INTERANNUAL CHANGES IN THE CALANOID COPEPOD COMMUNITY OFF SOUTHERN BAJA CALIFORNIA, MEXICO

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ABSTRACT

The calanoid copepod community was studied from zooplankton samples collected along transect 570 (off Bahía Magdalena) of the CICIMAR sampling grid during four spring cruises carried out during 1983–86. The null hypothesis postulating no interannual differences of the copepod community was tested. Calanoids represented between 84% and 96% of the total copepod numbers. Interannual variability of abundance was high: the overall abundance was lowest in 1985 and highest in 1984. A characteristic pattern of calanoid species abundance occurred each year; each arrangement could be considered as the result of local resource partitioning in which the abundance of a given species is in some way equivalent to the portion of niche space it occupies. In 1983 three species showed high abundance but a reduced distribution: *Subeucalanus subcrassus*, *Euchaeta rimana*, and *Pleuromamma abdominalis*. Between 1984 and 1986, *Calanus pacificus* was the most abundant and widely distributed, and was considered to be the representative species of the Copepoda during this period. Results of this study allowed rejection of the null hypothesis: interannual changes in oceanographic conditions are reflected in the copepod community, which shifted from a low-diversity, high-dominance stage during non–El Niño conditions to a more tropical, diverse community during the 1983 El Niño event. The southern boundary of the California Current system off Baja California varies, with changes identifiable through analysis of the structure of the calanoid copepod community.

INTRODUCTION

Calanoid copepods are among the most representative taxa of the pelagic mesozooplankton, and are both highly diverse and abundant (Angel 1994). The copepods of the California Current area have been surveyed for decades (Esterly 1924; Brodsky 1950; Fleminger 1964, 1967; Bowman and Johnson 1973), and only some dynamic aspects have been described (Longhurst 1967; McGowan and Miller 1980).

However, relatively little is known about the behavior of the pelagic Copepoda along middle and southern Baja California, part of the southernmost boundaries of the California Current's area of influence. Taxonomic knowledge of the calanoid copepod fauna in the oceanic waters off the western coast of Baja California has been summarized by Hernández-Trujillo (1998) and Palomares et al. (1998).

The oceanic environment off Bahía Magdalena, on the western coast of Baja California, occupies a biogeographically interesting zone, the temperate-tropical transitional area. The limits of this area are not stable and have a wide range of interannual variation (Roden 1991). Transect 570 of the basic Centro Interdisciplinario de Ciencias Marinas (CICIMAR) sampling grid is located precisely in this key transitional area, off Bahía Magdalena. This transect was sampled by 37 cruises between 1982 and 1998. However, we determined that May was the only month during which four consecutive annual zooplankton samplings were performed. In fact, this month is particularly relevant because it is in May that the oceanographic conditions of the California Current reach their southernmost limits and have a detectable influence in the area. The May samples also include zooplankton from El Niño and non–El Niño years. So we used this material to estimate the extent of the interannual persistence or change of the community structure of calanoid copepods along transect 570 off the Baja California Peninsula. These data are intended to contribute to the understanding of interannual dynamics affecting the zooplankton distribution in this transitional area of the Pacific Ocean.

METHODS

Zooplankton samples were obtained with a bongo-type net in all the localities along transect 570 of the CICIMAR sampling grid in the Baja California Peninsula (BC). The transect is perpendicular to the coastline (fig. 1) and was sampled during May of four consecutive years: 1983–86. Stations 80 (112.45°W, 24.05°N, tow 250–0 m); 60 (112.25°W, 24.25°N, tow 250–0 m); and 45 (112.05°W, 24.45°N, tow 175–0 m) are separated from each other by about 20 nautical miles. The sampling methods, including fixation and preservation of the material, estimation of zooplankton biovolumes, and quantification of calanoid copepods is standard for all

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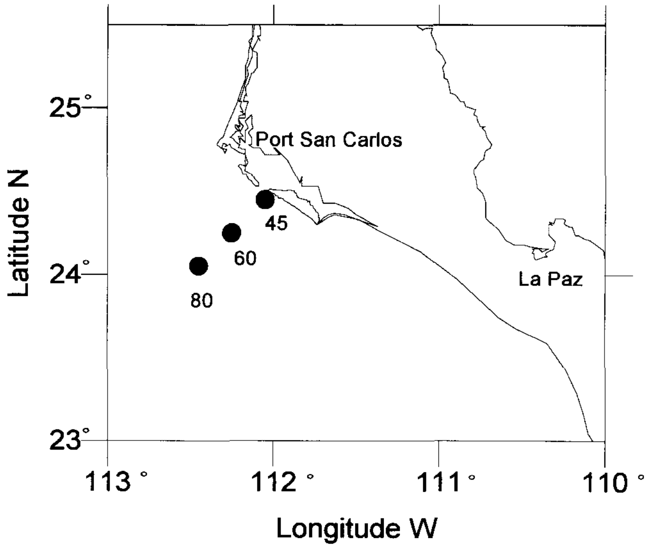

Figure 1. Locations of CICIMAR transect 570 on the western coast of southern Baja California.

CICIMAR zooplankton collections, and has been described in detail by Hernández-Trujillo (1998).

After the calanoid copepods from the samples were identified and counted, a rank abundance was plotted to present species abundance data (Magurran 1988) and to provide a direct comparison between communities of calanoid copepods with different numbers of species during the period of the study. Hence, the interannual variation of the calanoid copepod abundance was determined, considering the dominant species and the most frequent forms.

Surface temperature data were obtained at each station with an InterOcean CTD; a decadal time series of the sea-surface temperature (SST) for May 1980–90 was built by integrating data from Cole and McLain (1989) and from the CD-ROM COADS of NOAA. Temperature anomalies were estimated as well.

RESULTS

The taxonomic analysis of the total copepod fauna in the studied samples yielded 50 species. The numbers of copepod species and calanoid species during each year surveyed are presented in tables 1 and 2. There were differences in calanoid communities between 1983 and 1986 (fig. 2). The upper curves represent the least diverse community, dominated by one species; the lower curves were the most diverse. In comparison to 1983, the overall species richness decreased 26% in 1984 and 59% in 1985. This situation was reversed in 1986, when the species number increased 18.5% from the 1983 figure. The species of Calanoida followed the same general trend, but not for their relative density within the community structure. Calanoid copepods represented, in all cases, between 80% and 96% of the species richness.

TABLE 1
Number of Copepod Species in Transect 570 during May 1983–86

Year	Number of copepod species	Number of calanoid species	Percentage of calanoids
1983	27	26	96
1984	20	17	85
1985	11	10	91
1986	32	27	84

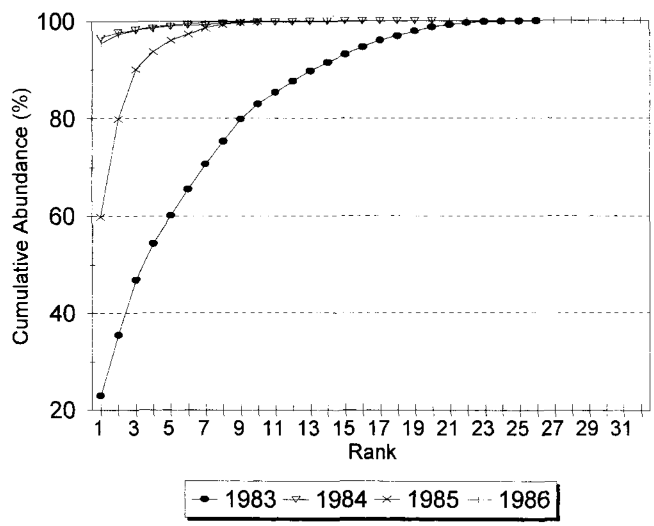

Figure 2. Rank abundance of calanoid copepod species along transect 570 (1983–86).

Considering the biogeographic affinities of the 50 species recorded, 62% are tropical, 16% subtropical, 14% equatorial, and 8% transitional forms. Interannual variation of the biogeographic composition showed that the tropical component of the community was consistently the most relevant (55%–67%) during the four years considered (fig. 3).

The interannual average abundance of calanoid copepods along transect 570 showed a wide range of variation: its maximum value occurred in 1984, with 112,832 individuals·1000 m^{-3} (fig. 4), its minimum value in 1985 (259 ind·1000 m^{-3}). The general trend of the local calanoid copepod community showed a decreased abundance toward the coastal areas (fig. 5).

The interannual analysis of the community structure showed that during 1983 three calanoid species were the most representative in terms of density: *Pleuromamma abdominalis*, *Euchaeta rimana*, and *Subeucalanus subcrassus*; despite this, their distribution was relatively reduced. In contrast, the most important in 1984 were *Calanus pacificus*, *Calanus minor*, and *Pleuromamma gracilis*. In both 1985 and 1986, *C. pacificus*, *P. abdominalis*, and *Rhincalanus nasutus* were clearly dominant and most widely distrib-

TABLE 2
Copepod Species Recorded during May (1983–86) at CICIMAR Transect 570

Species	Affinity	May 1983	May 1984	May 1985	May 1986
Calanus pacificus	Transitional	■	■	■	■
Candacia bipinnata	Transitional			■	
Eucalanus californicus	Transitional	■			■
Rhincalanus nasutus	Transitional	■		■	■
Acartia clausi	Subtropical	■			■
Calanus minor	Subtropical		■		■
Candacia pachydactyla	Subtropical		■		
Corycaeus typicus	Subtropical				■
Gaetanus secundus	Subtropical				■
Lophothrix frontalis	Subtropical				■
Pleuromamma quadrungulata	Subtropical	■			
Scolecithricella vittata	Subtropical		■		
Acartia danae	Tropical	■	■	■	■
Acrocalanus gracilis	Tropical				■
Aetideus armatus	Tropical	■		■	■
Caligus sp.	Tropical			■	
Candacia pectinata	Tropical			■	
Copilia quadrata	Tropical				■
Corycaeus lautus	Tropical		■		■
Corycaeus speciosus	Tropical		■		■
Eucalanus crassus	Tropical	■			
Euchaeta rimana	Tropical	■			■
Euchaeta media	Tropical	■			■
Euchirella amoena	Tropical	■			■
Haloptilus mucronatus	Tropical	■	■		■
Haloptilus ornatus	Tropical	■	■		■
Labidocera acutifrons	Tropical	■			
Oithona plumifera	Tropical	■	■		■
Oncaea venusta	Tropical				■
Paracalanus parvus	Tropical	■			■
Phaenna spinifera	Tropical		■		
Pleuromamma gracilis	Tropical		■		
Pleuromamma abdominalis	Tropical	■	■	■	■
Pontellopsis perspicax	Tropical	■			
Pontellopsis sp.	Tropical		■		
Pontellopsis villosa	Tropical				■
Sapphirina gastrica	Tropical				■
Scolecithricella bradyi	Tropical	■	■		■
Scolecithricella sp.	Tropical	■			
Scolecithrix danae	Tropical	■		■	■
Scottocalanus sp.	Tropical				■
Temora discaudata	Tropical	■	■		
Aetideus giesbrechti	Equatorial		■		
Candacia catula	Equatorial		■		
Candacia curta	Equatorial			■	■
Candacia truncata	Equatorial	■			■
Eucalanus attenuatus	Equatorial	■	■	■	■
Subeucalanus subcrassus	Equatorial	■	■		
Undinula darwini	Equatorial	■			

Shaded columns indicate that the species was present.

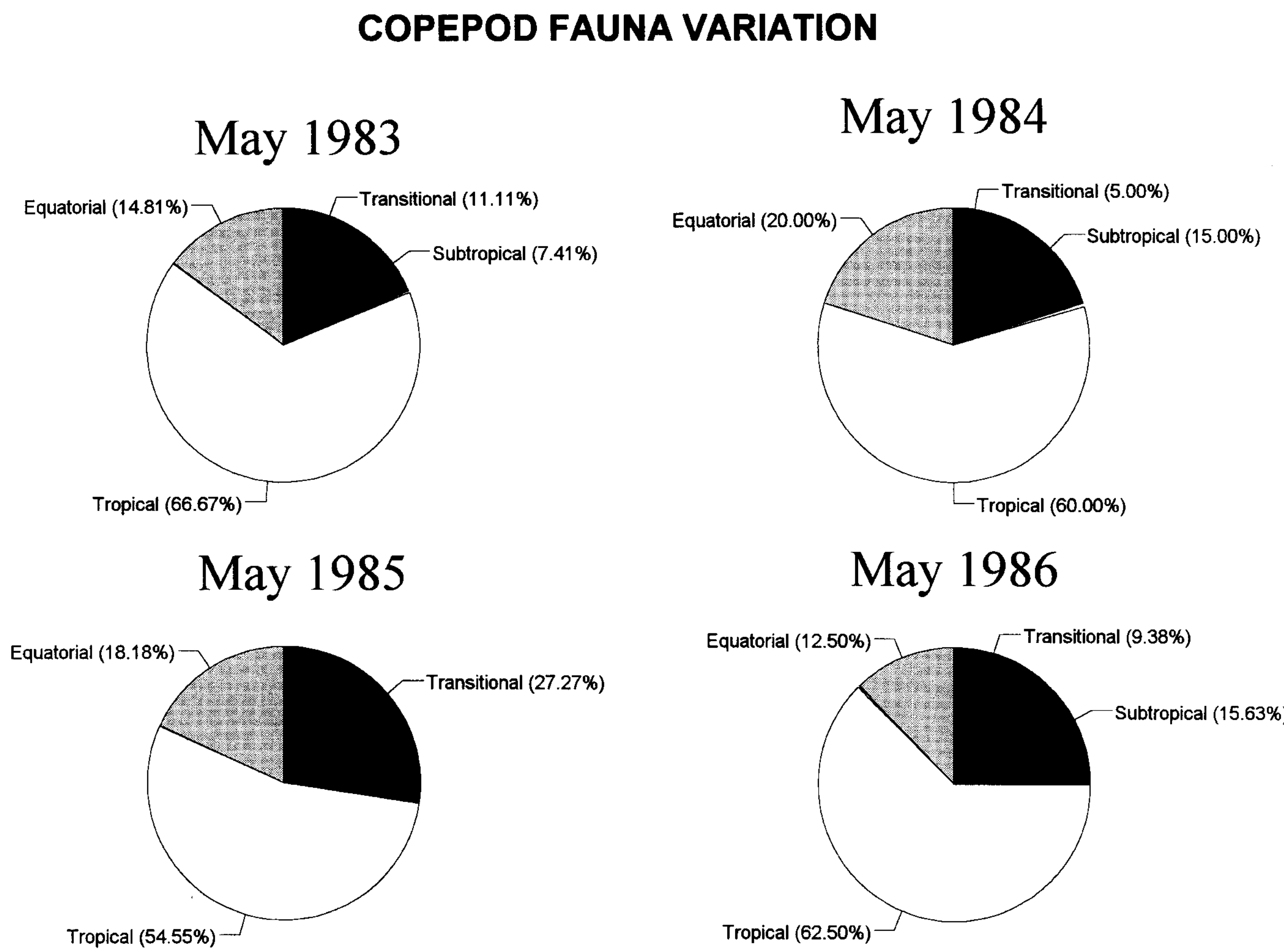

Figure 3. Variation of the biogeographic structure of the copepod fauna during May 1983–86.

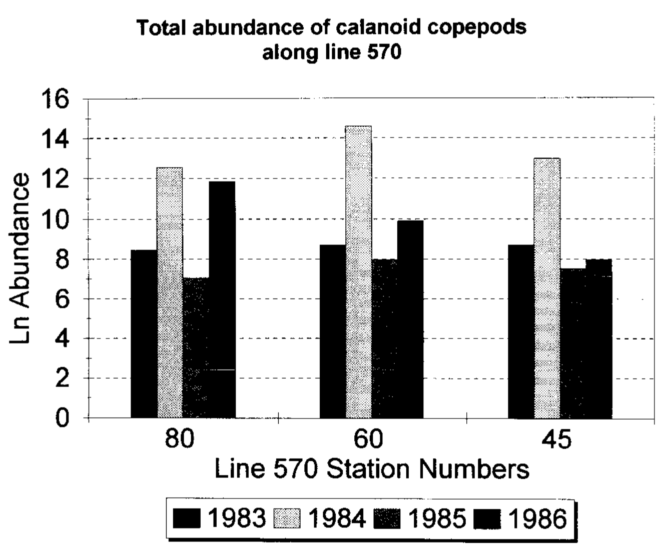

Figure 4. Total abundance of calanoid copepods along transect 570 (1983–86).

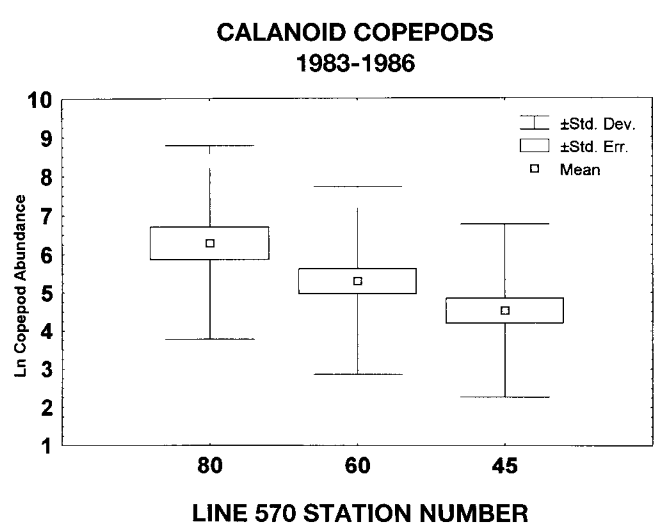

Figure 5. Ocean-coast distribution of calanoid copepods during May 1983–86.

uted (figs. 6 and 7). Due to this dominance, except for 1983, the interannual abundance of *C. pacificus* is representative of that shown by the calanoid copepods together (fig. 8a).

Changes in zooplankton biovolume values were evident among the different years considered. The highest value (>500 ml·1000 m^{-3}) was recorded in 1983; the lowest in 1985 (<25 ml·1000 m^{-3}; fig. 8b).

The SST showed a maximum average value in 1983 (19.9°C); the lowest value was recorded in 1985 (15.1°; fig. 8c). The SST showed a definite trend in terms of the coast-ocean gradient, with lower values toward the coast during the four years studied. The mesoscale interannual analysis of decadal SST (1980–90) and the corresponding anomaly in the area between 22° and 24°N varied widely during May (fig. 9). The highest temperature of the decade (22.8°) was recorded in May 1983. Lowest values within the same 10-year period were recorded in 1988 (19.4°) and 1989 (20.1°). The anomaly analysis showed that seawater stayed longer during the 1980–90 period (fig. 9).

DISCUSSION

According to Lynn and Simpson (1987), the coastal surface waters of the California Current flow southward along BC (32° to 25°N) between March and May; this is part of a highly variable seasonal pattern in the region. Near the BC coasts, SST increases southward from 15° to 20° in winter, and from 20° to 25° in summer (Badán 1997). Considering the topography of the 20°C isotherm as a reference for the advancement or retreat of the California Current, figure 10 shows that in 1984 and 1985 waters with temperatures over 20° were distributed south of transect 570; in 1985, they reached as far south as Cabo San Lucas. In contrast, in 1983 and 1986, SST values over 20° were distributed north of Bahía Magdalena.

This strong SST variability had different effects on the structure of the local calanoid copepod community.

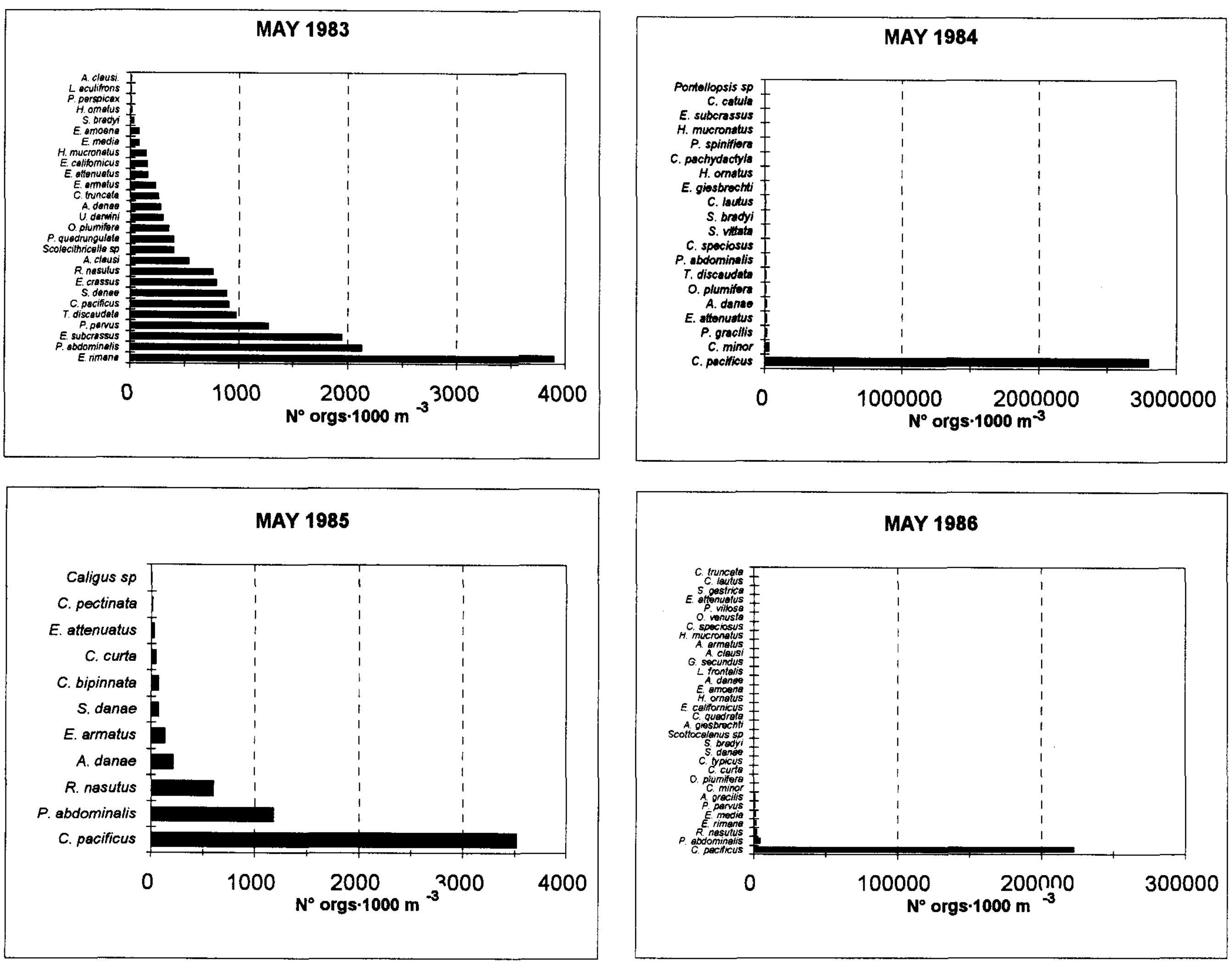

Figure 6. Abundance-diversity of the pelagic Copepoda in May 1983–86.

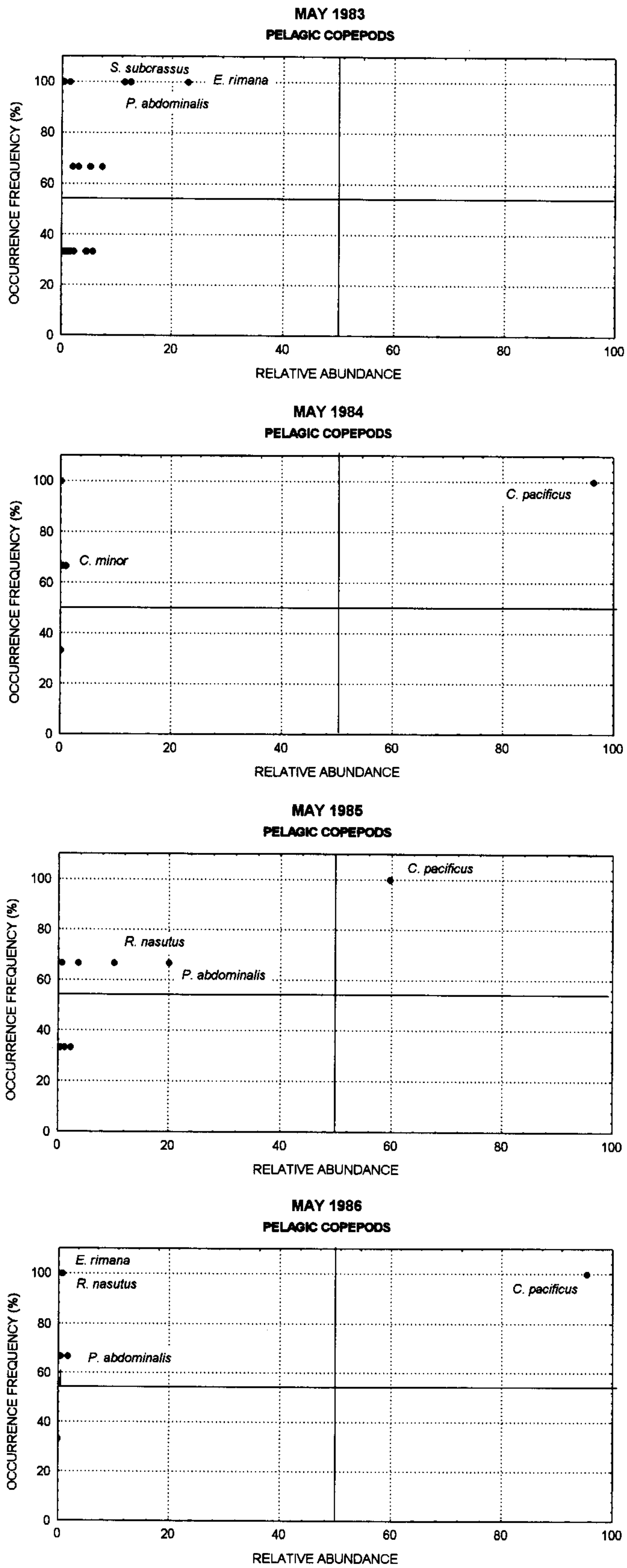

Figure 7. Frequency–relative abundance of the calanoid copepods in May 1983–86.

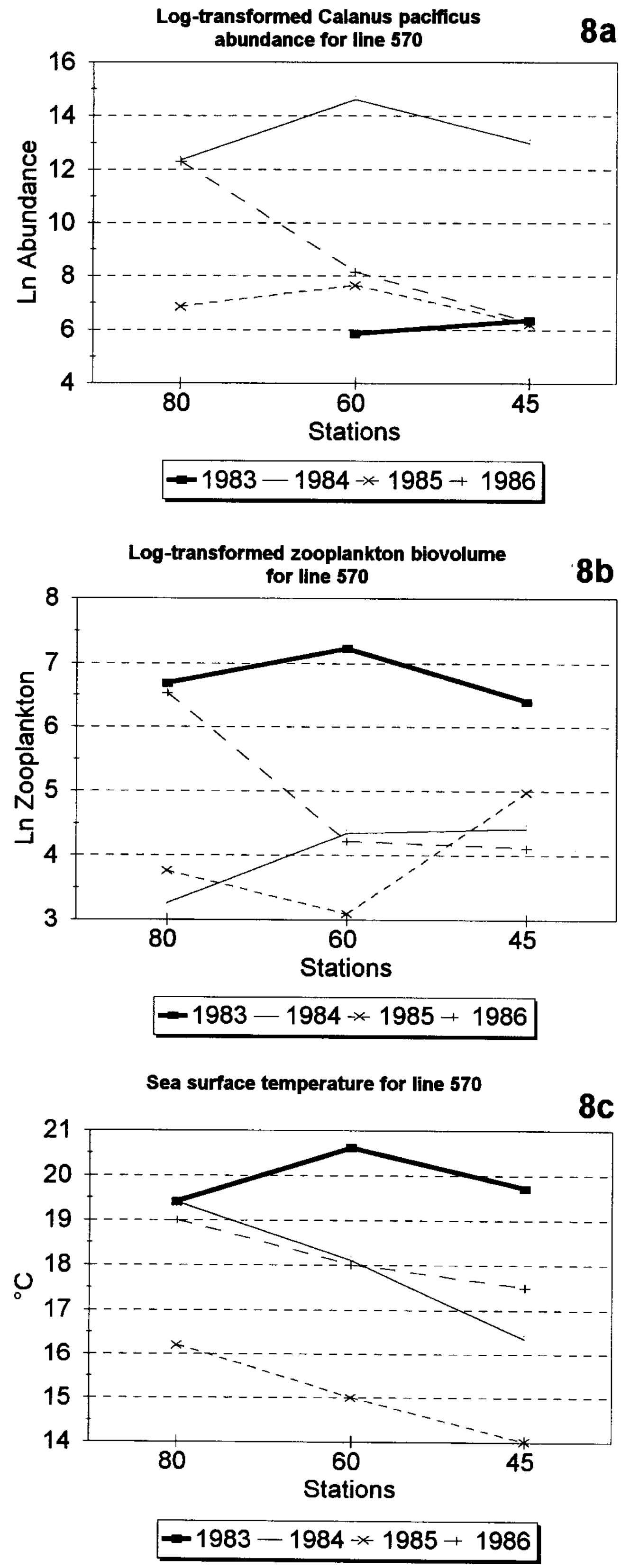

Figure 8. Ocean-coast distribution of (*a*) the abundance of *Calanus pacificus*, (*b*) zooplankton biomass, and (*c*) sea-surface temperature along transect 570 during May 1983–86.

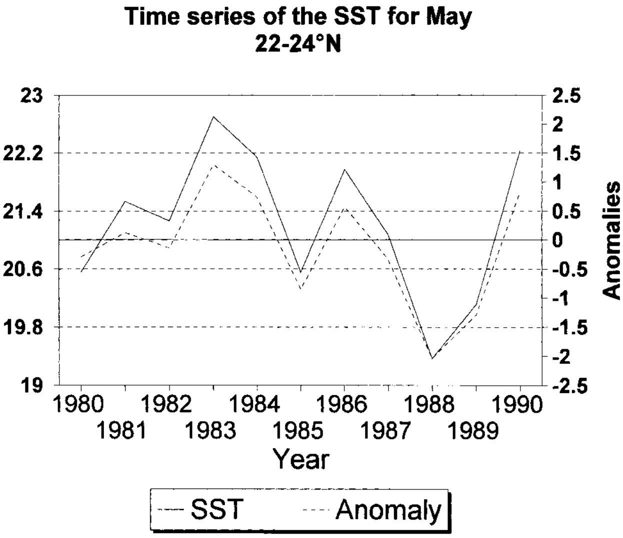

Figure 9. Time series of SST data and anomalies between 22° and 24°N (1980–90).

One of the most relevant was the induction of a stage featured by low species dominance, higher diversity, and a relatively complex community structure during the onset of anomalous warm conditions such as those related to El Niño 1983. Another consequence was to promote, with relative consistency, the persistence of a simplified structure, with a high dominance of a single species, and a reduced diversity in relatively colder conditions related to the influence of the California Current (Wolter 1987; Wolter and Timlin 1993; Hernández-Trujillo 1998).

The species richness recorded in the surveyed area represented between 9% and 26% of the faunal diversity previously known in the area off southern Baja California (Hernández-Trujillo 1998; Palomares et al. 1998), thus only a few species periodically become the dominant forms of the calanoid copepod community in the area. The changes in this community were followed through successive modifications of its structure, which showed different stages of complexity.

The sharpest changes were evident in 1983, when the abundance and frequency of the calanoid copepods did not center on a particular species, contrasting to the profile observed in the other years. The extreme dominance of *C. pacificus* during 1984–86 simplified the community structure. As has been shown by Hernández-Trujillo (1998), temperature and salinity conditions modify the structure of the pelagic copepods off the western coast of southern Baja California.

It is clear from figure 3 that the temperature increase is related to the invasion of warmer waters of tropical origin and to a higher proportion and abundance of tropical species. During these conditions, the distribution of resources is more homogeneous because of the decreased population of *C. pacificus*.

Interannual changes in the calanoid density values, and particularly for *C. pacificus*, seem to be only weakly related to food availability. Photosynthetic pigment concentrations reported by Zuria-Jordán et al. (1995) off Bahía Magdalena in May 1983–86 were 3.5, 3.5, <1, and 8 $mg \cdot m^{-3}$, respectively. These concentrations were associated, in the same sequence, to phytoplankton densities varying from 960 to $4 \cdot 10^{-3}$; $2 \cdot 10^{-3}$ to $47 \cdot 10^{-3}$; $2 \cdot 10^{-3}$ to $490 \cdot 10^{-3}$; and $240 \cdot 10^{-3}$ to $328 \cdot 10^{-3}$ $cel \cdot l^{-1}$; nannophytoplankton was dominant in all cases (Martínez-López 1993).

Most of the dominant species, including *C. pacificus*, are herbivorous forms, enhanced by a phytoplankton-rich environment (Zuria-Jordán et al. 1995). In 1985, when conditions were different, the pigment concentration was lowest, the SST was 1°C below the average, and the overall abundance and species richness of copepods decreased. However, these apparently adverse conditions did not affect the community structure of copepods. Despite the reduced abundance and species richness in 1985, the dominant and codominant species were mostly the same and in a similar relative proportion.

The analysis of the time series of pigments obtained by Zuria-Jordán et al. (1995) showed that the anomalies detected between 1983 and 1985 were always negative during May off Bahía Magdalena; the anomaly was positive only in 1986. This is an inverse situation with respect to the SST anomalies, suggesting that phytoplankton values dropped as a consequence of the warming produced by El Niño 1982–83 in the surveyed area (Martínez-López 1993). The event showed detectable residual effects in the zooplankton until 1984 (Hernández-Trujillo and Esquivel-Herrera 1997); for copepods, the effect was a reconstitution of structure, from a complex stage to a simpler one.

El Niño 1982–83 had important effects in the BC area, including the reduced hydrologic rate of mixing of surface and subsurface waters (Wooster and Fluharty 1985) and the decrease of both zooplankton and phytoplankton abundance. Our results show that part of the strong oceanographic influence of El Niño 1983 persisted for years after the event, even in the southern BC area. This is reflected in the calanoid copepod community structure, with the shift from the dominance of one species to a shared dominance of several others, the high rate of specific renewal, and 60% of tropical species.

An ecological explanation for differing behavior of calanoid copepods under similar conditions of SST (see fig. 10) could be food availability, which favors only a few species. This idea is supported by the results of Hernández-Trujillo (1999a), who found that the highest densities of calanoid copepods, including *C. pacificus*,

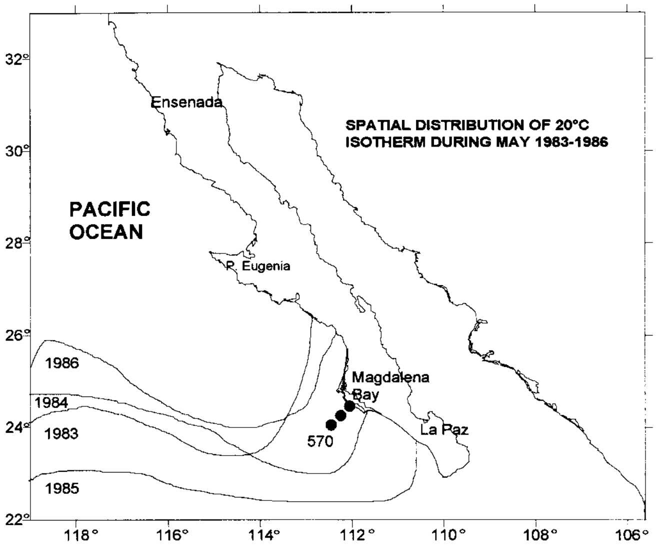

Figure 10. Spatial distribution of the 20°C surface isotherm off the west coast of southern Baja California.

were related to nannophytoplankton concentrations between 5,000 and 25,000 cel/l^{-1} and SST between 16° and 22°C.

The conditions related to transect 570 represent an adequate situation for surveying interannual changes in the structure of the copepod community and its relation to El Niño and non–El Niño years. Our work is intended to provide insights into the effects of the acyclic onset of new conditions to which the general zooplankton community, and particularly that of the pelagic copepods, must adapt (Funes et al. 1995; Palomares-García and Gómez-Gutiérrez 1996; Hernández-Trujillo 1999a, b). It is expected that these interannual variations are comparable to or stronger than the seasonal ones (Chelton et al. 1982). In fact, the seasonal data of Hernández-Trujillo (1998) for the copepod community in the same area supports this idea. This information is particularly relevant for a transitional area such as BC, where knowledge about these aspects is still limited, thus providing complementary data about the behavior of zooplankton toward the southern boundaries of the California Current system.

CONCLUSIONS

Interannual variation of the calanoid copepod community in the surveyed area was high. A single species was dominant during three consecutive years, but the codominant ones were not the same each year, and they did not occupy the same niche. The persistent characteristic of the community was the stability of *C. pacificus* and *Pleuromamma abdominalis*, representative of non–El Niño years.

The expected tropical conditions associated with El Niño 1983 were clearly reflected in the local copepod structure as an apparent evenness in the use of the available resources and an increased complexity. During 1984–86, the wide dominance of a single species suggests an asymmetric distribution of the resources and represents a reduced stage of complexity.

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LITERATURE CITED

Angel, M. V. 1994. Biodiversity of the pelagic ocean. Conserv. Biol. 7:760–762.

Badán, D. A. 1997. La Corriente Costera de Costa Rica en el Pacífico Mexicano. *In* Contribuciones a la oceanografía física en México, M. F. Lavín, ed. Monografía 3 Unión Geofísica Mexicana, pp. 99–112.

Bowman, T. W., and N. W. Johnson. 1973. Distributional atlas of Calanoida in the California Current region, 1949 and 1950. Calif. Coop. Oceanic Fish. Invest. Atlas 19:1–200.

Brodsky, K. 1950. Calanoida of the Far Eastern seas and polar basins of the USSR. Key to the fauna of the USSR N° 35, Inst. Acad. Sci. USSR (Translated from Russian by the Israel Program for Scientific Translations. Jerusalem 1967), 440 pp.

Chelton, D. B., P. A. Bernal, and J. A. McGowan. 1982. Large-scale interannual physical and biological interaction in the California Current. J. Mar. Res. 40(4):1095–1125.

Cole, D. A., and D. R. McLain. 1989. Interannual variability of temperature in the upper layer of the North Pacific eastern boundary region, 1971–87. NOAA Tech. Memo., NMFS-SWFC-125, 9 pp. + 5 figs. + appendix.

Esterly, O. C. 1924. The free-swimming copepoda of San Francisco Bay. Univ. Calif. Publ. Zool. 26(25):81–129.

Fleminger, A. 1964. Distributional atlas of calanoid copepods in the California Current region. Part I. Calif. Coop. Oceanic Fish. Invest. Atlas 2:1–313.

———. 1967. Distributional atlas of calanoid copepods in the California Current region. Part II. Calif. Coop. Oceanic Fish. Invest. Atlas 7:1–213.

Funes, R. R., R. González, and A. Esquivel. 1995. Distribución y composición específica de larvas de peces durante y después de El Niño, en la costa del Pacífico de Baja California Sur (1983–1985). Hidrobiológica 5(1–2):113–125.

Hernández-Trujillo, S. 1998. La comunidad de copépodos pelágicos en la costa del Pacífico de la península de Baja California (1984–1989). Ph.D. thesis, ICMyL-UNAM, México D.F., 127 pp. + 2 anexos.

———. 1999a. Key species in the pelagic copepod community structure on the west coast of Baja California, Mexico. Calif. Coop. Oceanic Fish. Invest. Rep. 40:154–164.

———. 1999b. Variability of community structure of copepoda related to El Niño 1982–83 and 1987–88 along the west coast of Baja California peninsula, Mexico. Fish. Oceanogr. 8(4):284–295.

Hernández-Trujillo, S., and A. Esquivel-Herrera. 1997. Asociaciones interespecíficas de copépodos en la costa oeste de Baja California Sur, México. Hidrobiológica 7:65–74.

Longhurst, A. R. 1967. Diversity and trophic structure of zooplankton communities in the California Current. Deep-Sea Res. 14:393–408.

Lynn, R. J., and J. J. Simpson. 1987. The California Current system: the seasonal variability of its physical characteristics. J. Geophys. Res. 92(C12): 12,947–12,966.

Magurran, A. E. 1988. Ecological diversity and its measurement. London: Chapman & Hall, 179 pp.

Martínez-López, A. 1993. Efectos del evento El Niño 1982–83 en la estructura del fitoplancton en la costa occidental de Baja California Sur. M.Sc. thesis. CICIMAR-IPN, La Paz, BCS, México, 95 pp.

McGowan, J. A., and C. B. Miller. 1980. Larval fish and zooplankton community structure. Calif. Coop. Oceanic Fish. Invest. Rep. 21:29–36.

Palomares-García, R., and J. Gómez-Gutiérrez. 1996. Copepod community structure at Bahía Magdalena, Mexico during El Niño 1983–84. Estuarine Coastal Shelf Sci. 43:583–595.

Palomares-García, R., E. Suárez-Morales, and S. Hernández-Trujillo. 1998. Catálogo de los copépodos (Crustacea) pelágicos del Pacífico noroeste de México y zonas adyacentes. CICIMAR-ECOSUR, México D.F., 200 pp.

Roden, G. I. 1991. Subarctic-subtropical transition zone of the North Pacific: large-scale aspects and mesoscale structure. *In* Biology, oceanography, and fisheries of the North Pacific transition zone and subarctic frontal zone, J. A. Wetherall, ed. NOAA Tech. Rep. NMFS 105: 1–38.

Wolter, K. 1987. The southern oscillation in surface circulation and climate over the tropical Atlantic, eastern Pacific, and Indian Oceans as captured by cluster analysis. Clim. Appl. Meteorol. 26(4):540–558.

Wolter, K., and M. S. Timlin. 1993. Monitoring ENSO in COADS with seasonally adjusted principal component index. *In* Proceedings of the 17th Annual Climate Diagnostics Workshop, Norman, Okla., pp. 52–57.

Wooster, W. S., and D. L. Fluharty. 1985. El Niño north. Niño effects in the eastern subarctic Pacific Ocean. Washington Sea Grant Program. Univ. Wash., Seattle, 312 pp.

Zuria-Jordán, I. L., S. Alvarez-Borrego, E. Santa María-Del-Angel, and F. E. Müller-Karger. 1995. Estimación de biomasa fitoplanctónica , derivada de datos de satélite, frente a Baja California Sur, Ciencias Marinas 21(3):265–280.