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Euphausiacea and Copepoda of the oceanic front off Cabo San Lucas B.C.S. México (August 1988)

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Abstract: The distribution, abundance, and species composition of Euphausiacea and Copepoda in relation to the environmental conditions were studied. Material was collected from nine stations on a transect that ran from offshore the southwest coast of Baja California Sur (21° 05.4 N, 112° 35.4 W) to the coast of Sinaloa (23° 44.8 N, 107° 37.5 W). In this area an oceanic front separates the waters of the Gulf of California from those of the Pacific Ocean. Tropical species of Euphausiacea *(Euphausia eximia, E. distinguenda, E. tenera, Nematoscelis gracilis,* and *E. diomedeae)* were abundant at the mouth of the Gulf of California. The first four species were found in reproductive condition. Most Copepoda were temperate-tropical. *Pleuromamma abdominalis, Paracalanus parvus,* and *Euchaeta marina* were the most abundant, together with two transitional species, *Calanus pacificus* and *Rhincalanus nasutus.* Species composition and diversity was different on each side of the front. Abundance of both groups was related mainly to water temperature.

Key words: Euphausiacea, Copepoda, distribution, oceanic front, Baja California Sur.

Oceanic fronts are bands along the sea surface where water density changes abruptly. These are caused by thermal or saline conditions induced by horizontal and vertical flow (Griffiths 1965, Owen 1981, Franks 1992). Sometimes these fronts represent a "hydrographic wall" that separates different water masses and their inherent phytoplanktonic and zooplanktonic communities. These oceanic fronts are convergence zones where species concentrate, particularly planktonic organisms moved by the currents and turbulent flows (Yamamoto *et al.* 1981, Fernández *et al.* 1991, Franks 1992).

According to Griffiths (1965), Longhurst (1967), and Legeckis (1978), the most conspicuous oceanographic feature of the Gulf of California's entrance is the oceanic front near Cabo San Lucas, Baja California Sur. This front is strongest in spring, when the California Current consists mainly of cold water, persists throughout the summer and is weakest in the fall or winter (Griffiths 1965, Longhurst 1967, Roden 1971). Early studies reported the influence of oceanic fronts on the abundance of planktonic organisms like Copepoda, Euphausiacea, Siphonophorae, Chaetognatha, and Larvacea (Griffiths 1963, 1965). However, these studies failed to show the species composition and the biogeographical affinities of the species at the front. In this study, we describe the species composition, distribution, and abundance of Euphausiacea and Copepoda as a function of the physico-chemical and biological parameters recorded along a transect at the entrance of the Gulf of California and off the Southwest coast of Baja California.

MATERIAL AND METHODS

Nine stations, each separated by 20 nautical miles, were sampled along a transect perpendicular to the Mexican Pacific coast. This transect ran from off the SW coast of Baja California Sur (21° 05.4 N, 112° 35.4 W) to the coast of Sinaloa (23° 44.8 N, 107° 37.5 W) (Fig. 1). Zooplankton samples were collected, from 3rd to 5th August 1988, with two nets (333 µm and 505 µm mesh) mounted on a Bongo frame towed obliquely from 210 m to the surface (Smith and Richardson 1977). The volume of strained water by each net was determined using a General Oceanic flowmeter. At each station, water samples were taken at 0, 10, 25, 50, 100, 200, 300, 400, 500, and 600 meters with Niskin bottles in order to measure water temperature (°C), salinity (°/oo), and dissolved oxygen ($ml \cdot l^{-1}$). Salinity was determined with a Beckman salinometer (Brown and Hamon 1961). The dissolved oxygen was determined by the modified Winckler method (Strickland and Parson 1960). Phytoplankton cell counts were performed using an inverted microscope in 10, 25, 50, or 100 ml settling chambers according to Utermöhl (1958). Nanophytoplankton (< 20 µm) and microphytoplankton (>20 µm) fractions were analyzed separately. The 505 µm net zooplankton samples were analyzed. Samples were split with a Folsom plankton splitter in aliquots of 1/2, 1/4, and 1/8 (Brinton 1979). Zooplankton displacement volumes were estimated following Beers (1976).

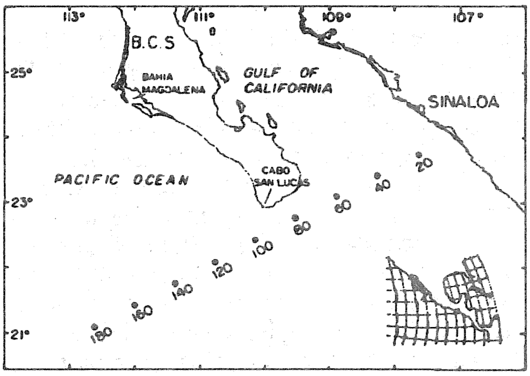

Fig. 1. Area covered by the CICIMAR 8807 oceanographic expedition.

Calyptopis, furcilia, juveniles, and adults of Euphausiacea were identified following Boden *et al.* (1955) and Brinton (1975). Sexual maturity of Euphausiacea was determined by identifying the spermatophore of the males and identification of the spermatophore adhering to the thelycum of the female or their internal ripe ovary and ovigerous sacs. Copepoda were identified following the keys of Grice (1961) and Fleminger (1975). Only adults were considered. Results are given as number of organisms per 1000 m^3 of strained water. Euphausiacea and Copepoda species were grouped biogeogrphically according to Brinton *et al.* (1986). The Simpson and Shannon-Wiener diversity and dominance indexes were also calculated for both groups according to Brower and Zar (1979).

RESULTS

The thermo-saline vertical structure showed that from stations 80 to 120 there was a strong horizontal temperature gradient (24 to 28°C) that separated the environmental conditions of the upper 150 m of the waters of the mouth of Gulf of California from the waters of the offshore southwest coast of Baja California. This gradient was the oceanic front. Temperatures as high as 28 °C in the upper 100 m are typical of the mixing layer in the Gulf of California. Temperature off the west coast of Baja California was ≤ 24°C at the same depth. The thermocline was found between 10 and 75 m offshore and between 100 and 120 m at the mouth of the Gulf of California (Fig. 2a). A strong horizontal saline gradient (33.8 to 34.2 °/oo) was observed between stations 80 and 120, separating the mouth of the Gulf of California (with salinity of 34.2 to 34.4 °/oo) from the offshore region (salinity < 34 °/oo) (Fig. 2b). The oxycline, represented by a 2.6 to 1 $ml \cdot l^{-1}$ gradient, had a distribution inverse to the thermocline. The oxycline was found deeper at the southwest coast of Baja California (120 to 170 m) than at the mouth of the Gulf (50 to 75 m) (Fig. 2c).

The oceanic front was identified by means of temperature-salinity diagrams. Stations 180 to 140 show similar patterns, with an inflection point at 100 m, indicating the presence of two water masses (Fig. 3a). The stations at the oceanic front, 80 to 120, showed the strongest stratification in temperature. The salinity was homogeneous throughout the water column from the surface to 200 m where there is an inflection point (Fig. 3b). Stations 20 to 60 showed a different distribution pattern, which represented tropical water in the first 200 m (Fig. 3c).

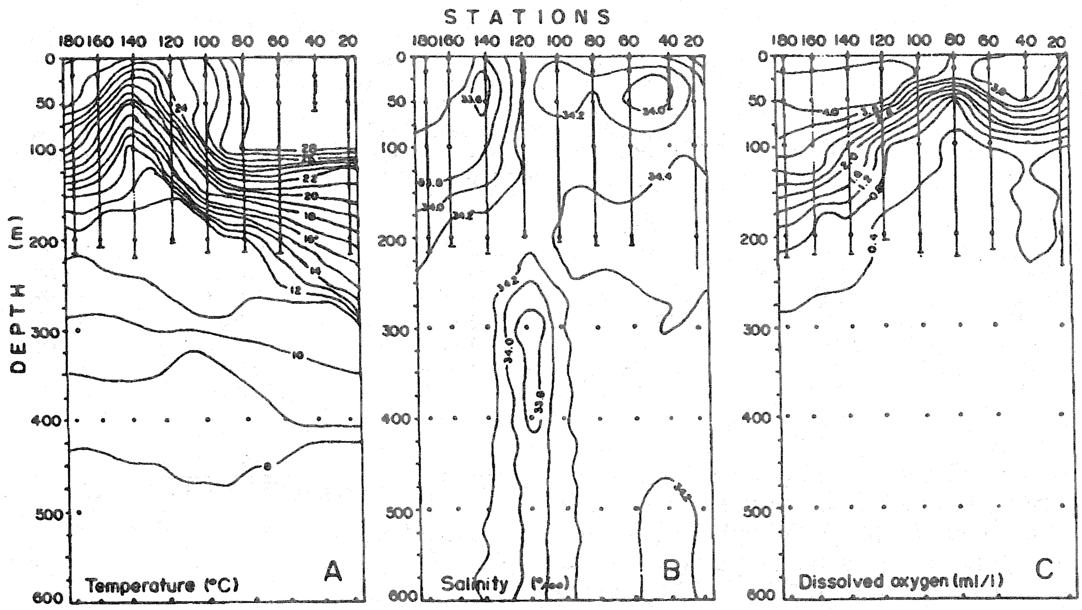

Fig. 2. Vertical profiles of temperature °C (a), salinity ‰ (b) and dissolved oxygen $ml \cdot l^{-1}$ (c). Maximum depth of the Bongo net tow at each station is indicated with a vertical line.

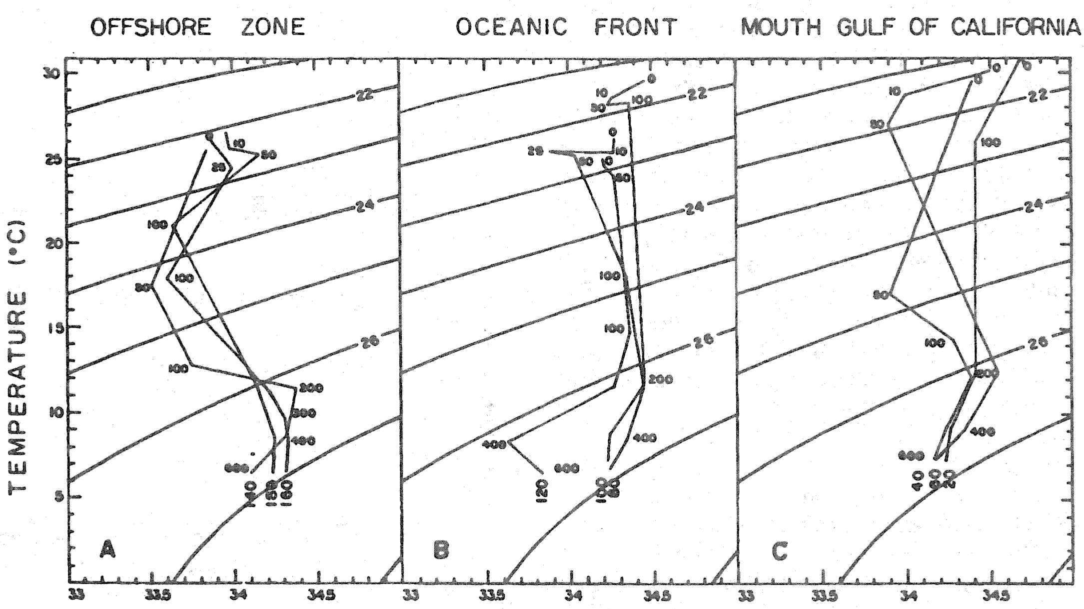

Fig. 3. Temperature-salinity diagrams for each station for the offshore zone (a), oceanic front (b) and mouth of Gulf of California (c).

TABLE 1

Values of abundance (org. 1000 m⁻³), index of diversity and dominance for Euphausiacea and Copepoda during August 1988

Station	Number of species	Abundance org. 1000 m^{-3}	Shannon-Wiener Index (H') Bits/ind.	Dominance Index	Simpson Index (S')
180	21	4514	2.6378	0.2351	0.7649
160	32	9154	2.7519	0.2492	0.7508
140	25	2960	3.2313	0.1525	0.8475
120	24	6187	3.3194	0.1524	0.8476
100	28	19254	3.1401	0.1685	0.8315
80	29	13865	3.5453	0.1074	0.8926
60	27	16064	4.0160	0.0734	0.9266
40	27	8114	3.4995	0.1324	0.8676
20	34	32021	3.1661	0.1781	0.8219

The abundance of nano- and microphytoplankton increased from offshore (< 5,000 cells l^{-1}) to station 80 (> 10,000 cells l^{-1}) (with the exception of the nanophytoplankton at the offshore station 180, 11,000 cells l^{-1}), followed by a sharp decrease at the mouth of the Gulf (Fig. 4 a-b). The highest zooplanktonic biomass (225 ml·1000 m^{-3}) was found offshore (station 160). This biomass decreased abruptly toward the southwest coast of Baja California then increased in the Gulf of California where values varied between 100 and 150 ml·1000 m^{-3} (Fig. 4c).

Eleven species of Euphausiacea were identified; four transitional (TS), two temperate-tropical (TETR), and five tropical (TR). The most abundant tropical species were *Euphausia eximia* , *E. distinguenda*, and *E. lamelligera*. The occurrences of each species together with indications of species abundance greater than the mean and the presence of early larval stages (calyptopis) are shown in Fig. 5 using a method proposed by Brinton (1979). Only *E. eximia* was found at all stations. The reproduction of the Euphausiacea was evidenced by the presence of calyptopis stage and adults in the reproductive phase. At the mouth of the Gulf, all tropical species, except *N. gracilis*, had recently reproduced. Only *N. flexipes*, *E. tenera*, and *E. eximia* showed evidence of reproduction in the offshore region. Except for *E. eximia*, Euphausiacea were scarce in the area where strong gradients of temperature and salinity were recorded (stations 100 and 120). There were high concentrations of calyptopis and furcilia of this species at the oceanic front (Fig. 5).

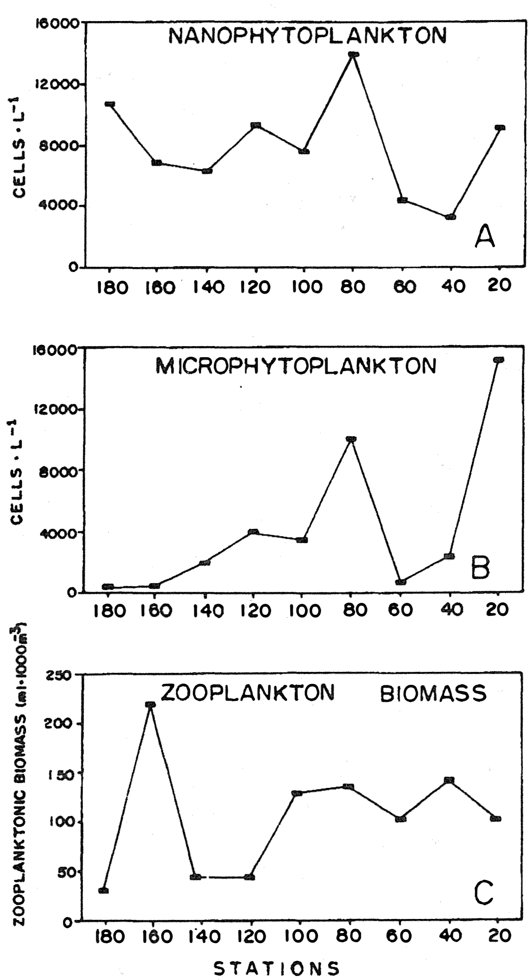

Fig. 4. Abundance of nanophytoplankton (a), and microphytoplankton (b) in cells l^{-1}, zooplankton biomass (c) in ml·1000 m^{-3}.

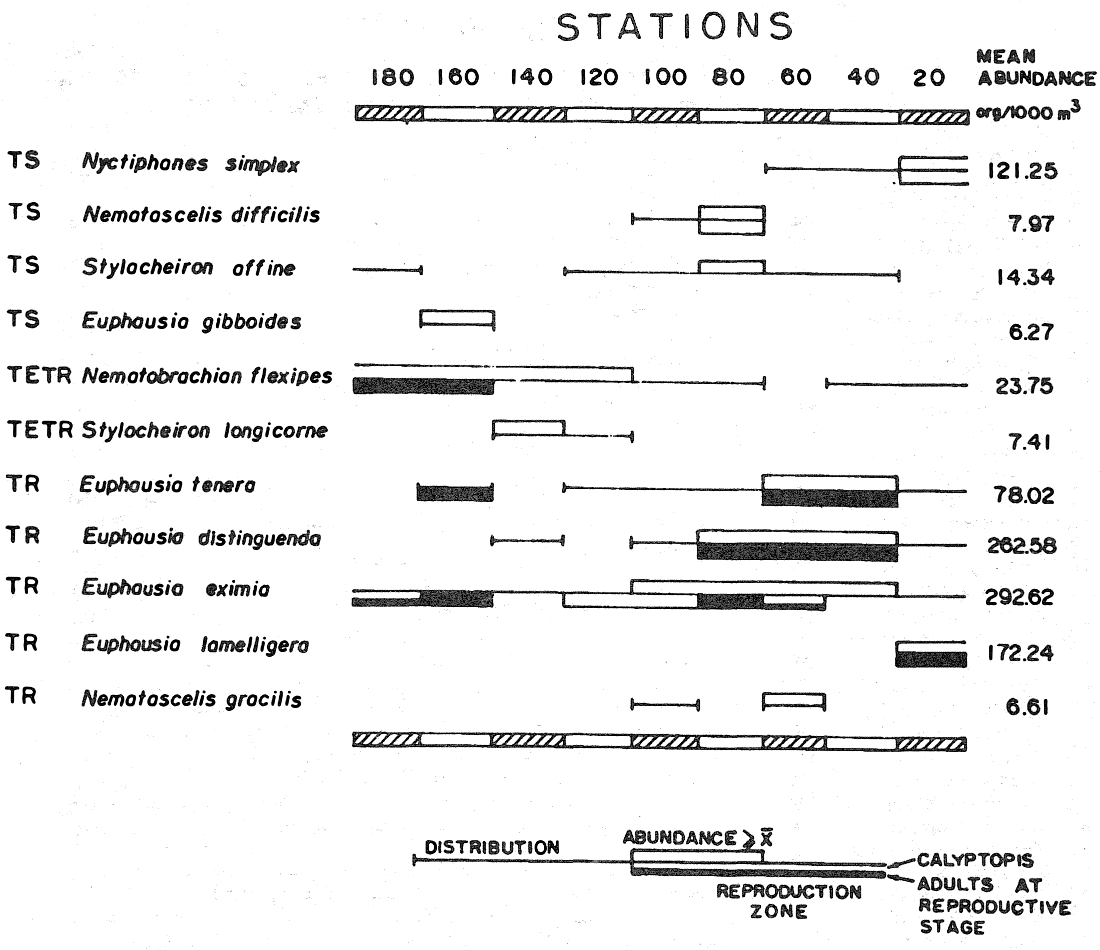

Fig. 5. Distribution and abundance of Euphausiacea grouped by biogeographical affinities, TR= tropical, TETR= temperate-tropical and TS= transitional, with the stations where the abundance was higher than the mean abundance of each species. The regions where reproductive activity took place are evidenced by calyptopis (white) and adults in reproductive phase (black).

Fifty one species of Copepoda were identified, four to genera level, of which 3 were temperate species (TE), 30 tropical (TR), 7 temperate-tropical (TETR), 5 equatorial (EQ), 4 transitional (TS), and 6 were unassigned (UN). The most abundant and most widely distributed species were *Paracalanus parvus*, *Pleuromamma abdominalis*, and *Euchaeta marina* (TETR), and *Calanus pacificus* and *Rhincalanus nasutus* (TS). The abundance of Copepoda was mainly associated with the tropical environmental conditions observed at the mouth of the Gulf of California where the abundance of 27 species was greater than their respective mean abundance for the nine stations of the transect. Eighteen species were more abundant at the offshore stations (Fig. 6). The Shannon-Wiener diversity and dominance indexes were between 2.6 to 4 bits/ind. The highest diversity values were found at the oceanic front and the mouth of the Gulf of California. The dominance index shows an pattern inverse to the diversity (Table 1).

DISCUSSION

The area between stations 80 and 120 can be considered the oceanic front that divides the

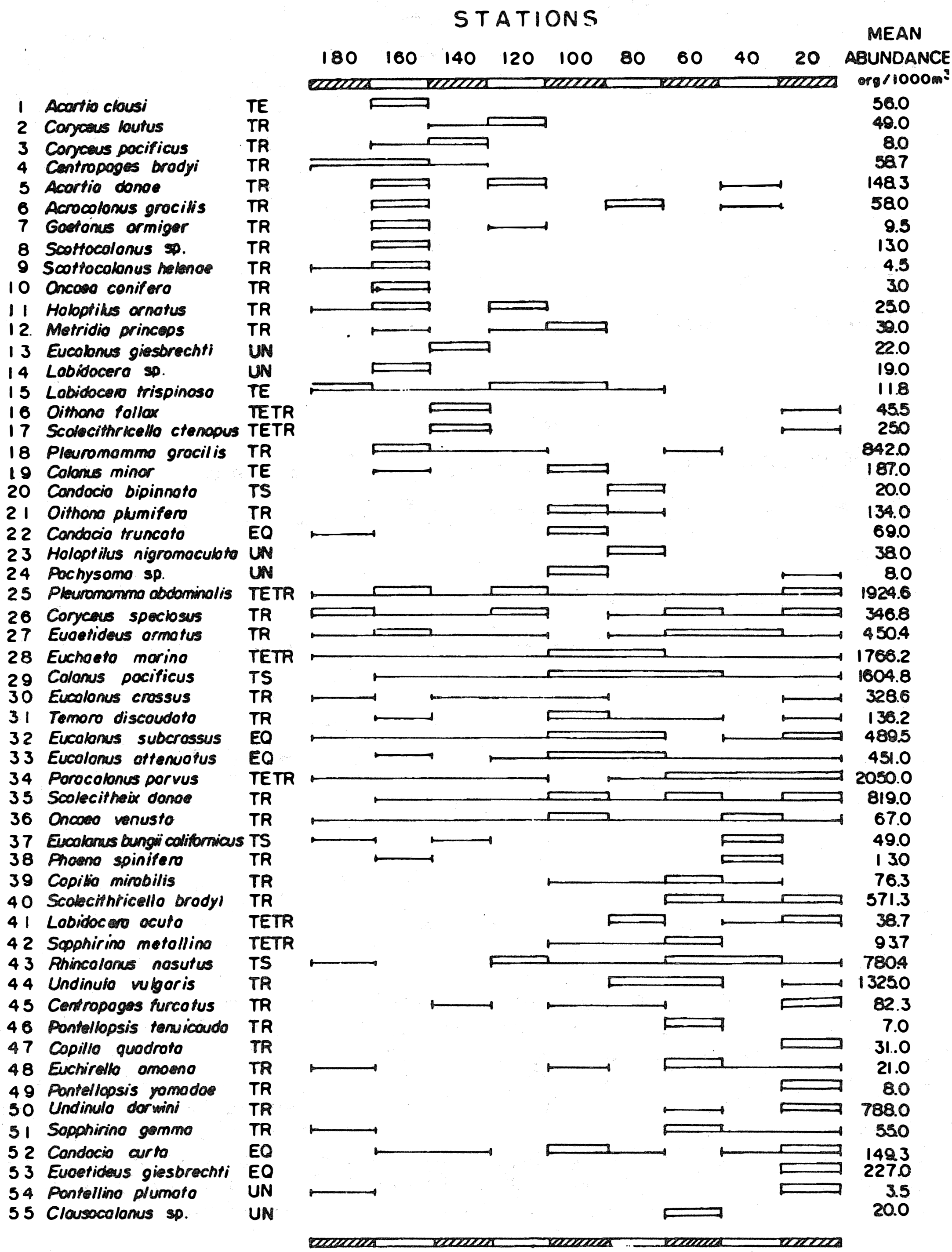

Fig. 6. Distribution and abundance of Copepoda grouped by biogeographical affinities, TE= temperate, TR= tropical, TETR= temperate-tropical, TS= transitional, EQ= equatorial, and UN= unassigne . Notice the stations whe e the abundance was higher than the mean abundance of each species along the transect.

environmental conditions of the offshore region and those of the mouth of the Gulf of California. This follows from the analysis of the data for phytoplankton (both fractions), zooplankton biomass, temperature, salinity, and dissolved oxygen. All of them follow variable patterns that emphasize the different environmental conditions on each side of the oceanic front. The diversity indexes (H' and S') were higher at the mouth of the Gulf of California than along the offshore part of the transect, indicating different communities of species on each side of the front.

Using temperature-salinity diagrams, we corroborated these different areas. According to Roden (1971) and Brinton (1981), salinity below 34 °/oo found in the first 200 m in the offshore region indicates water of the California Current. The temperature and salinity observed in the offshore region of the transect correspond to the values of this current. Stations 20 to 60 showed a different distribution pattern that represented tropical water in the upper 200 m. These results coincide with those of Baumgartner and Christensen (1985), who reported that the highest salinity recorded close to the surface at the mouth of the Gulf of California indicated tropical surface water from the south, with temperatures up to 25°C and salinity between 34.2 and 34.6 °/oo.

Griffiths (1963, 1965) reported the abundance of Copepoda and Euphausiacea at the oceanic front off Cabo San Lucas, without identifying species. In the present study, four patterns of distribution of Euphausiacea and Copepoda were observed along the transect through the oceanic front off Cabo San Lucas: 1) Species which occurred abundantly offshore in cold water (< 24° C) and salinity below 34 °/oo. These populations decreased gradually towards the front and finally disappeared in warm water (> 28° C at the mouth of the Gulf of California); 2) Species exhibiting the reverse pattern; abundant in high temperature and salinity waters (> 34.2 °/oo), with abundance decreasing in offshore waters; 3) Species evenly distributed over the entire transect; 4) Species which showed their maximum density at the frontal zone.

The majority of the Euphausiacea were tropical and temperate-tropical. Their reproductive centers were found on both sides of the oceanic front. This suggests that the oceanographic conditions at the front exert an important influence on the reproductive activity of these species. At the mouth of the Gulf of California, the minimum oxygen layer (< 1 $ml \cdot l^{-1}$) was between 75 and 100 m where the highest temperature (> 28°C) was observed in the first 100 m. These were favorable environmental conditions for the majority of the tropical species, but not for the others. According to Brinton (1979) and Longhurst (1985), tropical Euphausiacea, like *E. distinguenda, E. tenera, N. gracilis,* and *E. eximia,* undergo extensive vertical migrations and are well adapted to the tropical conditions and low oxygen concentration that prevail in the Eastern Pacific Ocean. The species mainly found on the warm side of the oceanic front (including adults in a reproductive phase) agree with the species composition of Euphausiacea reported for this region by Brinton and Townsend (1980) and Sánchez-Osuna and Hendrickx (1984). The Euphausiacea *Stylocheiron affine* and *S. longicorne,* which do not migrate and are unable to tolerate low oxygen content (Brinton 1967, 1979), were scarce and were only found at the oceanic frontal zone where the minimum oxygen layer was below 100 to 200 m. It is possible that the oceanic front in Cabo San Lucas acts as a hydrographic wall for the transitional species *N. difficilis* and *N. simplex,* which are the most abundant species throughout the Gulf of California (Lavaniegos-Espejo *et al.* 1989). When the oceanic front disappears, the new oceanographic condition might allow mixing of the populations of *N. difficilis* and *N. simplex* from both sides of the peninsula of Baja California (Brinton and Townsend 1980).

The four types of distribution mentioned above were recognized quite clearly for the Copepoda. Tropical species were always the most abundant at all stations of the transect. The Copepoda species reached a maximum abundance at the oceanic front and at the mouth of the Gulf of California. Seasonal changes in the dominant species of Copepoda were reported along the west coast of Baja California: *Eucalanus subcrassus* (EQ), *Paracalanus parvus* (TETR) in FebruaryMarch; *Calanus pacificus* (TS) and *Pleuromamma abdominalis* (TETR) in May; and *Undinula vulgaris* (TR), *Eucalanus attenuatus* (EQ) in September

(Cervantes-Duarte and Hernández-Trujillo 1989). This shows biogeographically different communities according to t e seasonal variability of the environmental conditions reported by Lynn and Simpson (1987). In the study area, the trend appears to be similar at least as far as biogeographic affinities are concerned.

The oceanic front was featured by an abrupt increase of phytoplankton. This increase in primary production may be a possible response to the turbulent flows that frequently occur in these frontal systems. High primary production at oceanic fronts in other regions in the world was also found by Yamamoto *et al.* (1981) and Franks (1992).

The high abundance of phytoplankton at the oceanic front does not coincide with the high abundance of Copepoda or Euphausiacea found mainly in the warm water of the transect. To explain this, it is necessary to consider the effect of the environmental conditions and physiological time scales of the spreading and attenuation of the biomass peak as its energy propagates through various trophic levels. A pulse of nutrients forced into the euphotic zone by a physical process (*e.g.*, wind-driven upwelling) will be converted into phytoplanktonic biomass over a period of days, and into crustacean biomass over weeks (Franks 1992). During this period, the original biomass peak spreads throughout the community and is translocated by the prevailing currents of the region. Thus, the highest phytoplanktonic abundance found at oceanic fronts may result in a strong non-correlation with the zooplanktonic biomass, particularly during the highest abundance of Copepoda and Euphausiacea.

According to the oceanic front classification described by Franks (1992), the oceanic front off Cabo San Lucas may be considered as one front between different water masses caused mainly by changes in salinity. This type of front showed a strong seasonal variation, though fronts are typically relatively stable over small time scales showing little change during periods of days. The time variations of this type of front are on a large scale relative to phytoplankton regeneration rates (Franks 1992). For these reasons, we would expect the phytoplanktonic abundance to correlate well with the physical system. This was evidenced by the abrupt rise of phytoplankton abundance in the oceanic frontal zone.

Griffiths (1965) and Longhurst (1967) suggested that the highest concentrations of all planktonic organisms that occurred at the oceanic front off Cabo San Lucas and other similar fronts are mainly caused by physical aggregation, the mixing of the neighboring water masses, more than by local production or population development caused by an eutrophication processes. T e data obtained partially supports this hypothesis, because a variability of the abundance and species composition of Copepoda and Euphausiacea along the transect was observed.

According to Griffiths (1963, 1965), Wyrtki (1964, 1965, 1967), and Longhurst (1967), the oceanic front off Cabo San Lucas begins to develop during May, becoming strongest in July and August, and weakest through the fall and winter. Longhurst (1967) reported that after August the northward moving core of equatorial water may underlie a coastal undercurrent bringing tropical surface water up from the south and into the mouth of the Gulf of California and along the southwest coast of the peninsula, frequently reaching Bahía Magdalena. During this period the oceanic front off Cabo San Lucas disappears. This northward movement becomes particularly intense during years recognized as ENSO events (Baumgartner and Christensen 1985).

This hypothesis suggests that the oceanic front off Cabo San Lucas is a seasonal phenomenon of the southern California Current system, with the consequent increase in the number of species of Euphausiacea and Copepoda at the mouth of the Gulf of California and off the southwest coast of the peninsula of Baja California. This may be the most important influence on the distribution and abundance of these organisms. Based on the data from this study, we believe that the oceanic front present in August 1988 apparently was in the transition phase between its origins and its northward movement as a part of the seasonal current pattern reported by Griffiths (1963, 1965), Wyrtki (1964, 1965, 1967), Longhurst (1967), Roden (1971), and Lynn and Simpson (1987). Support of this idea is provided by the biogeographical affinity of the dominant species along the transect as well as their abundance. We noted obvious changes in some characteristics of the community (*e.g.*, diversity, abundance) that could be associated with the origins of this physical phenomenon, especially in this temperate-tropical transition zone.

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RESUMEN

Se estudió la distribución, abundancia y composición de especies de los eufáusidos y copépodos en relación con las condiciones ambientales a lo largo de un transecto perpendicular a la costa mexicana del Pacífico. Este cubrió desde la parte oceánica de la costa occidental de Baja California Sur (21° 05.4 N, 112° 35.4 W) hasta la costa de Sinaloa (23° 44.8 N, 107° 37.5 W). Un frente oceánico separó el agua del Golfo de California y del Océano Pacífico. Los eufáusidos tropicales *Euphausia eximia*, *E. distinguenda*, *E. tenera*, *Nematoscelis gracilis* y *E. diomedeae* presentaron sus mayores abundancias en la boca del Golfo de California, encontrándose en estado de reproducción las cuatro primeras especies. La mayoría de las especies de copépodos fueron de afinidad biogeográfica templado-tropical. Las que dominaron fueron *Pleuromamma abdominalis*, *Paracalanus parvus* y *Euchaeta marina*. Dos especies transicionales, *Calanus pacificus* y *Rhincalanus nasutus*, fueron las más abundantes. La composición específica y la diversidad de especies fue diferente en ambos lados del frente oceánico, la abundancia de ambos grupos presentó una asociación principalmente con la temperatura.

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