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Long-term changes in zooplankton volumes in the California Current System—the Baja California region

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ABSTRACT: A retrospective analysis of zooplankton volumes (1951 to 1996) was performed for the area between Punta Baja (30° N) and Punta Abreojos (26.7° N) in relation to the warming anomaly that has taken place in the California Current System during the last 2 decades. The seasonal cycle of median standing stock of zooplankton in this area showed a moderate alternation between high values from June to October (median monthly volumes between 86 and 108 ml/1000 m^3) and low values from November to May (58 to 77 ml/1000 m^3). The quarterly long-term means of zooplankton volumes were the lowest in winter, as were wind speeds. The standard deviations associated with the long-term means indicated interannual variability was higher than seasonal variability. The time series showed an interval of high zooplankton volume between 1952 and 1957. Following the strong ENSO (El Niño Southern Oscillation) of 1957–1958, a period of low values occurred which extended into the early 1960s. There was a slow recovery of zooplankton biomass through the rest of the 1960s, but it did not reach the earlier high values. Available data suggest the increasing trend reached a peak in 1975. Subsequently, from 1976 to the ENSO of 1982–1983, the biomass decreased. For the remainder of the 1980s, the few existing data showed an erratic behavior of the biomass. In the 1990s, there has been a decrease to values even lower than those observed during the 1957–1958 ENSO. Nonseasonal anomalies for zooplankton and environmental variables were significantly different ($p < 0.001$) among decades but not between the northern (30° to 28° N) and southern (28° to 26° N) areas. The decrease in zooplankton volume in this region over the last 2 decades is less than that reported for the Southern California Bight. This may be partly caused by seasonal northward movements of tropical zooplankton species along the Baja California coast, Mexico.

KEY WORDS: Zooplankton · Biomass · Climatic changes · Baja California

INTRODUCTION

Zooplankton are an important component of the pelagic food web. They are the food source for some fish larvae and diverse schooling fish species, some mammals and birds. An inverse correlation between zooplankton volume and temperature has been documented for the California Current System (CCS) (Bernal 1979, 1981, Chelton 1981, Chelton et al. 1982, McGowan 1984, 1985), which indicates the strong influence of interannual events like El Niño. An extensive study of the variability of zooplankton biomass between 1951 and 1982 indicated a decrease in total

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zooplankton biomass and a degree of seasonality in the CCS with increasing latitude (Roesler & Chelton 1987). Nonseasonal variability examined by Roesler & Chelton (1987) using empirical orthogonal function analysis was coupled to variations in the southward transport of the California Current. Recently, there has been renewed interest in the relation between zooplankton and climate in the context of global climate change. A decline in zooplankton biomass has been documented off southern California over the last 20 yr coincident with an increase of about 1.5°C of the sea-surface temperature (Roemmich & McGowan 1995a, b, Smith 1995). This has been explained as a result of long-term changes in atmospheric pressure over the Pacific that started in winter 1976–1977 (Emery & Hamilton 1985, Nitta & Yamada 1989, Miller et al. 1994, Trenberth & Hurrel 1994), and which have produced warming in the California Current (Hollowed & Wooster 1992) and cooling in the central North Pacific Ocean (Venrick et al. 1987, Graham 1994, Latif & Barnett 1996, Gu & Philander 1997). These changes are associated with a strong Aleutian low, which would be expected to produce more vigorous cyclonic circulation in the North Pacific subarctic gyre, and a high zooplankton standing stock (Brodeur et al. 1996), but also a diminished advection in the CCS. However, the warming of the California Current could also be caused by the greenhouse effect associated with an intensification of upwelling (Bakun 1990) and sea-level rise (Roemmich 1992) along the west coast of North America. Questions arise as to whether long-term warming is the same at other latitudes influenced by the CCS, leading to coherence of the biological responses, and whether we are facing a discrete shift in climate or something more oscillatory.

The CCS spans more than 27° of latitude. Some environmental variables exhibit progressive latitudinal changes, making it hard to outline regional divisions. Differences in wind stress, intensity of coastal upwelling, coastal morphology, freshwater inflow, and mesoscale activity have led to the division of the CCS into 4 regions (Parrish et al. 1981, U.S. GLOBEC 1994). The southernmost region or region IV, off Baja California, Mexico (30° to 23° N), has been described as a zone with several major promontories in the coastal relief and negligible freshwater input, which influence physical processes such as advection, mesoscale activity, alongshore wind stress and upwelling, and moderate seasonality in biological productivity (U.S. GLOBEC 1994).

The boundaries between regions oscillate latitudinally as a function of climatic variability. Oceanographic processes have been investigated mainly in the USA sector of the California Current, in regions I and II, and part of region III. Region IV has received notably less attention than the more northern regions (Bernal 1979, 1981, Chelton et al. 1982, Roesler & Chelton 1987). Baja California has been proven to be unique in comparison to the northern CCS, in that it exhibits an extension of the convergent zone (negative wind stress curl) to the coast (Bakun & Nelson 1977), promoting a regular input of nutrients and biological productivity. Thus, it is important to understand the processes within this region. The progressive reduction of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) sampling grid since 1970 has interrupted the valuable time series of oceanographic variables collected since 1949 (Hewitt 1988), and unfortunately Mexican oceanographers have shown little interest in establishing a permanent monitoring program in this area. Because region IV has been proven to be a unique region within the CCS, being closely coupled to events occurring in the Eastern Tropical Pacific, in the present study we examined existing data to see if the zooplankton standing stock of region IV has shown the same long-term patterns as those reported for a region further north in the Southern California Bight.

METHODS

Zooplankton displacement volumes and 10 m depth temperatures used in this study were from the area between Punta Baja (30° N) and Punta Abreojos (26.7° N). The study area includes the large prominence of Punta Eugenia that produces a notable influence on the local circulation (Nelson 1977, Hewitt 1981), and is a biogeographic limit for some temperate species (Brinton 1962). Therefore, we divided the study area into 2 regions based on the coastal topography: a northern area from Punta Baja to Punta Eugenia (CalCOFI lines 110 to 120) and southern area from Punta Eugenia to Punta Abreojos (CalCOFI lines 123 to 130) (Fig. 1). The sources of the data were: (1) CalCOFI cruises (lines 110, 113, 117, 120, 123, 127, and 130) between 1951 and 1984, (2) Centro Interdisciplinario de Ciencias Marinas (CICIMAR) cruises between 1981 and 1991, and (3) Instituto de Ciencias del Mar y Limnología-Universidad Nacional Autónoma de México (ICMyL) cruises from 1994 to 1996 (Fig. 1). Because of differences in sampling depth and net type throughout the CalCOFI history, the conversion factors of Ohman & Smith (1995) were used to standardize data before 1978. For the CICIMAR and ICMyL cruises, the sampling methods were the same as those used at present by CalCOFI (maximum tow depth of 210 m and bongo net of 500 µm mesh). The operational procedures of the ICMyL sampling protocol are described in more detail in Robinson et al. (1995).

The time series (1951 to 1995) of sea-surface temperatures (SST) and northern and eastern wind velocities are from the Comprehensive Ocean-Atmosphere Data Set (COADS), given in squares of 2° × 2°, for the regions between 30° and 28° N and 116 and 120° W and between 28° and 26° N and 114° and 118° W. The best sampling coverage off Baja California was performed during the CalCOFI cruises from 1951 to 1969 (Fig. 1, Table 1). In the 1950s, CalCOFI cruises were made monthly. There were 92 cruises in that decade. In the 1960s, the frequency of cruises tended to be quarterly with occasional years sampled. After 1969, the frequency of cruises became more sporadic, with intervals up to 3 yr of sampling completely lacking. Finally, after 1984, no more CalCOFI cruises were made to collect samples in the Baja Californian sector.

Mexican oceanographic cruises along the west coast of Baja California have been scarce and with a lack of a clear continuous monitoring program, partially caused by lack of supporting funds and partially because of little inter-institutional cooperation. The few existing samples are dispersed among different institutions and most of the zooplankton volume data are unpublished with the exception of the study of Hernández-Trujillo et al. (1987). Among these cruises, the CICIMAR ones, between 1981 and 1991, are useful because of the use of sampling methods that were comparable with those used by CalCOFI. The ICMyL cruises also used CalCOFI type sampling, but the coverage was limited to the coastal region (up to 40 nautical miles off the coast) between Cedros Island and Punta Abreojos (28° to 26.7° N).

Zooplankton volumes expressed in ml/1000 m^3 were transformed to natural logarithms to normalize the data. Quarterly means were calculated for all data, considering winter as December to February, spring as March to May, summer as June to August, and fall as September to November. To remove the seasonal cycle, the long-term quarterly means were subtracted from the quarterly means of each year (see Table 2). The nonseasonal anomalies were aggregated by decade and area to perform a 2-way analysis of variance (ANOVA). Unplanned comparisons between pairs of means were based on the Tukey method of studentized range. Pearson product-moment correlation was used to compare nonseasonal anomalies among variables. For correlation analysis, we excluded the periods with temporal gaps for one or more variables.

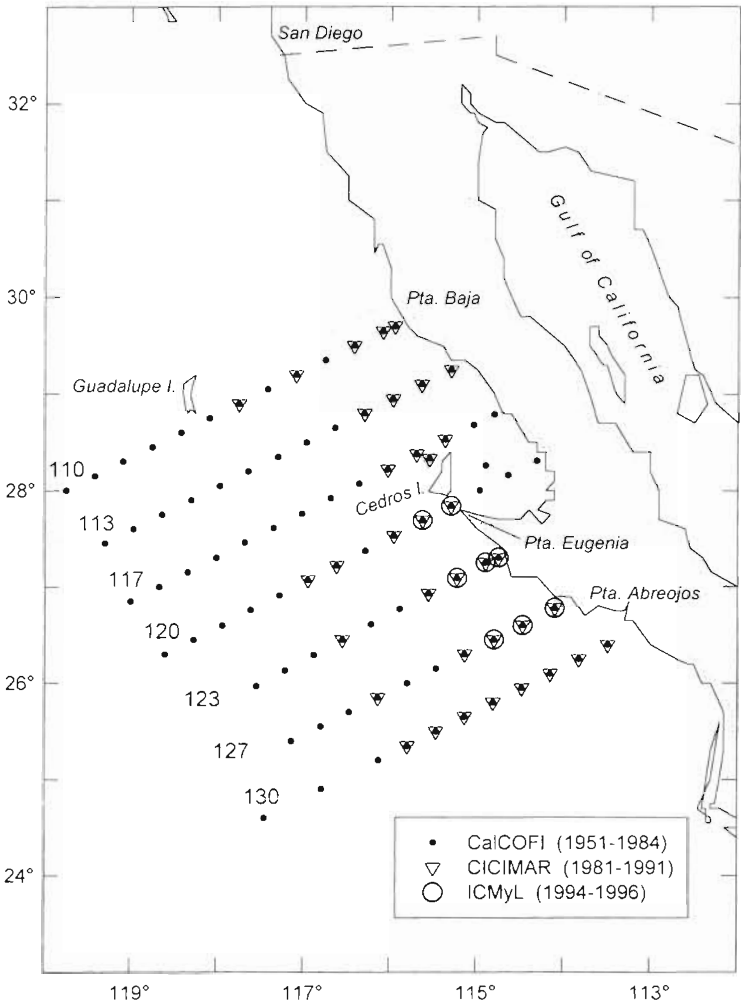

Fig. 1. Sampling stations of the CalCOFI, CICIMAR and ICMyL cruises. Numbers indicate CalCOFI sampling lines. Dotted lines shown the regions used in the data analysis of the present study

Table 1. Number of zooplankton samples from the middle part of Baja California (30° to 26.7° N)

Decade	North Years	 Cruises	 Samples	South Years	 Cruises	 Samples
1950s	9	92	3232	9	91	1445
1960s	10	72	2754	10	65	1502
1970s	5	22	728	4	16	333
1980s	7	21	290	9	17	185
1990s	4	7[a]	15	4	7[a]	35

[a] During 6 of these cruises, several tows per station were made (about 6). Therefore, the real number of samples used was higher, but we took an average per station

RESULTS

The seasonal cycle of zooplankton standing stock, including data for the period from 1951 to 1996 and constructed using monthly median values, showed moderate changes, with alternating periods of high values from June to October (median monthly volumes between 86 to 100 ml/1000 m^3) and low values from November to May (58 to 77 ml/1000 m^3) in the northern area of Baja California. The period of high biovolumes in the southern area of Baja California was limited to between August and October (89 to 108 ml/1000 m^3). The seasonal changes were not significant, however, as may be observed by the high standard deviation associated with the long-term means (Fig. 2). The quarterly long-term means of zooplankton volumes were similar (Table 2). Temperature and the speed of the east wind, however, showed more seasonality. In spring, winds increased to a maximum causing a decrease in temperature (Table 2). The peak of zooplankton was in summer. The highest temperatures were found during fall in both areas (Table 2).

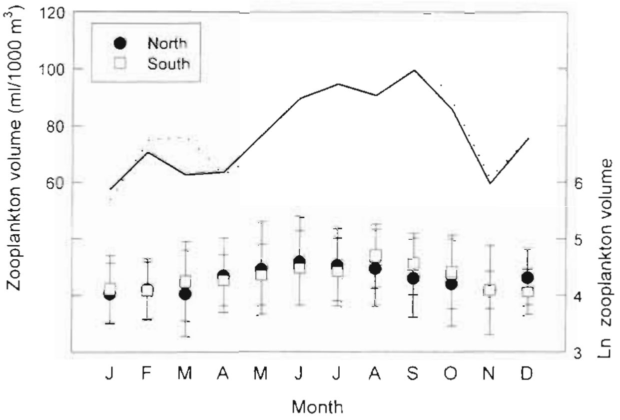

Fig. 2. Long-term monthly medians of zooplankton volume north (solid line) and south (dotted line) of Punta Eugenia, Baja California. Symbols and error bars are means and standard deviations of zooplankton volumes transformed to natural logarithms

The interannual variability of the zooplankton volumes (Fig. 3) showed an interval of high zooplankton volumes between 1952 and 1957. Following the strong ENSO of 1957–1958, a period of low values occurred, which extended into the early 1960s. Zooplankton biomass increased slowly throughout the rest of the 1960s, but did not reach the earlier high values. There are many gaps in the data, but overall it appears that the increasing trend peaked in ca 1975. From 1976 until the ENSO of 1982–1983, the strongest event recorded in the period under study (McGowan 1984), there was another period of decline. In the southern area, the decrease appeared to stop earlier (in 1981). For the rest of the 1980s the few available data showed erratic behavior, and in the 1990s, values of zooplankton biomass were even lower than those observed during the 1957–1958 ENSO. These alternate periods of increase and decrease in biomass are more evident when the seasonal cycle is removed (bars in Fig. 3). The statistical comparison between areas and decades using data of nonseasonal anomalies of zooplankton biomass (2-way analysis of variance) showed significant differences ($F = 6.25$, $p < 0.001$) among decades but not between areas (Table 3). Unplanned comparisons among pairs of means indicated the negative anomalies of the 1990s were lower than for the other decades. Because in the last 2 decades the available samples were mainly from the coastal zone in CalCOFI lines 120 to 130, we performed an additional 1-way ANOVA, excluding other lines and offshore stations. We found the anomalies in zooplankton volume were positive for the 1950s and 1960s, and significantly higher than those for the 1990s ($F = 5.249$, $p < 0.001$).

Temperatures at 10 m depth at the stations where the zooplankton samples were collected showed long-term quarterly means of 16.5 (winter), 16.0 (spring),

Table 2. Long-term seasonal means (± standard deviation) for zooplankton volumes and environmental variables in areas north and south of Punta Eugenia in the period 1950 to 1996. SST: Sea-surface temperature

Variable	Area	Winter	Spring	Summer	Fall
Ln zooplankton volume	N	4.11 ± 0.48	4.27 ± 0.74	4.58 ± 0.60	4.17 ± 0.76
	S	4.11 ± 0.57	4.26 ± 0.56	4.55 ± 0.56	4.43 ± 0.68
10 m depth temperature (°C)	N	16.5 ± 0.8	16.0 ± 0.8	18.0 ± 1.3	19.6 ± 1.3
	S	17.9 ± 1.2	16.5 ± 1.4	19.1 ± 2.2	21.7 ± 1.7
SST (°C)	N	16.8 ± 0.7	16.5 ± 0.7	18.9 ± 0.8	19.9 ± 0.7
	S	18.1 ± 0.9	17.0 ± 0.8	19.8 ± 0.9	21.4 ± 0.9
North wind (m s^{-1})	N	3.63 ± 0.72	4.90 ± 0.70	4.56 ± 0.63	4.30 ± 0.67
	S	4.25 ± 0.76	5.15 ± 0.59	4.52 ± 0.68	4.44 ± 0.64
East wind (m s^{-1})	N	1.86 ± 0.75	3.55 ± 0.50	2.93 ± 0.41	2.25 ± 0.48
	S	1.52 ± 0.57	3.29 ± 0.39	2.87 ± 0.43	2.13 ± 0.42

Table 3. Means of nonseasonal anomalies (calculated by removal of long-term quarterly means from quarterly means of each year) for zooplankton volumes and environmental variables per decade, combining data from both geographical areas. Results of the analyses of variance (*F*) and the significance (p) are shown for the factor decades (for the factor areas, the results were not significant and are not shown). Number of data points used is given in parentheses

Variable	1950s	1960s	1970s	1980s	1990s	*F*	p
Ln zooplankton volume	0.18 (72)	−0.04 (73)	0.01 (22)	−0.04 (28)	−0.68 (13)	6.25	<0.001
10 m depth temperature (°C)	0.02 (72)	−0.13 (73)	−0.37 (22)	1.03 (27)	−0.90 (11)	6.42	<0.001
SST (°C)	−0.18 (80)	−0.17 (80)	−0.33 (80)	0.32 (80)	0.58 (48)	17.81	<0.001
North wind (m s^{-1})	−0.22 (80)	−0.22 (80)	0.05 (80)	0.24 (80)	0.25 (48)	9.44	<0.001
East wind (m s^{-1})	0.08 (80)	−0.12 (80)	0.02 (80)	0.09 (80)	−0.14 (48)	3.36	0.010

18.0 (summer), and 19.6°C (fall) in the northern area. A similar seasonal variation in temperature at a depth of 10 m was found in the southern area (Table 2). The long-term variations in the 10 m depth temperature showed inverse trends to those in zooplankton volume from the 1950s through to the 1980s (Figs. 3 & 4). After 1976, there was a period of positive anomalies, which was more clearly seen in the southern region. During the most recent years (1994 to 1996), zooplankton volume and temperature were both exceptionally low. There were no differences in temperature anomalies between areas but only among decades, so that, in the statistical results shown in Table 3, the data from different areas are combined. The positive anomalies of the 1980s were the highest in the period under study. The 1990s had negative mean anomalies, even below those of 1950s. Considering only the coastal stations, the 1-way ANOVA also indicated differences in temperature anomalies between the 1980s and the other decades ($F = 5.180$, $p < 0.001$).

SSTs from the COADS were similar in both areas (Fig. 5). The lowest negative anomalies were observed between 1974 and 1975. After these cold years, positive SST anomalies were recorded with maximum values during the ENSO of 1982–1983. A similar situation was observed in the 1950s, when a period of negative anomalies preceded the ENSO 1957–1958. SST anomalies for both geographic areas were similar but there were differences among decades (Table 3). The statistical results for SST were similar to those for temperatures at 10 m, with highest anomalies occuring during the 1980s, but they were not consistent for the 1990s.

The northward component of local wind in the area between Ensenada and Punta Baja showed a sustained period of low velocities during the 1950s and 1960s, interrupted only once by a 1.5 yr period of strong winds during 1952–1953. South of Punta Eugenia, the north wind showed more interannual shifts, but from 1956 to 1959 and through most of the 1960s, the winds were lower than the mean of all time series (Fig. 6). In

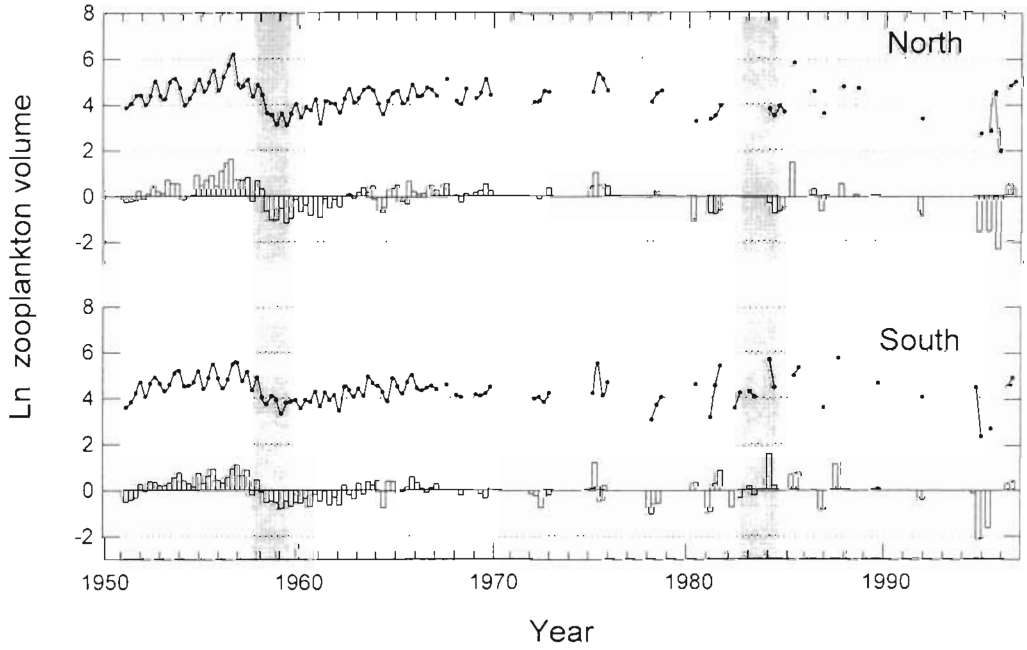

Fig. 3. Time series of quarterly means (line) for ln-transformed zooplankton volumes in the areas north and south of Punta Eugenia. The time series after removing the seasonal cycles (bars) is also shown. The strong ENSO (El Niño Southern Oscillation) events of 1957–1958 and 1982–1983 are indicated with shaded strips

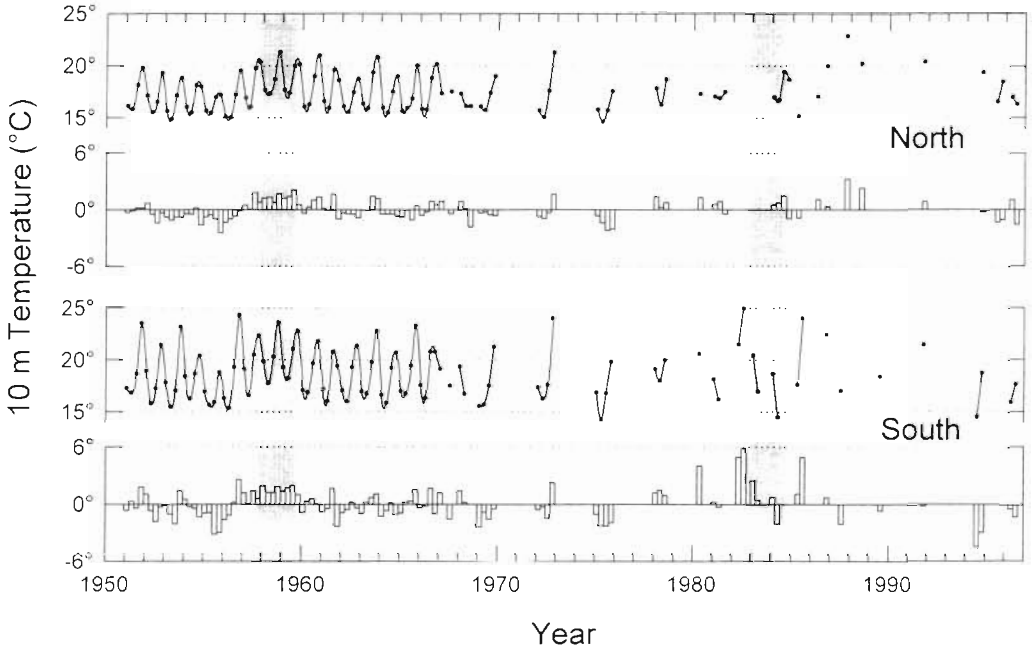

Fig. 4. Time series of quarterly means (line) for temperature at 10 m depth in the areas north and south of Punta Eugenia. The time series after removing the seasonal cycles (bars) is also shown. The strong ENSO events of 1957–1958 and 1982–1983 are indicated with shaded strips

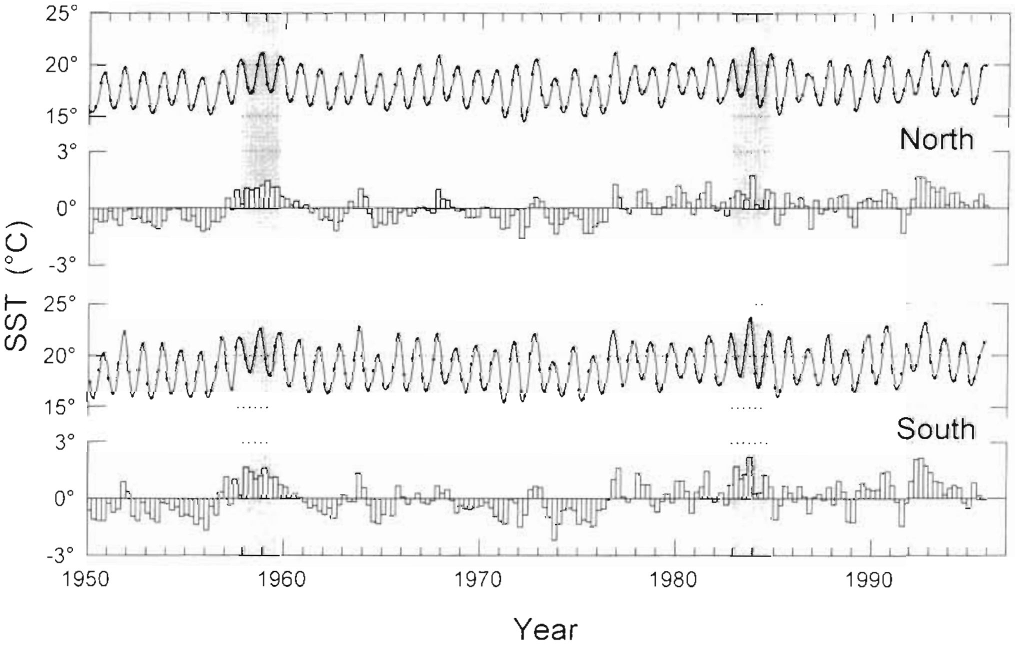

Fig. 5. Time series of quarterly means (line) for sea-surface temperature from the COADS in the north (30°-28° N, 116°-120° W) and south (28°-26° N, 114°-118° W) regions. The time series after removing the seasonal cycles (bars) is also shown. The strong ENSO events of 1957-1958 and 1982-1983 are indicated with shaded strips

the winter of 1980, the north wind showed one of its lowest historical speeds in both areas, but after that its intensity increased, particularly after 1985.

Decadal trends in the eastern component of the wind were different to those for the northern component (Fig. 7). The 2-way ANOVA was significant for the factor decades (Table 3) but the Tukey's test between pairs of means did not show differences in the eastward component. The north and east wind speeds showed similar patterns that differed between the 2 strong ENSOs, with negative anomalies in 1957-1958 and positive ones in 1982-1983. For the nonseasonal anomalies of wind strength, both areas were also statistically similar.

Nonseasonal anomalies of zooplankton showed significant negative correlation with 10 m depth temperature and SST (Table 4). The 10 m depth temperature anomalies were positively correlated with SST. The 2 components of wind were positively correlated with one another The east wind component appears to have more influence on the SST, as suggested by the negative correlation between these variables. At 10 m

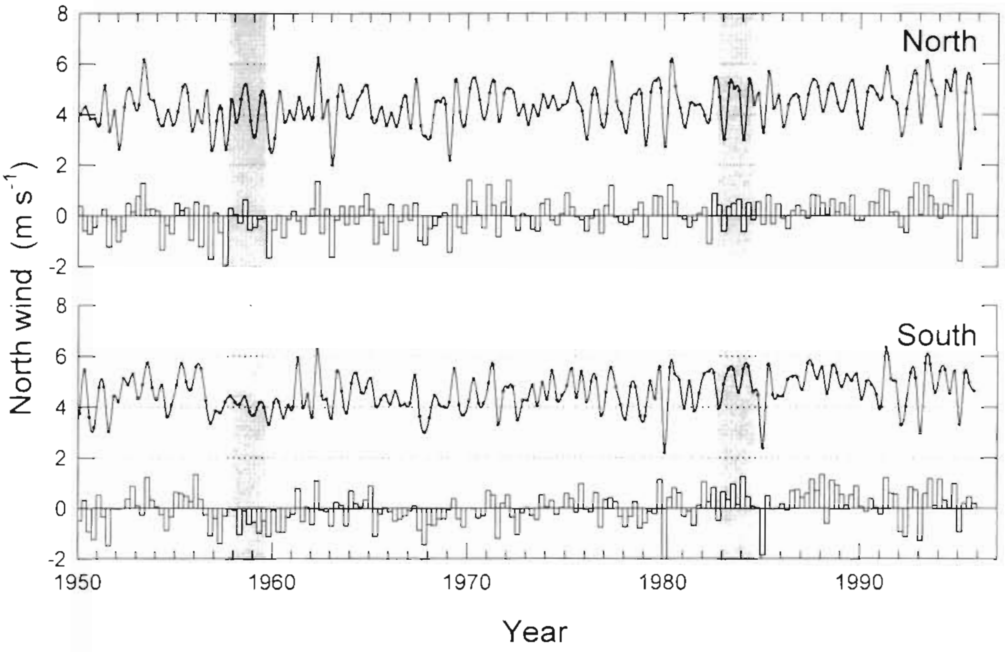

Fig. 6. Time series of quarterly means (line) for north winds from the COADS in the north (30°–28° N, 116°–120° W) and south (28°–26° N, 114°–118° W) regions. The time series after removing the seasonal cycles (bars) is also shown. The strong ENSO events of 1957–1958 and 1982–1983 are indicated with shaded strips

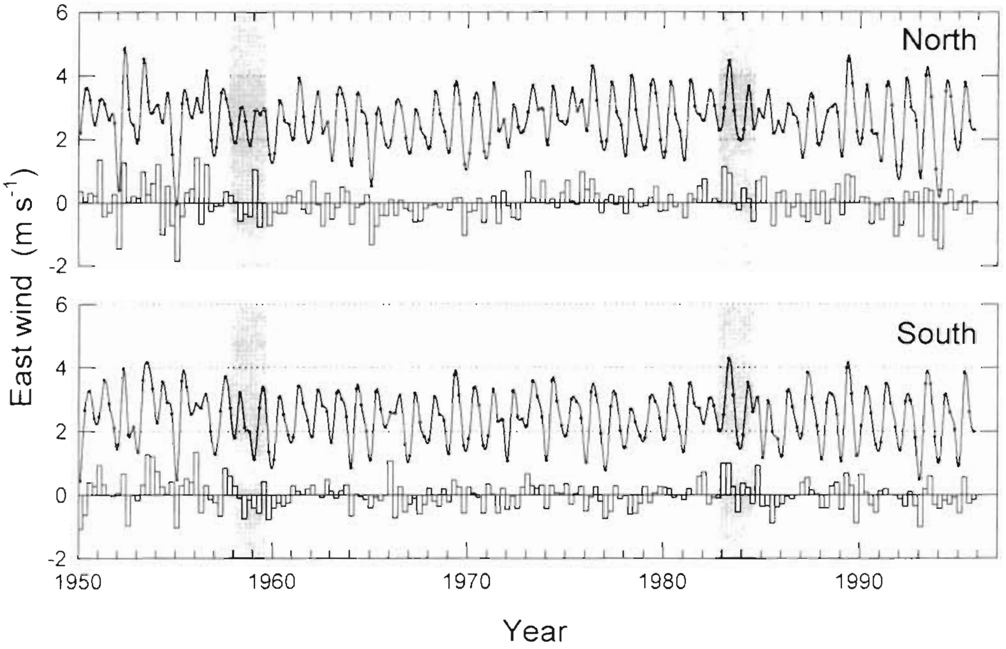

Fig. 7. Time series of quarterly means (line) for east winds from the COADS in the north (30°–28° N, 116°–120° W) and south (28°–26° N, 114°–118° W) regions. The time series after removing the seasonal cycles (bars) is also shown. The strong ENSO events of 1957–1958 and 1982–1983 are indicated with shaded strips

Table 4. Correlation matrix among zooplankton volume and environmental variables using nonseasonal anomalies (*significant correlation at 0.05 level). Number of data points used is given in parentheses

Variable	Zooplankton	10 m depth temperature	SST	North wind	East wind
Ln zooplankton volume	–	−0.19*	−0.33*	0.11	0.10
10 m depth temperature (°C)	(205)	–	0.56*	−0.15*	−0.10
SST (°C)	(204)	(201)	–	−0.10	−0.11*
North wind (m s^{-1})	(204)	(201)	(368)	–	0.23*
East wind (m s^{-1})	(204)	(201)	(368)	(368)	–

depth the influence of the north wind component was more important as is apparent from its negative correlation with temperature (Table 4).

DISCUSSION

The time series of data from the CalCOFI monitoring program has helped us to understand the eastern boundary current system of the CCS. Large-scale interannual fluctuations in zooplankton volumes have been observed in some cases to be coincident with El Niño events (Chelton et al. 1982, Roesler & Chelton 1987), but other large fluctuations had no obvious cause in the Eastern Tropical Pacific. Chelton et al. (1982) suggested that causal mechanisms might involve events on a larger scale (i.e. basin wide). A recent study incorporating CalCOFI data from over the last 2 decades have shown a progressive decline in zooplankton volumes correlated with a long-term warming in the California Current (Roemmich & McGowan 1995a, b). That study was restricted to the region off southern California where long-term CalCOFI time-series data are available. The question arose as to whether these trends occurred in the other regions of the CCS. This is of particular interest because the Southern California Bight is a partially isolated region within the California Current (Smith 1995). The changes in temperature were explained by basin-scale changes in the atmospheric circulation over the North Pacific which started during the winter of 1976-1977 (Graham 1994, Miller et al. 1994, Trembert & Hurrell 1994). Latif & Barnett (1996) suggested that the decadal variability is based on a cycle involving unstable ocean-atmospheric interactions over the North Pacific. Our analysis also indicated decadal differences in zooplankton biomass in the Baja California region, but the link with climate is not clear. Though significant differences in nonseasonal anomalies of zooplankton volume were found among decades (Table 3), a more careful examination of mean values (unplanned comparisons) showed differences only between the 1990s and the other decades. If only coastal stations, which were more intensively sampled in the last 2 decades, are considered, the differences observed were only between the 1990s and the first 2 decades of the series. The decline of zooplankton in the Southern California Bight for CalCOFI lines 80 and 90 (see Fig. 2 of Roemmich & McGowan 1995a) occurred throughout the 1980s and 1990s, but off Baja California zooplankton volumes during the 1980s were in the range of those seen in the 1950s and 1970s, which suggests a minor impact of global climate change on the zooplankton standing stock in this region of the CCS. An alternate hypothesis is that the tropical fauna make a major contribution to the biovolume in the area off Baja California, masking the negative impact of climate change (increasing temperature and winds) on the temperate fauna. Smith (1995) showed how subtropical sardine biomass increased over a period of 10 yr (1985 to 1994), whereas the temperate anchovy biomass decreased over the same period. A shift in zooplankton community structure during the last 20 yr is suggested by reported changes in euphausiid species (Brinton 1996). Therefore, biovolume may be a poor index in assessing climatic effects, and retrospective studies on the structure of the zooplankton species composition are required. Decadal changes in community structure have been documented for other areas, such as the central North Sea, where a dominance of calanoid copepods in the period from 1958 to the late 1970s shifted to echinoderm larvae in the 1980s and early 1990s (Lindley et al. 1995).

Our stations with low biovolumes during the 1990s also recorded the lowest 10 m depth temperatures of the time series (Fig 4). These were probably biased because sampling was closer to the coast during the 1990s (ICMyL cruises), where active upwelling was a dominant feature (Fig. 1). Considering only the coastal stations, temperature anomalies from the 1990s were on the same order as other decades, except for the 1980s. The remaining time-series of temperatures were consistent with those found offshore (SST) and consistent with the warming in other regions of the California Current (Cole & McLain 1989, Graham 1994, Trenberth & Hurrell 1994). During the last warm spell, warming might have been a result of shoaling of upwelled water (Roemmich & McGowan 1995a), low vertical mixing, and low California Current transport (Roemmich 1992). Miller (1996) reported decadal and interannual variations in the thermocline off the California coast. He suggested a thermocline deepening associated with a decadal-scale change in the gyre-scale North Pacific thermocline after winter 1976-1977. The increase of north winds along the Baja California region (Fig. 6, Table 3) may be also attributed to the Pacific Basin warming event. The trend toward an intensification of wind stress alongshore had been noted previously by Bakun (1990) off California and in other upwelling systems around the world and was interpreted as a result of the greenhouse gas effect caused by an accumulation of CO_2 in the earth's atmosphere. In particular, for the period from 1980 to 1989, carbon dioxide emission from fossil-fuel burning and tropical deforestation amounted to 7.7 ± 1.1 Gt C yr^{-1}, increasing the atmospheric CO_2 concentration to about 200% of the CO_2 emissions for 1980 to 1989 (Siegenthaler & Sarmiento 1993). In the California Current, Bakun (1990) found a significant increase in the wind stress north of 32° N, but not in the Baja California region, perhaps caused by the climatic influence of the Gulf of California. However, Baumgartner & Christensen (1985) did not find any discernible relationship between events in the Gulf of California and independent modes of variability in the North Pacific gyre. In the present study, only the north wind speed indicated a progressive increase from 1950 to 1990 off Baja California (Table 3). The east wind component did not show this progressive trend (Fig. 7). Based on the north wind component, we would expect increased upwelling activity, similar to the other upwelling systems. In this case, there appears to be a contradiction between a decline in zooplankton volume and increased upwelling activity in the actual climatic regime, or at least the inference that the upwelled water was less rich in nutrients because of a deepening of the pycnocline.

Other differences in patterns of zooplankton volume between the Baja California region and the Southern California Bight occurred during the ENSO of 1982–1983. The few data for the area north of Punta Eugenia showed negative anomalies as expected, while the southern area had some values close to the mean but one showing a very high positive anomaly in the first quarter of 1984 (Fig. 3). In the Southern California Bight, the strong ENSOs of 1957–1958 and 1982–1983 gave low biovolumes (Roemmich & McGowan 1995a), although the shift from high to low values that preceded the ENSO event of 1957–1958 was more remarkable than that of the ENSO of 1982-1983. The increase in temperature at 100 m was also acute at the onset of the 1957–1958 ENSO in the Southern California Bight, but this is difficult to ascertain for the situation prior to 1982–1983 because of the gaps in the time series (see Fig. 2 in Roemmich & McGowan 1995a). Differences in the evolution of the ENSO have been extensively discussed (Quinn et al. 1984, Emery & Hamilton 1985, Wang 1995). In an attempt to explain the major anomalous warming of the eastern-central Equatorial Pacific Ocean under the scheme of the ENSO, Wang (1995) included the 6 most significant episodes (1957–1958, 1965, 1972, 1982–1983, 1986–1987, and 1991–1992). The characteristics of the transition from cold to warm (ENSO) were different in pre-1977 and post-1977 events, notably the evolution of SST anomalies throughout the Pacific (Wang 1995). We did not find differences in SST between the major ENSOs (1957–1958 and 1982–1983) but differences were observed in zooplankton volume and in wind components. The wind patterns observed during 1957–1958 (negative anomalies) contrasted with those of the 1982–1983 (positive anomalies) period. Whereas some of the environmental variables appear to be in agreement with the new theoretical developments of the ENSO cycle, the zooplankton volumes did not show the same decreasing response off Baja California as those observed in other California Current regions during the 1980s. It may be argued that the data available for the last 2 decades in the Baja California region are scarce. Intensive oceanographic surveys in the Baja California sector are therefore required to examine recent trends in the zooplankton standing stock in the southern part of the California Current System. Coordinated cooperation among several Mexican oceanographic research institutions from northwest Mexico is needed to develop an inter-institutional program to study the pelagic ecosystem with at least a seasonal frequency, and with the view of making it a southward extension of the U.S. CalCOFI program.

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