eggs and larvae.

The CCE-LTER augmented CalCOFI surveys (Table 1) to expand the understanding of the ecosystem (high taxonomic resolution sampling of the pelagic food chain and higher tropic levels) and to further constrain biogeochemical cycles (DIC, Talk, DOC/N, POC/N). The CCE program takes samples at all 66 standard CalCOFI stations and carries out extensive measurements at 8 'cardinal' stations (Fig. 1).

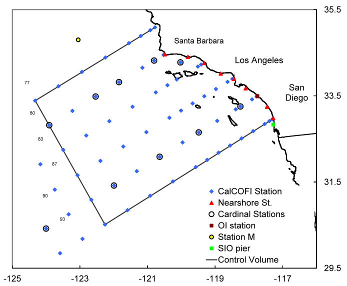

Fig. 1. The standard CalCOFI station pattern. The 66 CalCOFI stations are occupied on all cruises. During the winter and spring cruises the pattern is extended north for observations of hydrographic properties and distributions of fish eggs. CCE cardinal stations are chosen to represent different 'floral' regions. Off Dana point the Dana Point Ocean Institute, a CCE associate, maintains a nearshore Chl a time series with CCE support. Ken Smith maintains a sediment trap station at Station M. The control volume area is used for calculating biogeochemical fluxes in and out of the area.

Table. 1. The standard CalCOFI and CCE measurements. The basic CalCOFI measurements that have been carried out consistently since 1949 are shown in red, those carried out since 1984 are shown in blue.

Parameter	Group	Method
Meteorology	CalCOFI	Visual & instruments
Currents to ~500 m	CCE-LTER	ADCP, data analysis
Station hydrography (T, S, chl, O_2)	CalCOFI	CTD
Irradiance	CalCOFI	PAR meters
Underway hydrography	CalCOFI	Sensors in ships intake
Light transmission at 660 nm	CalCOFI	Transmissometer
Oxygen	CalCOFI	Auto-Winkler
Oxidized nutrients N, P, Si	CalCOFI	Autoanalyzer
Ammonium	CalCOFI*	Autoanalyzer
Sea surface pCO_2	NOAA & MBARI	IR absorbance
TCO_2, TAlk, pH	Dickson, CalCOFI	various
Sea surface pH	Martz, CalCOFI	electrode
Particulate C, N	CCE-LTER	Dry combustion
Dissolved organic C N	CCE-LTER	Combustion
Primary Production	CalCOFI	14C uptake
Chlorophyll a	CalCOFI	Flourometry
Phytoplankton size structure	CCE-LTER	Flourometry
Taxon-specific pigments	CCE-LTER	HPLC
Phytoplankton physiology, sea surface	CCE-LTER	Adv. Laser Flurometry
Bacteria and picoautotrophs	CCE-LTER	Flow-cytometry
Nano- and microplankton	CCE-LTER	Microscopy
Mesozooplankton biomass	CalCOFI	Net tows
Mesozooplankton-size classes	CCE-LTER	OPC, LOPC
Mesozooplankton-sentinel species	CCE-LTER	Microscopy, ZOOSCAN
Fish eggs and larvae	CalCOFI	Net tows, CUFES
Seabird species and abundance	Sydeman, Farallon Inst.	Visual observation
Cetacean species and abundance	Hildebrand	Visual and acoustic
Krill, small pelagics, micronekton	NOAA & CCE-LTER	Acoustics and trawl

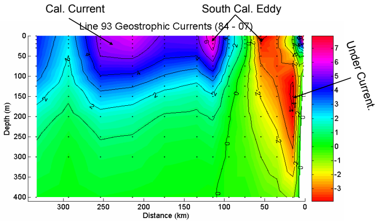

Fig. 2. North-South geostrophic currents along CalCOFI Line 93. Shown are the California Current, the Southern California Eddy and the Undercurrent. The data shown are long-term averages for the years 1984 to 207. The location of the surface currents is highly variable year to year; the location of the undercurrent is relatively stable.

Currents:

The fresh and cold California Current (CC) enters the CalCOFI domain from the north, northwest (Fig. 2). It is the dominant influence on surface water masses in the Southern Cal. Bight. The other important surface water masses are those entering the domain from the west, derived from the central North Pacific, and those derived from coastal and open ocean upwelling which are often found inside the CC.
The warm and salty Undercurrent originates in the Eastern Tropical North Pacific (ETNP). It flows at depths of ~ 100 to 300 m along the coastal margins of Baja, Southern and Central California. Through eddies breaking off from the UC and drifting westward its waters contribute to properties at depth off Southern California.

Hydrography: A standard data product of each cruise are fields of hydrographic properties, i.e. temperature, salinity, dynamic height (proxy for surface currents) and biological properties (Fig. 3). For example in January 2005 the California Current was located in the offshore regions of the CalCOFI study area (Fig. 3A). Upwelling was not observed and consequently phytoplankton biomass was still moderate along the coast (Fig. 3D).

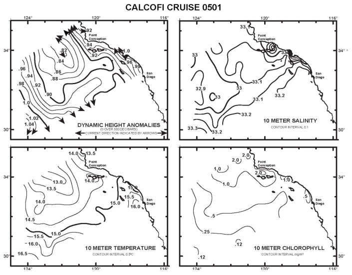
CALCOFI CRUISE 0501

Fig. 3. Spatial patterns for a CalCOFI cruise in January 2005, including upper-ocean geostrophic flow estimated from the 0/500 dbar dynamic height field, 10 m salinity, 10 m temperature, and 10 m chlorophyll *a*.

Nutrient and Oxygen Time Series

The σ_t 26.4 isopycnal is found at a depth of about 200 m off S. California. Properties at this isopycnal (Fig. 4) are affected by both local and basin-wide processes. Spiciness at the isopycnal has been fairly constant over the last decade, suggesting that no dramatic changes in water masses have occurred. However, over the last decades concentrations of oxygen decreased and nitrate increased (c.f. Bograd et al, 2008; McClatchie et al. 2010); the latter reaching values that have not been observed since these measurements begun in 1984. The relatively constant values of N*, at least over the last decade, are consistent with the hypothesis that the balance of remineralization and denitrification in the tropical North Pacific has not changed dramatically. The spatial expression of the nitrate increase shows the strongest signal in the offshore areas and relatively weak signals along the coast (Fig. 5), consistent with a basin-wide mechanism forcing the observed changes rather than forcing by changing properties of the California Undercurrent. The most likely explanation of the observed signals is the process described in a modeling study by Rykaczewski and Dunne (2010) that predicts as a consequence of global warming increased concentrations of nitrate in the CCS due "to enrichment of deep source waters entering the CCE resulting from decreased ventilation of the North Pacific".

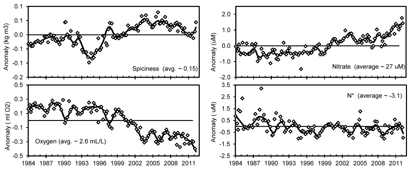

Fig. 4. Anomalies of hydrographic properties at the σt 26.4 isopycnal (open diamonds) averaged over the standard CalCOFI stations. Shown are anomalies of spiciness, oxygen, nitrate, and N*. N* is a biogeochemical indicator which reflects the deficit of nitrate in a system relative to concentrations of phosphate. The solid line represents a loess fit to the data, the dotted line designates a value of zero; average values for the properties are given as well. (Bjorkstead et al. in press)

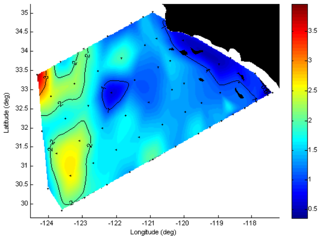

Fig. 5. The spatial distribution of nitrate concentration anomalies at the 26.4 isopycnal for the time period summer 2011 to spring of 2012 relative to the 1984 to 2008 time period..

The Ecosystem – Phytoplankton Community Structure

The CCE program monitors phytoplankton community structure using a variety of approaches. Shown here are results based on distributions of taxon-specific pigments, which are converted to contributions of different taxa to total Chl a (TChl a) using the method of Goericke and Montoya (1998).
The variability of phytoplankton biomass in our system is dominated by diatoms or dinoflagellates, the bloom species; other taxa never form blooms. To elucidate relationships between different taxa, taxon-specific biomass is plotted against TChl a (Fig. 6). The pigment-biomass of non-bloom-forming taxa varied as an asymptotic function of TChl a (Goericke, 2011). Observed patterns for any taxon were often strikingly similar in different environments (based on data not only from the CCE but also the Sargasso Sea, Arabian Sea and nearshore environments) but differed substantially between taxa in any one environment. These patterns were also observed in grow-out experiments lasting 3 to 5 days.

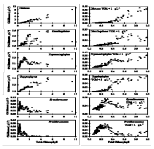

Fig. 6. The pigment biomass of selected algal taxa plotted against TChl a for the California Current System. All data were subjected to 7-point smoothing (boxcar). Unsmoothed data for Prochlorococcus are shown in Fig. 3C. Plots in the left-hand column are for the whole range of TChl a values and plots in the right-hand column are for TChl a < 1 µg L-1.

Simple functions were used to describe these patterns, which can be used to predict phytoplankton community structure from TChl a. The observed patterns are consistent with predictions derived from a simple conceptual model (Fig. 7) that suggests that total phytoplankton biomass is generally limited by the availability of a critical nutrient, i.e. by bottom-up forces, but that the biomass of some taxa, particularly picoautotrophs, is controlled by grazers under mesotrophic to eutrophic conditions, i.e. top-down forces. The distribution of cyanobacteria suggests that their population dynamics, unlike those of other taxa, is not tightly lined to the dynamics of their grazers, likely because the latter are grazing concurrently on heterotrophic bacteria.

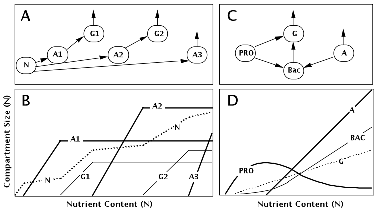

Fig. 7. Food web diagrams and predicted biomass variations as a function of a system's nutrient content (NT). A. Food web consisting of one nutrient pool (N), three autotrophs (A1, A2, A3) and two grazers (G1, G2). B. Variations of predicted nutrient concentrations and autotroph and grazer biomass as a function of NT for the system shown in A (adapted from Thingstad, 1998). C. A food web showing interactions between Prochlorococcus (PRO), one grazer (G), heterotrophic bacteria (BAC) and other autotrophs (A). D. Biomass variations of autotrophs (PRO, A), heterotrophic bacteria (BAC) and a grazer (G) as a function of nutrient content for the system shown in C. (Goericke, 2011)

The Ecosystem – Zooplankton biomass and nutrients

Zooplankton displacement volume (ZDV), a proxy for zooplankton biomass, has been measured since 1949. A visual comparison of ZDV anomalies and nitracline depth (Fig. 8) suggests that these two variables covary. The significant covariation of the two parameters was established using an autoregressive model with external inputs (ARX [4, 2, 0]), c.f. Box and Jenkins, 1970). Autoregressive since the time series of ZPD anomalies has significant autocorrelations at lags of 1 and 3 seasons. Significant effects of nitracline depth were observed at lags of zero and 1 season, with regression coefficients (± 95% conf. interv.) of -0.028 (±0.009) and 0.014 (±0.011) for the lags of 0 and 1 season, respectively. Measured and modeled data closely covary (Fig. 8C). The negative relationship between ZDV and nitracline depth for a zero lag is easily understood: decreases in nitracline depth will lead to increases in phytoplankton biomass, increases that are likely to be due to larger phytoplankters (Goericke, 2011). The disproportionate increase in large phytoplankters may cause the increase in zooplankton biomass. However, the positive relationship between ZDV and nitracline depth for a lag of one season is more difficult to understand.

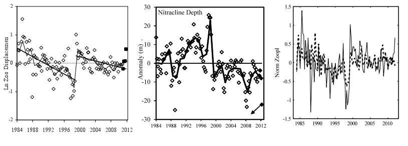

Fig. 8: A. cruise averages of the anomalies of the log of zooplankton displacement value relative to the 1984 to 2011 time period. Symbols used are as described in Fig. 4. B. Nitracline depth anomalies for the CalCOFI region plotted against time C. The solid line represents the detrended data shown in A. The dashed line are the predicted value based on the ARX [4, 2, 0] model fit to the data. Note that zooplankton data are only available up to the fall of 2011. Goericke, unpubl.

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