ZOOPLANKTON BIOMASS AND COPEPOD COMMUNITY STRUCTURE IN THE GULF OF CALIFORNIA DURING THE 1982–1983 EL NIÑO EVENT

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ABSTRACT

From March 11 to 23, 1983, we studied zooplankton biomass distribution and copepod community structure in the Gulf of California. Maximum biomass occurred in the eastern side of the central gulf; in general, biomass did not show the reduction typically reported for other ecosystems during El Niño events. Copepods and cladocerans were the dominant taxa, with copepodite stages of *Oithona* sp. and *Penilia avirostris* the most abundant populations. We identified 76 species of copepods: 60 calanoida, 14 cyclopoida, and 2 harpacticoida. Of these, 17 are reported for the first time in the gulf. Calanoid copepods with tropical-subtropical affinity composed 69% of the total, while those with equatorial and temperate affinities were 17% and 14%, respectively. Of the copepods with tropical-subtropical and equatorial affinities, those from oceanic habitats were the most abundant, whereas the most abundant temperate-water species were coastal habitat types. The spatial pattern of the copepod community structure showed two main assemblages, one in the central and the other in the southern parts of the gulf. These two regions correspond to zones with different physical and primary production characteristics.

RESUMEN

La distribución de la biomasa y la estructura de la comunidad del zooplancton del Golfo de California fueron estudiadas del 11 al 23 de marzo de 1983. La máxima biomasa se registró en la costa oriental del golfo central. En general, la biomasa del zooplancton no disminuyó como ha sido reportado para otros ecosistemas durante eventos El Niño. Los grupos dominantes fueron copépodos y cladóceros, siendo los copepoditos de *Oithona* sp. y *Penilia avirostris* las poblaciones más abundantes. Dentro del grupo de los copépodos se registraron 76 especies: 60 calanoides, 14 ciclopoides y 2 harpacticoides. Diecisiete de estas especies se reportan por primera vez para el Golfo de California. Entre las especies de copépodos calanoides, las de afinidad tropical-subtropical constituyeron el 69%, mientras que las de aguas ecuatoriales y templadas registraron 17% y 14%, respectivamente. Dentro de las especies de afinidad tropical-subtropical y ecuatorial, las de hábitat oceánico fueron las más abundantes, mientras que la máxima abundancia de las especies de afinidad a aguas templadas correspondió a las de hábitat costero. La distribución espacial de las poblaciones de copépodos mostró dos grandes regiones faunísticas en las zonas central y sur del golfo, las cuales corresponden a diferentes características ambientales del Golfo de California.

INTRODUCTION

Climatic and oceanographic anomalies in the eastern tropical Pacific at the end of 1982 indicated the beginning of an El Niño event that has been considered the strongest of the century (Cane 1983; Rasmusson 1984). The 1982–83 El Niño event caused drastic changes in phytoplankton biomass and productivity in Peruvian waters (Chávez et al. 1983, 1984), as well as in the availability of fisheries resources (Barber and Chávez 1986). In the California Current, zooplankton abundance was also decreased (McGowan 1983, 1984).

Thermal and sea-level anomalies in the Gulf of California at the end of 1982 indicated that the El Niño phenomenon extended into the gulf (Robles-Pacheco and Christensen 1984; Robles-Pacheco and Marinone 1987). In contrast to the California Current, however, phytoplankton biomass and productivity was increased, with rates up to seven times higher than in normal years (Valdéz-Holguin and Lara-Lara 1987; Lara-Lara and Valdéz-Holguin 1987).

In this paper we describe the zooplankton biomass and copepod community structure in the Gulf of California during the 1982–83 El Niño event.

STUDY AREA

The Gulf of California is located in an arid environment between the Baja California Peninsula

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and mainland Mexico (Figure 1). It is a large evaporative basin, with free connection to the Pacific Ocean (Roden 1964). Length is about 1000 km, and average width is about 150 km. Topographically, the gulf is divided into a series of basins, with main hydrographic provinces separated by Ángel de la Guarda and Tiburon islands. There is a shallow basin to the north, and a sequence of deeper basins to the south (Alvarez-Borrego 1983). Strong, semicontinuous tidal mixing and seasonal upwelling occur in the central gulf, near the more northern islands; northwesterly winds cause upwelling on the eastern shore during winter and spring, and southerly winds cause upwelling on the west coast during summer (Roden and Groves 1959; Badán-Dangon et al. 1985).

METHODS

From March 11 to 23, 1983, zooplankton samples were collected at 22 stations (Figure 1) from R/V *El Puma* using a 60-cm-mouth-diameter, 0.333-mm mesh bongo net equipped with a flowmeter and towed obliquely between 250 m and the surface. Samples were preserved in 4% formaldehyde neutralized with sodium borate. Zooplankton biomass was estimated by displacement volume (Kramer et al. 1972) and by wet and dry weight measurements (Omori and Ikeda 1984). Subsamples were prepared with a Folsom splitter. Copepod species were identified from 11 representative stations (Figure 1) using Rose (1933), Grice (1961), Motoda (1963), Frost and Fleminger (1968), Nishida et al. (1977), and Alameda de la Mora (1980) as taxonomic references. Only 89% of the total copepods were identified to genus or species level because of the relatively high abundance of many copepodite stages that could not be identified. The copepod species diversity was calculated using the Shannon and Weaver (1949) index. Faunistic associations were assessed by estimating the similarity between stations with the Jaccard index, followed by a grouping technique, as described by Davis (1973). Surface temperature was measured with reversing thermometers, and

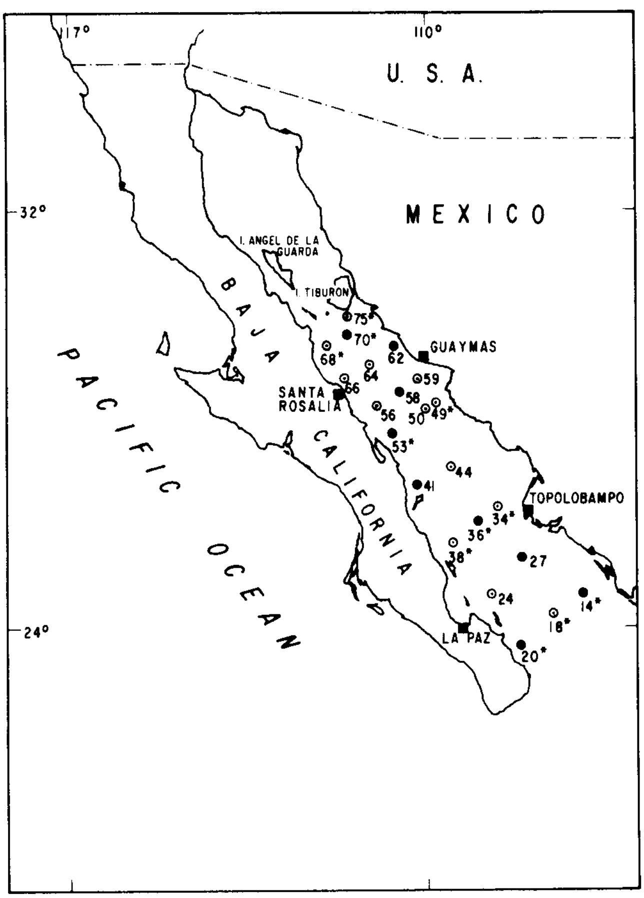

Figure 1. Stations sampled during March 1983: (⊙) day, (●) night. Asterisks denote stations where copepod species were identified.

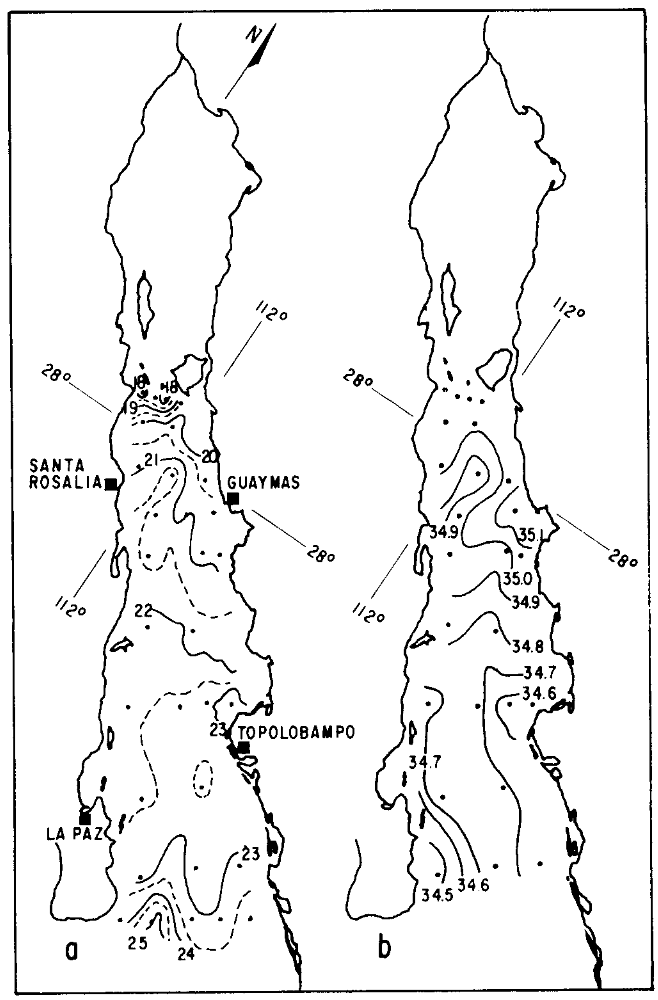

Figure 2. Surface temperature (*a*) and salinity (*b*) distributions in the Gulf of California during March 1983.

surface salinity with a Plessey 6230 salinometer from water samples collected in Niskin bottles.

RESULTS

Temperature and Salinity Distributions

March surface temperature (Figure 2a) ranged from 17.9° to 25.4°C, decreasing from the mouth to the central region; lowest temperatures occurred south of the Tiburon and San Esteban islands. A tongue of colder water extended southward in the eastern portion of the central gulf off Guaymas.

Surface salinity (Figure 2b) varied from 34.4 to 35.2‰, with lowest salinities at the mouth, and highest in the central gulf. A band of more saline water coincided with the cold water found off Guaymas.

Zooplankton Biomass

Zooplankton displacement volumes (Table 1) were higher in the eastern portion of the central gulf (Figure 3); biomass expressed in wet and dry weight (Table 1) showed much the same distribution. Average biomass in the central gulf (north of 27°N) was over twice that in the southern gulf (south of 27°N) (Table 1). Biomass values from stations in neritic waters (< 200 m deep) averaged about three times higher ($\bar{X}$ = 988 ml/1000 m^3) than stations located in water of greater depths ($\bar{X}$ = 295 ml/1000 m^3). Biomass differences between night ($\bar{X}$ = 383 ml/1000 m^3) and day ($\bar{X}$ = 378 ml/1000 m^3) tows were not statistically significant ($p > 0.05$).

Community Structure

Zooplankton abundance by number of individual animals averaged 767 individuals/m^3. Highest abundances were found in the central gulf ($\bar{X}$ = 1009 ind/m^3); the southern region averaged 564 ind/m^3 (Table 2). Copepods were the most important group, with 44.4% of total zooplankton abundance, followed by cladocerans (30.5%), chaetognaths (7.2%), and ostracods (6.5%). The remaining groups represented less than 3% of the total number of zooplankters.

TABLE 1
Zooplankton Biomass in the Gulf of California during March 1983

	Station	Displacement volume (ml/1000 m^3)	Wet weight (mg/m^3)	Dry weight (mg/m^3)
South	14	221.7	172.8	22.07
	18	141.2	94.2	12.17
	20	314.2	239.2	27.02
	24	352.4	201.7	25.99
	27	250.1	209.8	31.28
	34	123.4	64.9	7.96
	36	194.0	165.8	22.95
	38	170.2	87.2	9.63
	41	154.4	133.9	15.33
	44	174.9	117.5	15.07
$\bar{X}$		209.6	148.7	18.95
s		75.5	58.3	7.99
Central	49	257.4	230.9	26.85
	50	446.2	330.3	32.31
	53	289.1	260.1	28.50
	56	239.6	172.7	18.90
	58	266.6	244.2	26.30
	59	440.9	316.5	27.90
	62	1,814.4	1,402.1	103.00
	64	252.8	211.2	23.10
	66	350.5	343.4	32.20
	68	943.2	611.0	37.00
	70	141.9	156.7	13.70
	75	918.0	1,173.0	78.60
$\bar{X}$		532.3	454.3	33.36
s		486.0	410.0	26.20
$\bar{X}$	Total	385.0	315.3	29.01
s	Total	392.0	337.0	21.80

Stations are divided at 27°N lat.

TABLE 2
Zooplankton Taxonomic Group Abundances (ind/m³) at Eleven Selected Stations in the Gulf of California during March 1983

	Stations											
	South						Central					
Taxa	14	18	20	34	36	38	49	53	68	70	75	$\bar{X}$
Siphonophores	2	4	17	—*	5	7	14	34	6	15	22	10
Chaetognaths	33	47	68	34	84	47	54	73	48	30	85	52
Medusae	—	2	4	—	—	2	22	—	1	6	6	4
Copepods	155	87	391	292	297	342	429	550	231	214	710	336
Euphausiids	6	1	2	2	3	—	1	—	—	3	21	4
Amphipods	4	1	11	—	3	—	—	—	—	1	4	2
Cladocerans	240	7	31	90	243	153	421	614	240	155	359	231
Ostracods	35	49	42	46	134	61	53	67	26	30	22	51
Tunicates	3	7	21	2	—	16	13	12	27	25	10	12
Euphausiids (larvae)	—	—	—	—	—	—	10	7	14	36	120	17
Others	27	17	33	27	132	20	42	45	23	3	101	34
Total abundance	505	222	620	493	901	648	1050	1402	616	518	1460	767

*Dashes indicate abundance less than 1 ind./m³

Two species clearly dominated the zooplankton composition during March 1983: copepodite stages of the cyclopoid copepod *Oithona* sp. were most abundant in all samples except at stations 70 and 75, and the cladoceran *Penilla avirostris* was second in abundance at most of the stations. Of the copepods, the calanoida constituted 73% of total abundance, while the cyclopoida registered 26.8%, and harpacticoida only 0.2%.

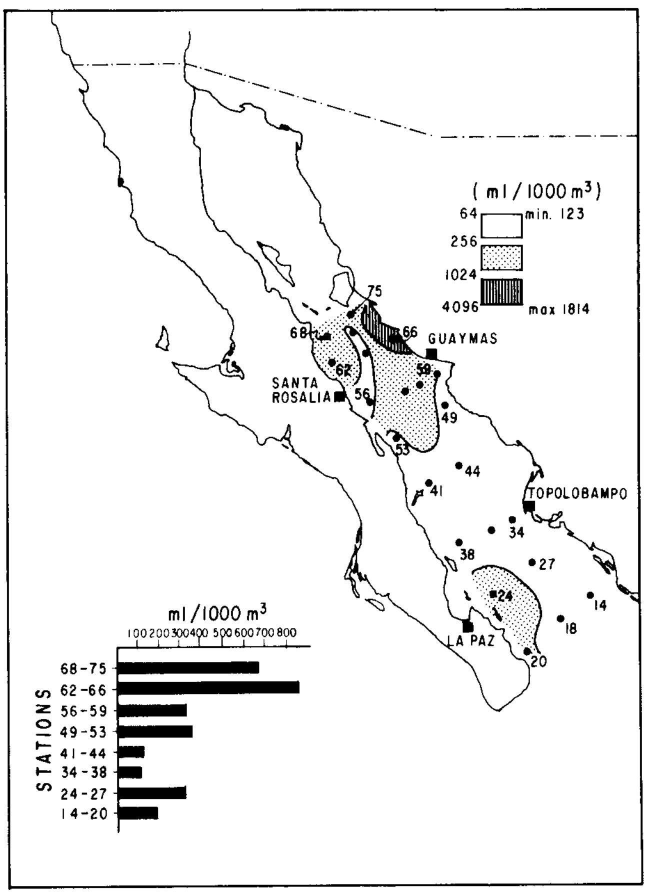

Figure 3. Total zooplankton biomass (displacement volume, ml/1000m³) for the Gulf of California, during March 1983. Bar graph shows average displacement volumes for the lines.

We identified 76 species of copepods (Table 3): 60 were calanoida, 14 cyclopoida, and 2 harpacticoida. The list of copepods reported for the Gulf of California by Brinton et al. (1986) does not include 12 of these species of calanoida, 3 cyclopoida, and the 2 harpacticoida. There was no difference ($p \geqslant 0.05$) in the number of species taken in night or day tows. In terms of relative abundance, among the calanoida, *Pleuromamma gracilis* was the most abundant (12.5%), followed by *Eucalanus subtenuis* (9.4%), *E. pileatus* (6.89%), *Acartia tonsa* (6.86%), and *Clausocalanus arcuicornis* (6.31%).

The calanoid copepod community was represented by species of tropical, equatorial, and temperate affinities (69%, 17%, and 14% relative abundance, respectively) (Figure 4a). We found that 78% of the tropical species were oceanic, 10% were from neritic waters, and 12% preferred coastal waters (Figure 4b). Of equatorial species, those with neritic and coastal affinities represented 25% and 17%, respectively; oceanic species (58%) were the most abundant (Figure 4c). Among the temperate species, 45% were from coastal environments, 37% from neritic waters, and only 18% perferred the oceanic habitat (Figure 4d).

Species diversity (Shannon index) decreased from the mouth (1.25 decits/ind) to the northernmost stations (1.0 decits/ind). Species richness was

TABLE 3
Copepod Species Found in Gulf of California, March 1983

Calanoida
Acartia danae o, trop
A. negligens o, trop
A. tonsa c, temp
Acrocalanus longicornis n, equat
Aetideus armatus n, trop
Calocalanus pavo o, trop
Candacia curta n, trop
**C. aethiopica*
C. catula n, equat
C. pachydactila o, equat
**C. varicans*
Canthocalanus pauper c, equat
Centropages furcatus n, trop
Centropages sp. n, trop
Clausocalanus furcatus o, trop
C. mastigophorus o, trop
**C. arcuicornis* o, trop
C. farrani o, trop
C. jobei o, temp
Calanus pacificus n, trop
C. tenuicornis o, temp
**Euaetideus bradyi* n, trop
**E. giesbrechti* o,
Eucalanus subtenuis o, equat
E. attenuatus o, equat
E. inermis o, equat
**E. mucronatus* o, equat
E. pileatus o, trop
E. subcrassus o, trop
Euchaeta acuta o, trop
**E. marina* o, equat
E. media o, trop
E. longicornis o, equat
Euchirella sp. o, trop
**Ischnocalanus tenuis*
Labidocera acuta n, equat
L. diandra c, equat
Lucicutia flavicornis o, trop
Nannocalanus minor
Paracalanus parvus c, trop
Phaenna spinifera
Pleuromamma abdominalis/edentata o, equat
P. abdominalis/typica o, equat
P. gracilis o, trop
Pontellina plumata o, trop
Pontellopsis sp. o, trop
Rhincalanus nasutus n, trop
**R. cornutus* o, trop
Scolecithricella ctenopus
S. abyssalis o, equat
**S. marginata* o
S. tenuiserrata o, trop
Scolecithrix bradyi o, trop
S. danae o, trop
**Spinocalanus* sp. o
Temora discaudata n, trop
Undinula darwinii o, equat
U. vulgaris n, trop
**Xanthocalanus* sp.

Cyclopoida
Corycaeus brehmi
C. clausi
C. flaccus
C. latus
C. lautus
C. ovalis
C. robustus
C. specious
Copilia mirabilis
Oithona spp.
**Oncaea media*
**O. venusta*
**Sapphirina darwinii*
S. nigromaculata

Harpacticoida
**Clytemnestra* sp.
**Microsetella norvegica*

*Species reported for the first time in the Gulf of California.
The abbreviations signify favored habitat and biogeographic affinities following Fleminger's categories (Fleminger 1967; and Fleminger in Brinton et al. 1986).
Habitat: c = coastal waters; n = neritic waters; o = oceanic mixed layer.
Biogeographic affinities: temp = temperate; trop = tropical to subtropical; equat = equatorial.

also greater at the southern gulf stations (29 to 37 species) than in the central area (18 to 30 species) ($p < 0.05$). Copepod species richness presented a positive correlation with the sea-surface temperature ($r = 0.83$; $p < 0.01$) and negative correlation with salinity ($r = -0.63$; $p < 0.01$); no significant correlations were obtained between the diversity index and temperature or salinity. Two very distinct faunistic associations (Figure 5) were evident in the grouping analysis: a group was distinguished at six stations in the southern gulf, and there was a central group at the stations north of 27°N.

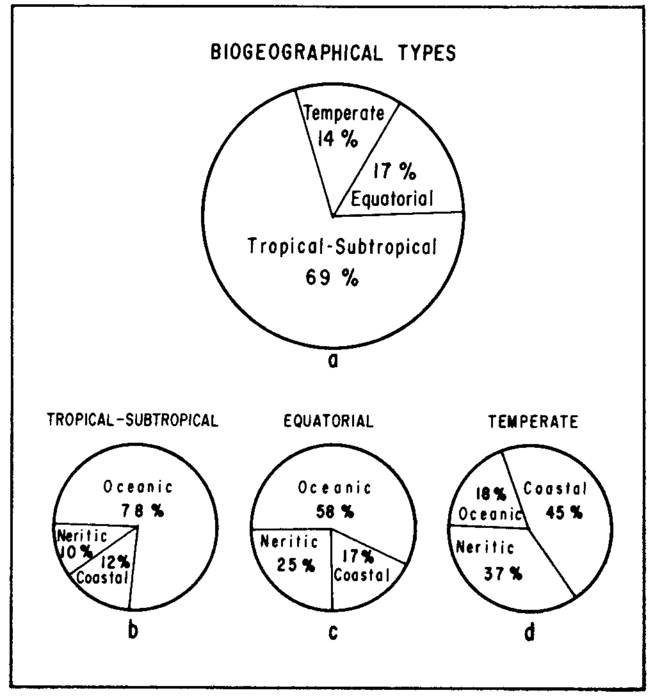

Figure 4. Biogeographical (*a*) and habitat qualities (*b–d*) of Gulf of California calanoid copepod fauna.

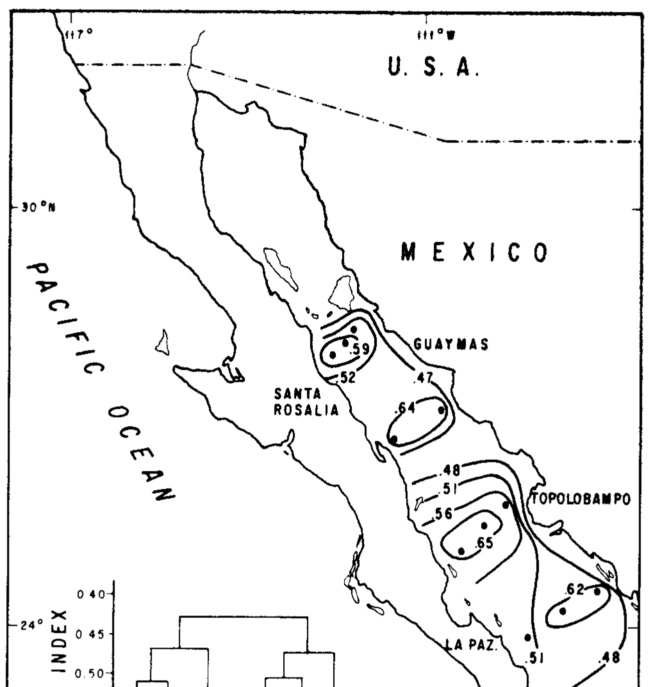

Figure 5. Spatial distribution of station similarity.

DISCUSSION

Temperature data indicates that unusual oceanographic conditions were recorded in the gulf during 1983 (Robles-Pacheco and Marinone 1987). For example, at 10-m depth, temperature readings were generally 2°C warmer than those registered by Brinton and Townsend (1980) during April 1957 in the mid-gulf region (between Isla Tiburon and 26°–27° N), and more than 3° in the eastern side at the mouth of the gulf.

Zooplankton biomass in the Gulf of California was not greatly decreased during the 1982–83 El Niño event, in contrast to that reported for Peru waters (Chávez et al. 1984) and the California Current (McGowan 1984). Our displacement volume values were of the same order as those reported by Brinton et al. (1986) for the Gulf of California during 1956–57 (relatively cold years in the California Current) and are comparable to those found in productive regions of the California Current in the coastal waters of California and Baja California (Brinton et al. 1986). Phytoplankton biomass and primary productivity rates in the gulf during spring 1983 and 1984 were higher than during normal years (Valdéz-Holguin and Lara-Lara 1987; Lara-Lara and Valdéz-Holguin 1987).

Although zooplankton biomass was not reduced, the community structure appeared to be affected. For example, the two dominant species throughout the gulf were the cyclopoid *Oithona* sp. and the cladoceran *Penilla avirostris*. The great abundance of these two species may have resulted from the domination (> 75%) by the nannoplankton (cells < 20 μm) of the phytoplankton biomass during this period (Valdéz-Holguin and Lara-Lara 1987). Experimental studies by Gore (1980) and Poulet (1978) have shown that these two species feed mainly on small particles. Large-particle grazers like *Calanus pacificus* (Frost 1972) were abundant only in the northernmost central region of the gulf, where microplankton dominated (Valdéz-Holguin and Lara-Lara 1987). This suggests that the phytoplankton size structure could have directly affected the population structure of copepods during March 1983.

The 12 species of calanoid copepods found in March 1983 and not reported by Fleminger (in Brinton et al. 1986) occurred in low abundances. Of these 12 species, 7 have been reported by Alameda de la Mora (1980) for the Gulf of Tehuantepec, and 10 by Grice (1961) for the Pacific equatorial waters region. The 3 cyclopoid and 2 harpacticoid species found in the gulf but not reported by Fleminger (in Brinton et al. 1986) also were reported by Alameda de la Mora (1980) from the Gulf of Tehuantepec. We suggest that copepod population structure is affected only during strong El Niño events because of the large invasion of tropical-subtropical waters. We also found that, in contrast to results reported by Manrique (1977) from a long-term study of zooplankton populations off Guaymas, the number of species from oceanic habitats doubled, another possible effect of El Niño events.

Two main copepod species assemblages were defined. In the first group there was a relatively large contribution of species with temperate affinities; this group occurred mainly in the central region of the gulf, where tidal mixing and upwelling are common and cause the cool water in this area (Badán-Dangon et al. 1985). The second assemblage comprised stations south of 27°N, where tropical and equatorial species were dominant. The species richness distribution, with a maximum in the southern gulf, agrees well with the two assemblages found. The two copepod assemblages correspond to the division of the gulf by Valdéz-Holguin and Lara-Lara (1987) into two zones: (1) the central gulf, in which, in several stations, the large contribution to total chlorophyll *a* and primary productivity was due to the microplankton size fraction (cells > 20 μm), associated with a particularly dynamic environment with high turbulence; and (2) the southern gulf, in which most of the chlorophyll *a* and primary production contribution was by the nannoplankton fraction (cells < 20 μm); this is related to a relatively stable environment with more oceanic influence.

We conclude that during our sampling period, El Niño had little effect on zooplankton biomass in the Gulf of California. The zooplankton population structure was, however, altered to some degree.

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