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Biological effects of El Niño 1997-98 on a shallow subtropical ecosystem: Bahía Magdalena, Mexico

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RESUMEN

La temperatura superficial del mar (TSM), biomasa zooplanctónica, concentración de clorofila *a* y los cambios en la abundancia de cuatro especies de copépodos: *Acartia clausi, Acartia lilljeborgii, Paracalanus parvus* y *Calanus pacificus*, y huevos y larvas de: *Sardinops caeruleus*, *Scomber japonicus, Opisthonema* spp. y *Anchoa* spp., fueron medidos y estimados en Bahía Magdalena, México de mayo de 1997 a diciembre de 1998 para estudiar la respuesta de estas especies a los cambios estacionales y a las condiciones anómalas inducidas por El Niño 1997-98. Se registraron anomalías positivas de temperatura superficial del mar durante 15 meses alcanzándose valores de hasta +4.4 °C durante el verano de 1997. La biomasa zooplanctónica fue dos veces menor que durante el Niño 1982-83, pero el patrón estacional se mantuvo. La máxima concentración de clorofila se presentó a fines de primavera y principios de verano (9.2 mg/m^3), con un mínimo (0.2 mg/m^3) en invierno. Se registraron cambios importantes en la abundancia, así como un incremento de especies tropicales de copépodos, en la fase más intensa del calentamiento. La especie templada *Calanus pacificus* asociada con la influencia de la Corriente de California se registró con bajas abundancias en los meses con las temperaturas más bajas. La variabilidad en la abundancia estacional de las especies autóctonas mantuvo la distribución previamente registrada en esta bahía, pero su abundancia disminuyó cerca de un tercio en comparación con la de El Niño 1982-83. La abundancia de peces pelágicos menores templados y tropicales mostró importantes cambios relacionados con este efecto de calentamiento, las larvas de *Sardinops caeruleus* disminuyeron en un 50% con respecto al niño 1982-1983, en tanto que *Opisthonema* spp. incrementó, su abundancia en un factor de 10 durante 1997-98.

Palabras clave: El Niño 1997-98, clorofila *a*, Bahía Magdalena, copépodos, pelágicos menores.

ABSTRACT

Sea surface temperature (SST), zooplankton biomass and chlorophyll *a* concentration, along with abundance of four copepod species: *Acartia clausi, Acartia lilljeborgii, Paracalanus parvus* and *Calanus pacificus*, and eggs and larvae of small pelagic fishes: *Sardinops caeruleus, Scomber japonicus, Opisthonema* spp. and *Anchoa* spp., were measured and estimated from May 1997 to December 1998 in Bahía Magdalena, Mexico. In order to study response of these species to seasonal environmental conditions and to the anomalous warming conditions driven by the 1997-98 El Niño event. Positive SST anomalies were present during 15 months with a maximum value of +4.4 °C recorded during summer of 1997. Zooplankton biomass was lower by half than the previous El Niño 1982-83, but the seasonal pattern was maintained. A chlorophyll concentration maximum of 9.2 mg/m^3 was observed in late spring to early summer, with a minimum of 0.2 mg/m^3 in winter. Copepod abundance changes and an increase of tropical species were registered during the most intense phase of the warming. The temperate copepod *Calanus pacificus* associated with the California Current, was recorded only during the cold period before the onset of El Niño. The seasonal abundance of autochtonous species followed the pattern previously recorded in the bay, but decreased by about one third, compared to El Niño 1982-83. The abundance of temperate and tropical small pelagic fishes showed important changes related to the intense warming effect, with half the abundance of previous reports for temperate *Sardinops caeruleus* while, tropical *Opisthonema* spp abundance increased by up to an order of magnitud in 1997-98.

KEY WORDS: El Niño 97-98, Chlorophyll *a*, Bahía Magdalena, copepods, small pelagic fishes.

INTRODUCTION

Plankton research in subtropical coastal lagoons is scarce and of short duration, but existing studies suggest a close coupling between seasonal changes of biomass and species composition to the circulation patterns and other hydrodynamic features (Palomares-García and Gómez Gutiérrez, 1996; Lavaniegos-Espejo and López-Cortés, 1997; Lavaniegos-Espejo and González Navarro, 1999). Along the West Coast of Baja California Sur, Mexico, seasonal changes induce a strong alternation between eutrophic and oligotrophic conditions (Longursht *et al*., 1967). Eutrophic conditions are associated with upwelling and with a strong presence of the California Current in the area, while oligotrophic conditions result from non-upwelling conditions and the presence of the Corriente Mexicana (Lavin *et al*., 1997). This alternation has an important influence on the seasonal variability of the species composition, and distribution of plankton in Bahía Magdalena, as this bay has a strong tidal water exchange with the adjacent Pacific ocean (Guerrero-Godínez *et al*., 1988; Álvarez-Borrego *et al*., 1975; Obeso-Nieblas *et al*., 1999).

On an interannual scale, the major source of variability in this area is ENSO events, which are teleconnected with extratropical latitudes (Philander and Rasmusson, 1985; Norton *et al*., 1985; Baumgartner and Christensen, 1985). These effects include changes in the circulation patterns, weaker winds than normal and, hence, a reduction of water enrichment and lower biological production and changes in the distribution of several fish species like sardines and thread herring (Lluch-Belda *et al*., 1986; Torres-Moye and Álvarez-Borrego, 1987; Martínez-López, 1993; Zuria-Jordan *et al*., 1995). The ENSO events exhibit some general climatic characteristics (Rasmunsson and Carpenter, 1982), but the individual events may differ markedly from the mean pattern (Philander, 1983; Norton *et al*., 1985). Two ENSO events of the 20th century have been remarkable because of their magnitude and departure from the mean pattern. The first occurred in 1982-83 and the second in 1997-98. The 1982-83 El Niño was outstanding for its magnitude and because it began at a different time of the year that the onset of previous El Niño events (Harrison and Cane, 1984; Glantz, 1996). The 1997-98 El Niño showed the largest temperature anomalies on record in the Eastern Equatorial Pacific, and the quickest onset, much sharper than the gradual temperature increase during 1982-83 (McPhaden, 1999; Lynn *et al*., 1998; Hayward *et al*., 1999). If there are different forms of El Niño events, a range of biological responses can be expected as function of the climatic variability associated with El Niño off the coasts of Baja California. Previous 1982-83 ENSO caused strong changes in the plankton of Bahía Magdalena (Nienhuis, 1986; Gárate-Lizárraga and Siqueiros-Beltrones, 1998; Palomares García and Gómez-Gutiérrez, 1996). As sea surface temperature rose, the plankton biomass showed a drastic decrease as well as changes in species composition (Gárate-Lizárraga and Siqueiros-Beltrones, 1998; Palomares-García and Gómez-Gutiérrez, 1996). The influence of warming on zooplankton species, particularly copepods, was especially evident in the replacement of the resident species *Acartia clausi* Giesbrecht, 1892, by *Acartia tonsa* Dana, 1849, and an increased abundance of tropical-equatorial copepod species that are normally found offshore (Palomares-García and Gómez-Gutiérrez, 1996). This phenomenon also caused a failure in reproduction of the sardine *Sardinops caeruleus* Jenyns, 1842, as evidenced by low egg production and larval recruitment (Saldierna-Martínez *et al*., 1987). The observations of the biological effects of the 1982-83 El Niño in Bahía Magdalena are a useful point of reference to compared the evolution of El Niño 1997-98. In this study we analyzed the distinctions between the changes in some key species associated with the strongest El Niño events of this century.

METHOD

Monthly oceanographic surveys were done from May 1997 to December 1998, at a 14 station sampling grid in Bahía Magdalena, Baja California Sur, Mexico. This bay is located in the West Coast of Baja California, between 24° 30' and 25° 48' N, 111° 48' and 112° 00' W (Figure 1). With a mean depth of about 20 m, the bay presents several navigation channels, and maintains a continuous communication with the Pacific ocean through an opening 4 km wide and a mean depth of 38 m. This area generally maintains antiestuarine features and is seasonally influenced by the presence of tropical and temperate water masses that flow along the Baja California peninsula.

Sea surface temperature (SST °C) was measured at each station with a bucket thermometer. The monthly SST anomaly series of Bahía Magdalena (January 1982 to September 1998) reported by Gómez-Gutiérrez *et al*. (1999) was extended to December 1998. Corresponding series of monthly mean zooplanktonic biomass (ZB) data from January 1982 to December 1998 were computed, and anomalies were extracted from both series with a 12-point running mean following Makridakis and Weelwright (1978) (Figure 2).

Water samples for chlorophyll analysis were taken using Niskin bottles at eight stations (Figure 1) at standard depths (0, 5, 10, and 15 m). Chlorophyll *a* samples were filtered through Whatman GF/F glass fiber filters (0.7 μm nominal pore size), frozen in liquid nitrogen and later analyzed spectrophotometrically after extraction in 90% acetone. Active chlorophyll *a* was calculated using the Jeffrey and Humphrey (1975) equations.

Zooplankton samples were obtained at each station, with standard conical 333 and 54 μm mesh nets with bridles at the front, fitted with calibrated flowmeters, and trawled at the surface for five minutes. The samples were preserved with 4% formaldehyde, buffered with sodium borate. Zooplanktonic biomass (ml/m^3) was determined by the volumetric method (Beers, 1976).

Copepod analysis

The copepod community structure analysis was made during May, August and November of 1997 and January of 1998 because the major environmental changes occurred during these months. The original samples from all the stations were subsampled with a Folsom splitter to as little as 1/16, depending on the original volume of the sample. Samples with less than 10 ml of zooplanktonic biomass were analyzed in their entirety. Only adult stages of copepods were identified and counted and their numbers were normalized to 100 m^3 of filtered seawater. The diversity per sampling station was calculated using the index of Shannon and Weaver (Pielou, 1967).

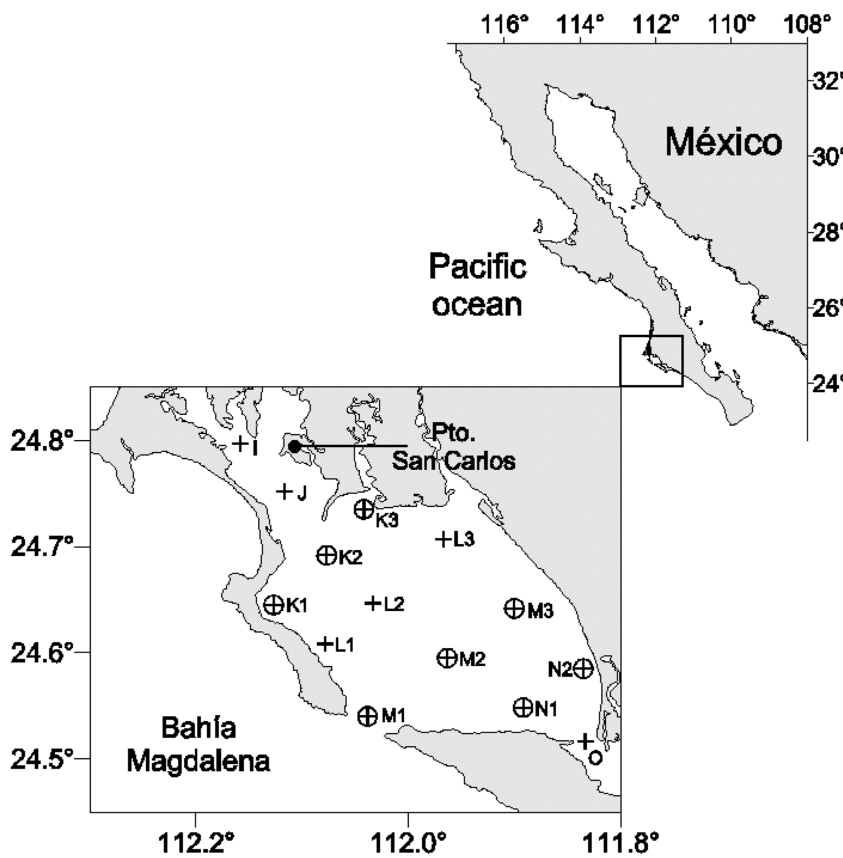

Fig. 1. Sampling grid in Bahía Magdalena, Baja California Sur, Mexico, including Chlorophill *a* and copepod size-abundance analysis stations (O); and copepod community and ichtyoplankton analysis stations (+).

Size-abundance analysis of four key copepod species: *Acartia clausi* Giesbrecht, 1889, *Acartia lilljeborgii* Giesbrecht, 1889, *Paracalanus parvus* (Claus, 1863), and *Calanus pacificus* Brodsky, 1948, were made from samples of both 333 and 54 μm mesh nets taken at eight sampling stations, from May 1997 to December 1998 (20 months) (Figure 1). Subsamples of 10 to 20 ml, depending of the volume of the original samples, were taken using a Stemple pipette. All copepodite stages and adults were identified, counted, and individual cephalothorax and total length were determined with an ocular micrometer, excluding eggs and nauplii. Size abundance was normalized to 100 m^3 of filtered seawater.

Ichtyoplankton analysis

The samples from the 333 μm net collected at the 14 stations were analyzed by completely sorting all fish larvae, which were identified using meristic, morphometric and pigmentation characteristics according to Watson and Sandknop (1996 a,b) and Ambrose (1996). Only eggs and larvae of four small pelagic fishes (*Sardinops caeruleus* (Girard, 1856), *Scomber japonicus* Houttuyn, 1782, *Opisthonema* spp. (Gill, 1861) and *Anchoa* spp. (Jordan and Evermann, 1927), are reported here, counted and normalized to 10 m^2 of filtered seawater, and expressed as an egg and larval index (Smith and Richardson, 1979).

RESULTS

Sea surface temperature, phyto and zooplankton biomass

The temperature anomalies calculated in Bahía Magdalena between January 1982 and September 1998 (Gómez-Gutiérrez *et al.*, 1999) showed two warming periods associated with the 1982-83 El Niño and the 1997-98 El Niño. During the first event, positive anomalies were recorded by November 1982 and reached the highest SST in July 1983 (+2.6 °C). Relatively small positive anomalies, considered a relaxation of El Niño, were found from October 1983 to May 1984, followed by a second peak of SST anomaly of

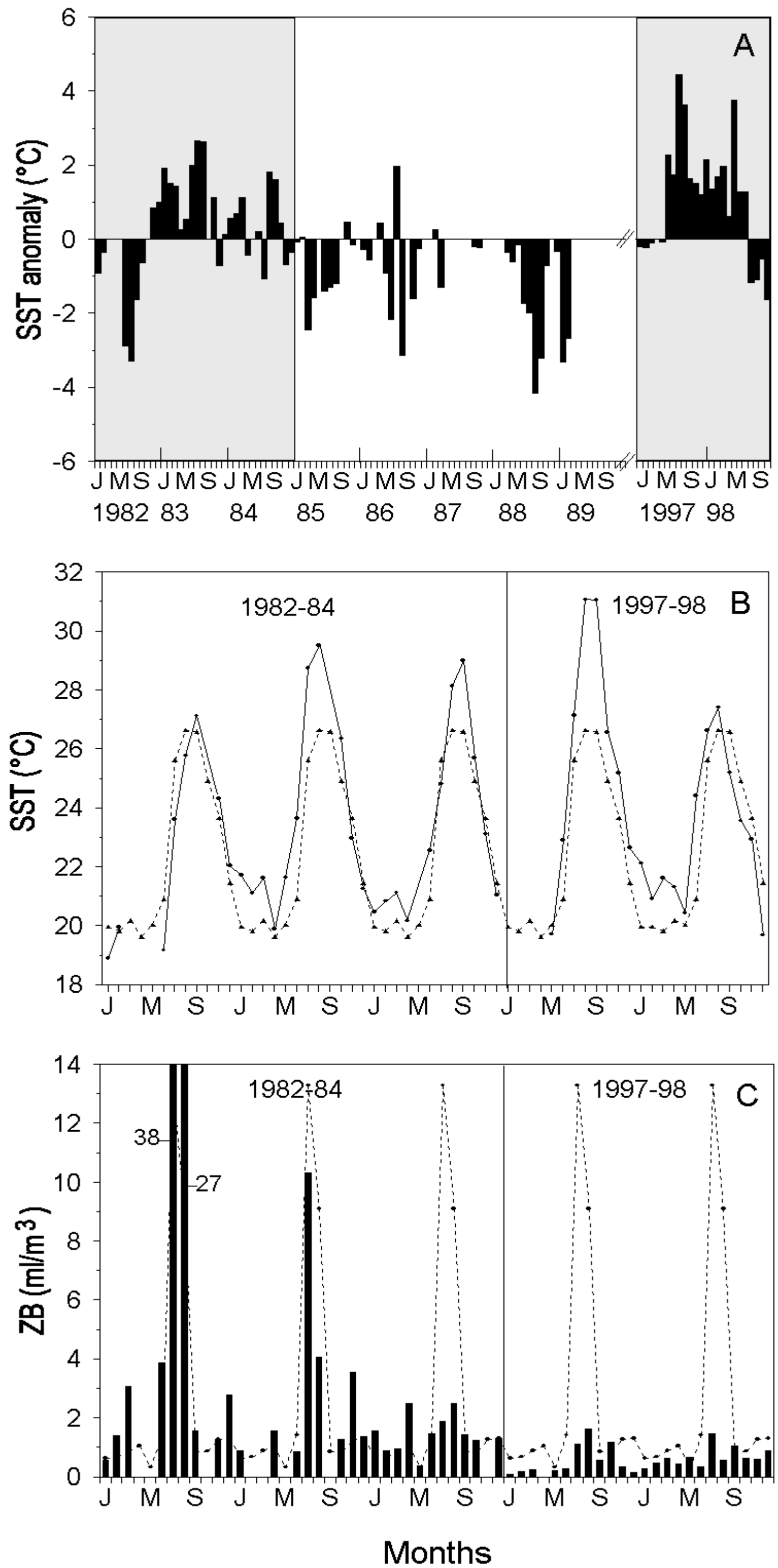

Fig. 2. A) Time series of SST anomalies (°C) in Bahía Magdalena. Shaded areas correspond to El Niño events. B) Monthly mean data of sea surface temperature (SST °C) (solid line), and seasonal mean SST (dotted line) during 1982-84 and 1997-98 ENSO events. C) Monthly data of zooplanktonic biomass (ZB ml/m[3]) (bars), and seasonal mean ZB (dotted line) during the same events.

+1.8 °C. (Figure 2A). The influence of this El Niño lasted for 24 months, from November 1982 to October 1984. During 1997-98, positive temperature anomalies reached higher values than during 1983-84, but were present only during 15 months, with the highest SST positive anomaly (+4.4 °C) in August 1997. Temperatures lower than the seasonal mean were recorded from September to December 1998 and can be related with La Niña event.

The time series of SST in Bahía Magdalena showed a large monthly mean SST range during 1997 (Figure 2B). The seasonal trend of mean SST showed the lowest values between January and June (19 to 21 °C). A drastic increase of SST occurred from June to September (21 to 26.5 °C), followed by a progressive decrease from October to December (25 to 21 °C). During anomalous 1997-98 conditions, SST followed the same seasonal trend but exhibited an increase of about 12 °C (19.5 to 31 °C) from May to August, 1997 (Figure 2B).

Time series of mean ZB in Bahía Magdalena showed a drastic decrease after 1982. In July 1982 a summer maximum of 38 ml/m^3 was recorded (Figure 2C). During 1983-84, the highest ZB value was four times lower than during the previous year and the peak of 1984 was absent. While the seasonal pattern of ZB was maintained during 1997-98, in spite of the differences in SST between one year to the next, the ZB values were lower than those of 1983-84.

During 1997-98 chlorophyll *a* concentrations were similar at all depth levels. Five-meters chlorophyll data showed low values from November 1997 to March 1998 (0.5 to 1.5 mg/m^3), followed by a strong increase during April to May (2.5 to 9.0 mg/m^3). Elevated values (> 4 mg/m^3) were found from May to July, followed by a progressive decline through the rest of the year. Although we only had four estimations during 1997, the chlorophyll concentration in October of this year was about twice as large as that of October 1998 (Figure 4A).

Copepod abundance

From 1997 to 1998 a total of 58 species of 31 genera of copepods were identified from the collections taken in the different surveys. The mean monthly abundance of the copepod species accounting for 90% of the total abundance during May, August and November 1997, and January 1998, are shown in Figure 3. The copepod community structure was usually typical of coastal lagoons with low diversity and few dominant species. A simple community structure was present during the first two months (May and August), dominated by *Calanus pacificus*, but became more complex the rest of the time. Copepod abundance maximized during August 1997, with *Acartia lilljeborgii* as the dominant species, followed by *Acartia clausi*. During Novem-

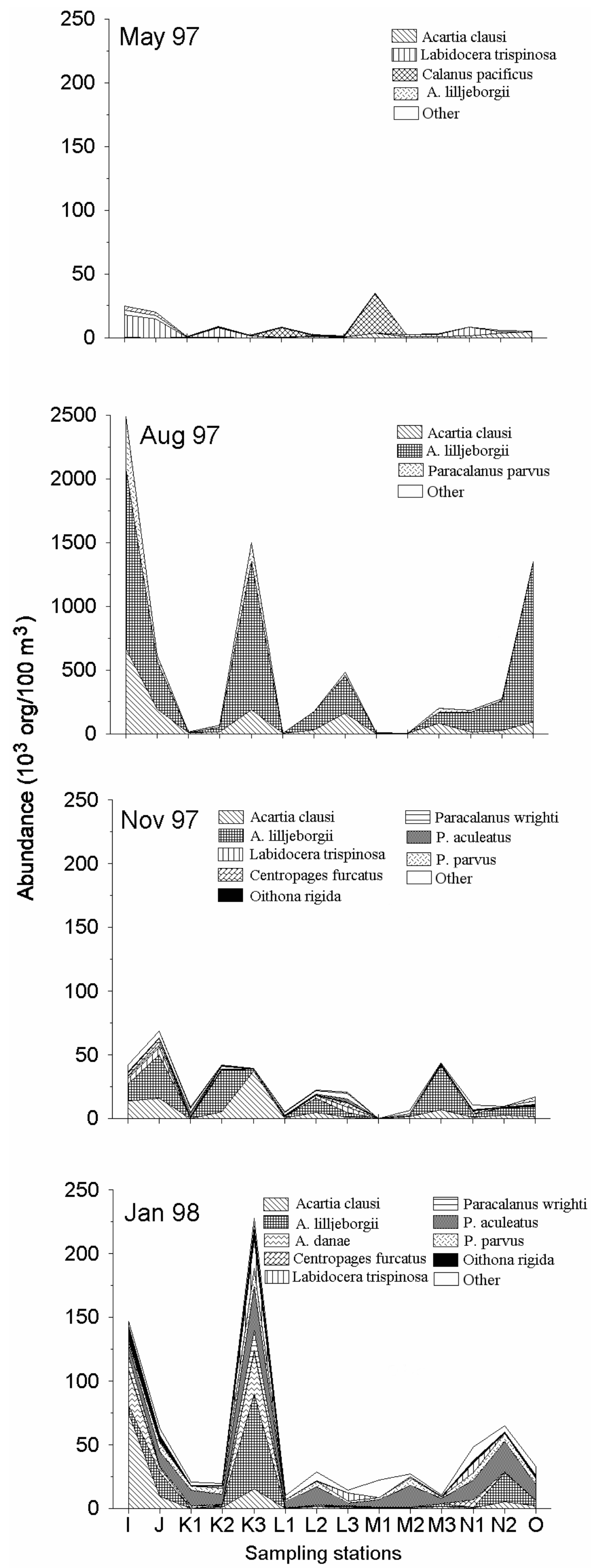

Fig. 3. Copepod community structure (abundance org/100 m^3) during the1997-98 El Niño in Bahía Magdalena. Graphs shows species accounting for 90% of total abundance.

Table 1

Copepod community diversity index (H' Bits/org) by sampling station, for May, August, and November 1997, and January 1998, in Bahía Magdalena

	May	Aug	Nov	Jan
I	0.82	1.57	2.71	2.35
J	0.70	1.42	2.28	3.05
K1	2.00	2.28	3.07	2.16
K2	0.84	2.27	1.24	2.74
K3	1.19	1.08	0.42	2.93
L1	0.24	0.47	3.83	2.92
L2	1.81	0.81	2.44	2.67
L3	2.00	1.23	3.41	2.87
M1	0.56	3.84	3.24	3.18
M2	1.43	3.92	3.07	1.77
M3	1.45	1.74	1.07	2.56
N1	0.79	1.12	3.10	3.08
N2	1.76	0.78	1.76	2.26
O	0.65	0.42	2.65	3.15

ber, copepod abundance decreased with eight species accounting for 90% of the total, with two of them being the dominant ones. During this time, we observed an increase in copepod diversity (Table 1) immediately after the onset of the warming period, especially near the mouth of the bay. In January 1998, the community became more complex, with dominance shared by few species, including *Paracalanus aculeatus* Giesbrecht, 1888, and two *Acartia* species (*Acartia clausi* and *Acartia lilljeborgii*).

An increase in the copepod diversity migth be related to seasonal changes in the California Current System, with strong southward flow, increasing the abundance of temperate species in the bay. As the California Current weakens, diversity increases owing to the presence of tropical and equatorial species brought about by the Corriente Mexicana.

This pattern could be reinforced during warming events by an anomalous advection of tropical copepod populations, which are observed in this bay only under El Niño conditions. Table 2 shows species of tropical and equatorial affinities that appeared only during the warming events of 1983-84 and 1997-98. We recorded as many as 22 and 21 species of these affinities during each event.

In order to understand the main changes in this community, we considered the monthly variations of four key copepods species in the bay, which represented from 54% to 90% of total zooplankton abundance, and represent the major component of zooplankton biomass within Bahía Magdalena (Palomares-García, 1992; Palomares-García and Gómez-Gutiérrez, 1996). During this 20 month study (May 1997 to December 1998), we do not detected significant changes in the successional annual pattern of the main autoctonous copepod species like *Acartia clausi, Acartia lilljeborgii*, and *Paracalanus parvus*. *Acartia* species exhibited their maximum abundance during the summer (Figure 4), in synchrony with the maximum zooplankton biomass in the area. Nonetheless, the peak of abundance for both *Acartia* species was higher in 1997 than 1998. In adult phase, *Paracalanus parvus* was dominant only during the winter season of 1998, but copepodite stages of this species were abundant during summer months of 1998, and related to chlorophyll *a* concentration between 2 to 4 mg/m^3 during that

Table 2

Tropical and subtropical copepod species recorded during El Niño events in Bahía Magdalena

Species	1983-84	1997-98
Acartia tonsa Dana, 1849	X	X
Acrocalanus gracilis Giesbrecht, 1888		X
Aetideus armatus Boeck, 1872	X	
Calanus pauper Giesbrecht	X	
Calocalanus pavo Dana, 1849		X
Candacia aethiopica Dana, 1849		X
Candacia catula Giesbrecht, 1889	X	X
Candacia longimana Claus, 1863	X	X
Canthocalanus pauper Giesbrecht, 1888		X
Centropages abdominalis Sato, 1913		X
Centropages gracilis Dana, 1849	X	
Centropages longicornis Mori, 1932	X	X
Clytemnestra scutellata Dana, 1852	X	
Copilia quadrata Dana, 1852	X	
Corycaeus longistylis Dana, 1848	X	
Corycaeus robustus Giesbrecht, 1891		X
Euchaeta indica Wolfenden, 1905	X	X
Euchaeta longicornis Giesbrecht, 1888		X
Metridia pacifica Brodsky, 1950	X	
Microcetella rosea Dana, 1848	X	
Oithona attenuata Farran, 1913	X	
Oithona decipiens Farran, 1913	X	
Oithona setigera Dana, 1852	X	
Oithona tenuis Rosendorn, 1917	X	X
Pareucalanus sewelli Fleminger, 1973	X	X
Pleuromamma quadrungulata Lubbock, 1856	X	
Pontella fera Dana, 1849		X
Pontellina plumata Dana, 1852	X	X
Pontellopsis armata Giesbrecht, 1889		X
Scolecithricella dentata Giesbrecht, 1892		X
Scolecithricella ctenopus Giesbrecht, 1888		X
Subeucalanus subcrassus Giesbrecht, 1888		X
Sapphirina angusta Dana, 1849	X	
Undinula vulgaris Dana, 1852	X	X

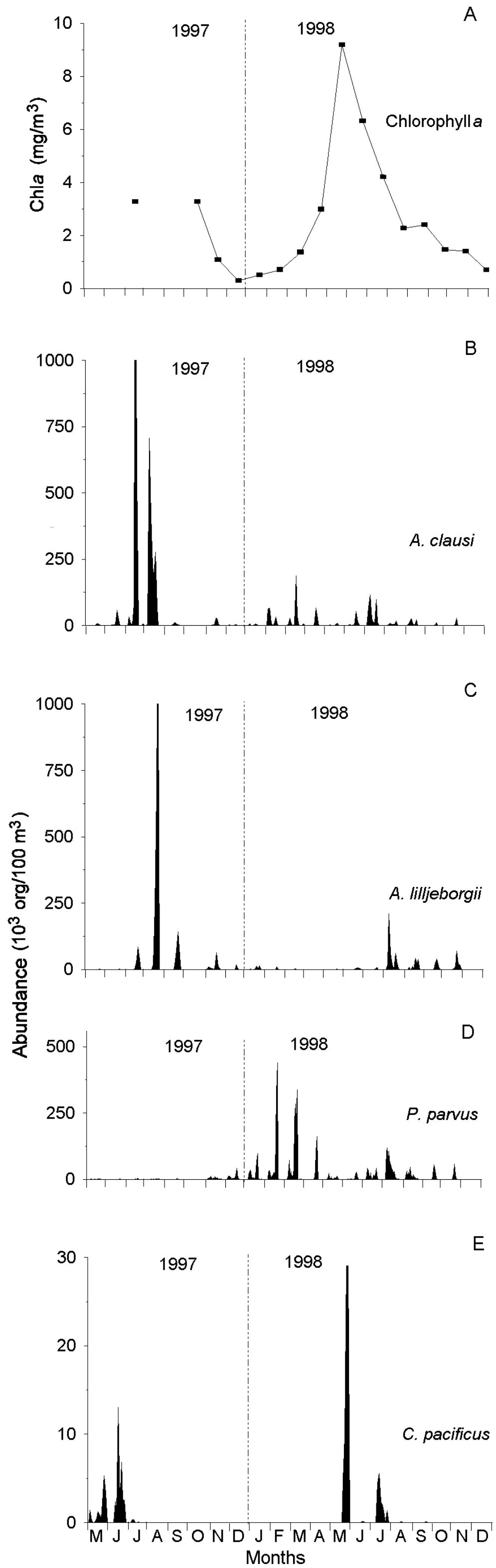

Fig. 4. A) Monthly mean chlorophyll *a* concentration (mg/m^3) at 5 meters depth (solid line) and (B - E) size abundance of four copepod species, during 1997-98 in Bahía Magdalena.

year. Aloctonous species, produced the largest abundance changes. All stages of the temperate species *Calanus pacificus* were observed during both events, but with very low abundance during the months when a strong influence of the California Current is expected (May-July), restricted to the portions of the bay near the mouth.

Small pelagic fishes

During 1982-83 and 1997-98, the early life stages of all main sardine species of Bahía Magdalena showed similar pattern of variation. The monterey sardine (*Sardinops caeruleus*) spawned during the cold season of 1982 and 1983, appearing with higher abundance during 1982 than during the onset of the warming event (Figure 5). In 1997 this species followed the same spawning trend practically disappearing during the cold season of 1998, and starting its recovery at the end of this year. In contrast, the tropical thread herring (*Opisthonema* spp.) spawned during the warm summer months and reached a maximum during the 1997-98 El Niño, eight times larger than during 1982-83.

Changes in the egg and larval indices of *Anchoa* spp. and *Scomber japonicus* were evident during the 1997-98 El Niño. *Anchoa* spp. showed a strong response to the warming event with a maximum abundance during the SST peak. During the second peak, the abundance diminished to a fourth of that. On the other hand, *Scomber japonicus* appeared in Bahía Magdalena in 1997-98 during the winter months and followed the same trend that *Sardinops caeruleus*.

DISCUSSION

The1997-98 El Niño event caused larger physical and biological changes in the Equatorial Pacific (McPhaden, 1999) than the 1982-83 event, which has been described as the most intense of the century (Cane, 1983; Cole and McLain, 1989). We recorded the effects of this warming event in Bahía Magdalena by June 1997, two months after its detection in the Equatorial region (McPhaden, 1999). As the El Niño 1982-83 event, one of the most significative effects of the 1997-98 El Niño included the northward advection of tropical waters, with a deepening of the thermocline and nutricline causing a decline of primary and secondary productions (Norton *et al*., 1985; Lynn *et al*., 1998). Although we lack estimations of chlorophyll during the onset of El Niño, all chlorophyll estimations were lower than 4 mg/m^{-3}, with exception of a peak observed during late spring-early summer. This pattern is similar to that of the zooplankton biomass recorded for this period but, with a small lag in between.

The marine biological response to physical changes varies from region to region, as a function of the origin and response capacity of the communities. The El Niño condition

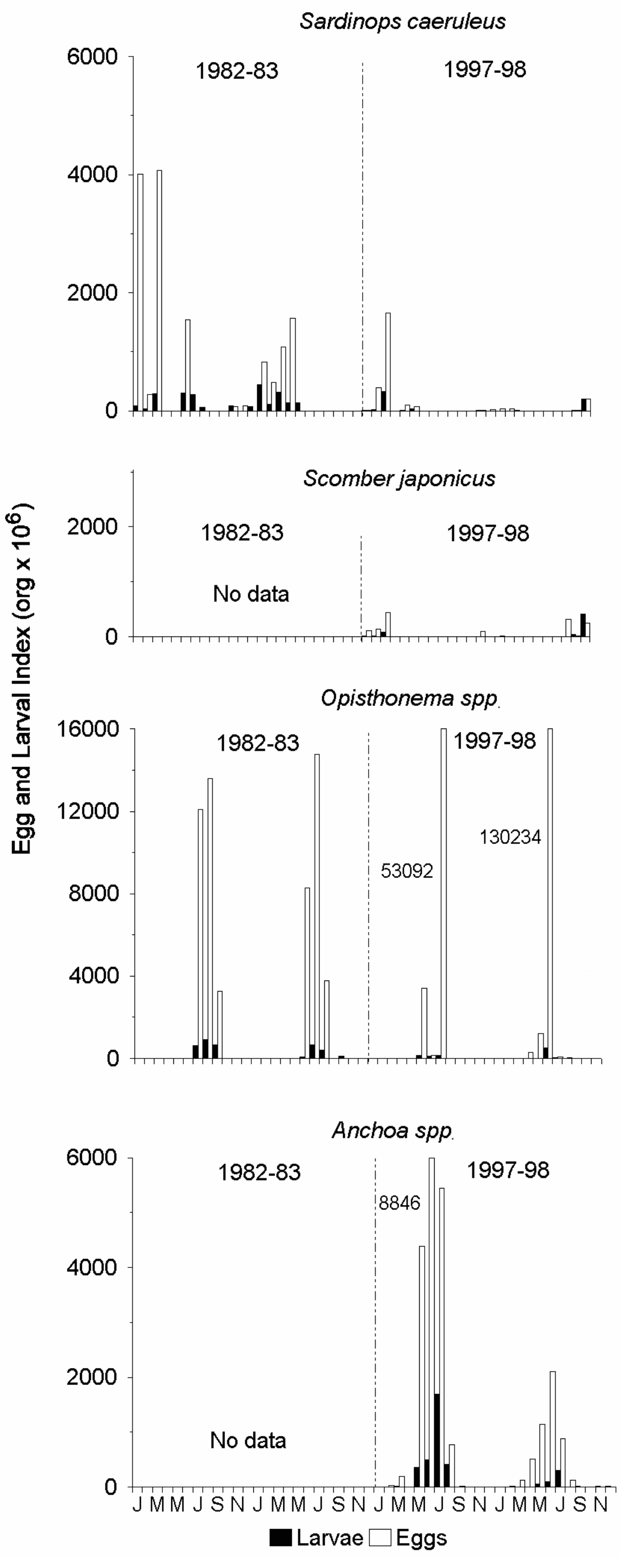

Fig. 5. Monthly mean egg and larval index (org x10[6]) of four small pelagic fishes during 1982-83 and 1997-98 in Bahía Magdalena.

is most intense in the oceanic zone. In neritic waters the warming effect is reduced by local processes of turbulent mixing, which furnish nutrients to the mixed layer and consistently sustain the phytoplankton and zooplankton biomass high (Petersen *et al*., 1986). Copepod species identified during the peak of the 1997-98 warming period in the neritic region off Baja California, showed a higher abundance of *Calanus minor* (Claus, 1863) Syn= *Nannocalanus minor* (Sars, 1925) (tropical oceanic) and *Subeucalanus subtenuis* (Giesbrecht, 1888) Syn= *Eucalanus subtenuis* Dana, 1852 (equatorial oceanic), than of the temperate species *Calanus pacificus* and *Rhincalanus nasutus* Giesbrecht, 1888 (Lavaniegos-Espejo *et al*., 2000). According to Palomares-García and Gómez-Gutiérrez (1996), the seasonal fluctuations of the dominant copepod species in Bahía Magdalena are the main cause of the ZB variability and thus play an important role in the secondary production within the bay. Notwithstanding the magnitude of the warming period during 1997-98, the seasonal abundance variability of the autoctonous species coincides with patterns previously reported for this bay (Palomares-García, 1992; Palomares-García and Gómez-Gutiérrez, 1996) in which the temporal succession coincides with the changes in the SST. Nonetheless these key copepod species showed some clear differences with respect to normal years. During the drastic increase of SST from May to August 1997 (19.5 to 31 °C), euriphage copepod species like *Acartia* spp. dominated the community structure, increasing the copepod production about double that of the cool season (Palomares-García *et al*., 1999). The phytophage species *Paracalanus parvus*, dominated during the period of lowest SST (January to May 20-22 °C) and during the highest phytoplankton production.

The increased presence of tropical and equatorial species is one of the most conspicuous biological changes related to anomalous advection of warm waters in this region (Lynn *et al*., 1998; Durazo and Baumgartner, 2002). In 1982-83 it caused an abnormal increase of tropical and equatorial copepod species in the neritic zone off the west coast of Baja California (Cervantes-Duarte and Hernández-Trujillo, 1989; Hernández-Trujillo, 1991). Several of these copepod species were also recorded, especially near the mouth, inside Bahía Magdalena during the warming peak of both the 1982-83 and 1997-98 events. However the tropical copepod assemblages were different from one event to the next (Table 2). During 1997-98 the presence of *Pontella fera* Dana, 1849, a tropical neritic species (not previously recorded in this bay reported before only for the central Gulf of California) (Palomares-García *et al*., 2002), points to a major advection of coastal tropical water (Lynn *et al*., 1998). A community change detected by Palomares-García and Gómez-Gutiérrez (1996) was the replacement of the dominant *Acartia clausi* by *Acartia tonsa* Dana, 1849, during the maximum SST anomaly in 1983. Nonetheless, during the initial warming of 1997-98 in Bahía Magdalena, an increase in the abundance of *Acartia clausi* and *Acartia lillgeborgii* was observed. A low abundance of *Acartia tonsa* was detected during this event. These results indicate that there may be different biological responses to particular El Niño conditions.

The seasonal pattern of temperature appears as a principal factor in the reproductive cycle of the small pelagic fishes in Bahía Magdalena. Eggs and larvae of northern tropical-subtropical species (*Opisthonema* spp. and *Anchoa* spp.) appear in summer, while eggs and larvae of temperate species (*Sardinops caeruleus* and *Scomber japonicus*) predominate during winter and spring (Saldierna-Martínez *et al*., 1987; Funes *et al*., 1998). During 1982-83 the presence of *Sardinops caeruleus* in its early life stages diminished inside Bahía Magdalena as well as in commercial catches, while egg and larvae of *Opisthonema* spp. increased at the same time that fishing captures peaked during the same period (Saldierna-Martínez *et al*., 1987; R. Funes com. pers. IPN-CICIMAR). A similar pattern was registered during 1997-98, when *Sardinops caeruleus* decreased, while previous records of *Opisthonema* spp. eggs and larvae were surpassed. Various authors have claimed that distribution and spawning areas of small pelagic fishes change during El Niño conditions (Bailey and Incze, 1985; Smith, 1985; Moser *et al*., 1987; Lluch-Belda *et al*., 1989). The decrease of *Sardinops caeruleus* and increase of *Opisthonema* spp. in Bahía Magdalena could be associated with a poleward shift in the spawning range of these species (Funes *et al*., 2000). Commercial catches have reinforced this idea because catches of *Sardinops caeruleus* in northern regions like Ensenada and Punta Eugenia increased during El Niño events (Félix-Uraga *et al*., 1996, 1998, 1999; García-Franco and Sánchez-Ruiz, 1998).

CONCLUSIONS

The physical and biological responses to the 1997-98 El Niño conditions in Bahía Magdalena were different to those observed during 1982-83, including major differences in the onset, magnitude and evolution. During 1997-98, SST increased by much as 31 °C recording the highest positive SST anomalies (+4.4 and 3.7 °C) for this latitude. In spite of the magnitude of the 1997-98 event, the recurrence of the seasonal succession of the key copepod species in this bay (Palomares-García, 1992; Palomares-García and Gómez-Gutiérrez, 1996), suggest that this ecosystem has a high stability, with dominant copepod species strongly adapted to seasonal and large-scale environmental changes Such as an ENSO. Copepod abundance and community structure did show different response to the varying warming conditions of the 1982-83 and the 1997-98 events. Although our ZB data series shows a diminishing trend after 1983, a summer maximum is maintained with the copepod populations representing 50 to 90% of the total zooplankton. Spawning magnitude of small pelagic fishes with tropical affinity was enhanced by the tropical warm water advected into the bay during the anomalous conditions of 1997-98.

Variations in the marine biological responses in the coast of Baja California is illustrated in terms of the climatic variability induced by the effects of two El Niño events. The decrease of ZB values in Bahía Magdalena shows a similar trend to that observed off southern California, where the zooplankton biomass shows a decreasing trend during the last twenty years (Roemmich and McGowan, 1995; Lynn *et al*., 1998).

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