Climatic Warming and the Decline of Zooplankton in the California Current

Dean Roemmich and John McGowan

Since 1951, the biomass of macrozooplankton in waters off southern California has decreased by 80 percent. During the same period, the surface layer warmed—by more than 1.5°C in some places—and the temperature difference across the thermocline increased. Increased stratification resulted in less lifting of the thermocline by wind-driven upwelling. A shallower source of upwelled waters provided less inorganic nutrient for new biological production and hence supported a smaller zooplankton population. Continued warming could lead to further decline of zooplankton.

Zooplankton play an important role in the biological cycling of carbon and other elements in the ocean. It is important to document trends in zooplankton biomass and also to understand how changes in climate may affect plankton. In this report, we describe 43 years of observations off the California coast and show that zooplankton have declined while the surface layers of the ocean have warmed. The decline is a major perturbation in the biota of the region because macrozooplankton form a significant part of the food web, may compete with larval fish for food, and are the main diet of some birds (*1*) and many schooling, commercially important fish species.

Our data come from the California Cooperative Fisheries Investigations (CalCOFI), a time series of physical, chemical, and biological measurements spanning an area of ocean greater than 130,000 km^2 (Fig. 1) since 1951. CalCOFI lines 90 and 80 are the most heavily sampled lines in the survey. Line 90 is in the Southern California Bight and line 80 is near Point Conception. Between 1951 and 1993 there were 222 cruises in which zooplankton were sampled by towing a 0.505-mm mesh net (*2*) at three or more stations (typically about 10) along line 90.

The zooplankton distribution is patchy in space and time. To produce a more Gaussian distribution for subsequent averaging, following the method described in (*3*), we computed the natural logarithm of the plankton volume, per 1000 m^3 of seawater strained, at each station. The transformed data were averaged over all stations from a given cruise along lines 90 and 80 to produce a time series for each line (Fig. 2, A and B). Zooplankton volumes decreased by about 80% from 1951 to 1993. In addition to this trend, there were low-frequency fluctuations with periods of years to decades. Because of the high interannual variability, it is uncertain whether the decline occurred gradually over the whole time series or more rapidly since the 1970s. The zooplankton volume at line 80 was consistently higher than at line 90, characteristic of the general northward increase in plankton volume, but the interannual variability and the downward trend were similar at the two lines.

We investigated the spatial dependence of the zooplankton decline by averaging over the initial and final 7-year periods of the survey at each station location (Fig. 3). These intervals were selected because they include a large number of cruises (71 and 27, respectively) but avoid effects of strong El Niño–Southern Oscillation episodes in California waters during 1958–59 and 1983–84. The decline from the initial to the final interval was about 80%. The difference appears to be uniform in space and is at least twice the standard deviation of the 7-year mean at each station. Spatial patterns were similar during both time intervals, with zooplankton increasing northward and shoreward.

For comparison with the zooplankton decrease, we analyzed temperature, salinity, and geostrophic transport in the upper 100 m at line 90. A warming trend previously identified (*4*) is evident (Fig. 2C). No trend was seen in upper-layer salinity or transport, although there were substantial decadal fluctuations in salinity, including a decrease of about 0.2 practical salinity unit (psu) from 1981 to the present.

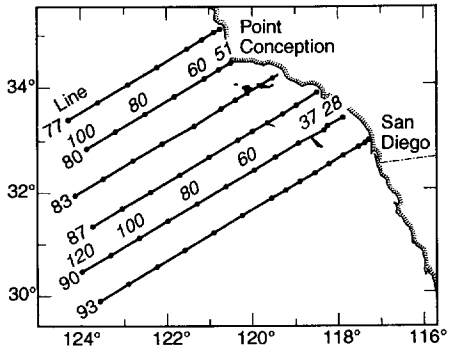

Fig. 1. CalCOFI survey plan, with station numbers (italics) indicated on lines 80 and 90.

We also averaged temperature, salinity, and geostrophic velocity over the same initial and final 7-year intervals as was done for the zooplankton data. Line 80 and line 90 surface temperatures (Fig. 4) warmed by an average of 1.2° and 1.6°C, respectively. Near Point Conception, the upwelling center for the region, surface temperature increased from 12.5° to 14.1°C between the two intervals. Temperature changes were reduced at depth, to 0.2°C at 180 m averaged along line 80 and at 270 m along line 90. As a result of the surface-intensified warming, the vertical stratification of the thermocline substantially increased and less cold waters came into contact with the atmosphere in the upwelling zones.

Salinity within the thermocline changed little between the initial and final periods. However, because of the warming, which in effect displaced isotherms downward, salinity on constant-temperature surfaces increased by up to 0.15 psu (at 10°C). Geostrophic velocity at line 90 showed an increase in the wind-driven recirculation—greater northward flow near shore and greater southward flow offshore—but no change in net transport.

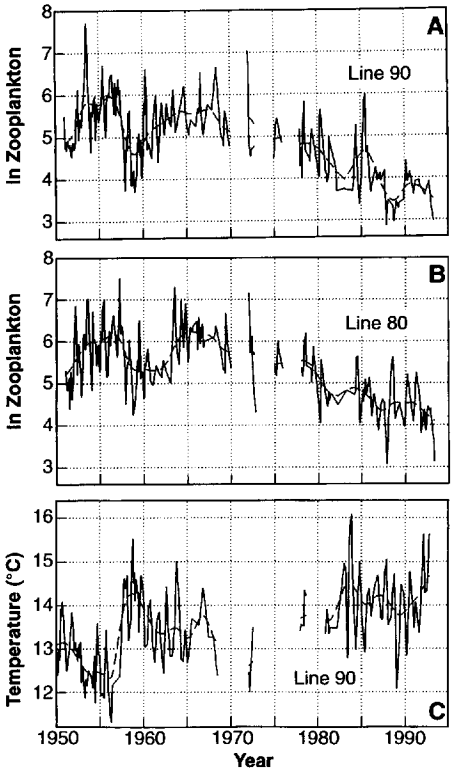

Fig. 2. Time series of log-transformed zooplankton volume (cubic centimeters of zooplankton volume per 1000 m^3 of seawater strained) for (**A**) line 90 and (**B**) line 80. On the logarithmic scale, a change of −1.6—which in (A) and (B) is the change from the mean of the 1950–1970 data to the minimum in the 1990s—is equivalent to an 80% decrease. (**C**) Time series of the upper 100 m average temperature for line 90.

Marine Life Research Group, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0230, USA.