Seasonal depth distribution of the crystal shrimp, *Penaeus brevirostris* (Crustacea: Decapoda, Penaeidae), and its possible relation to temperature and oxygen concentration off southern Sinaloa, Mexico

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With an estimated value of 30 million U.S. dollars, red or crystal shrimp, *Penaeus brevirostris*, is the sixth most important fishery resource in Mexico (Edwards, 1978; Rodriguez de la Cruz, 1981; Hernandez-Carballo, 1988). However, until recently very little was known about its general biology, ecology, and seasonal variation in relative abundance.

Penaeus brevirostris is a species limited to the eastern tropical Pacific off northern Sinaloa, Mexico, to southwest of Cabo Blanco, Peru, and Islas Galapagos (Perez-Farfante, 1988). In Mexico, it is normally fished in two areas: from southern Sinaloa to northern Nayarit and in the Gulf of Tehuantepec (Edwards, 1978; Hernandez-Carballo, 1988). *Penaeus brevirostris* occupies a wide range of depths. Postlarvae are found near the shore and in coastal lagoons (Calderon-Perez and Poli, 1987). Preadults and adults have been found at depths of 45–90 m off Mexico (Rodriguez de la Cruz, 1981; Hendrickx et al., 1984; Chapa-Saldaña[1]) and Peru (Cobo and Loesch, 1966) and at 3 m in estuarine channels (esteros) in Ecuador (Loesch and Avila[2]). The deepest record of crystal shrimp is 183 m (Perez-Farfante, 1988). In spite of its rather wide depth distribution, *P. brevirostris* is usually found deeper than *P. stylirostris* (estuarine and marine to 27 m, rarely to 45 m; Rodriguez de la cruz, 1981; Hendrickx, 1986; Perez-Farfante, 1988), *P. vannamei* (estuarine and marine to 36 m) (Rodriguez de la Cruz, 1981; Hendrickx, 1986) and *P. californiensis* (estuarine and marine to 50 m, rarely to 180 m) (Perez-Farfante, 1988). Occasionally, it is found co-existing with the latter (Chapa-Saldaña[1]). In two separate fishing surveys during the closed (nonfishing) season, the species was not found on traditional trawling grounds off Sinaloa and Nayarit (Barreiro and Lopez-Guerrero, 1972; Magallon-Barajas and Jacquemin-Poulet, 1976).

The purpose of this study is to determine whether the distribution of *P. brevirostris* varies seasonally with respect to depth (presumably, because of the bathymetric movements of the species) and to relate its distribution to temperature and oxygen variation near the bottom.

Material and methods

The study area (Fig. 1) lies at the entrance of the Gulf of California (Alvarez-Borrego, 1983) off the mouths of the Piaxtla River to the north (23°42'N, 106°49'W) and the Teacapan-Agua Brava Lagoon complex to the south (22°32'N, 105°45'W). It has been described as a transitional zone that has a complex and dynamic structure (Alvarez-Borrego, 1983). At the surface, there are three different types of water: 1) cold California Current water of low salinity (S ≤34.6 ppt) which flows southward along the west coast of Baja California; 2) warm eastern tropical Pacific water of intermediate salinity (34.65 ppt ≤ S ≥34.85 ppt) which flows into the area from the southeast; and 3) warm, highly saline (S ≥34.9 ppt) Gulf of California water (Roden and Groves, 1959; Stevenson 1970; Alvarez-Borrego, 1983). This region experiences upwelling events during the spring (Roden, 1964; Roden and Groves, 1959; Alvarez-Borrego and Schwartzlose, 1979). The oxygen content in the upper 100 m layer is greater than 1 mL/L; below 150 m the oxygen concentration falls to less than 0.5 mL/L and at intermediate depths (500–1,100 m) oxygen may be undetectable by the Winkler method (Alvarez-Borrego et al., 1978).

[1] Chapa-Saldaña, H. 1956. La distribución comercial de los camarones del noroeste de México y el problema de las artes fijas de pesca. Dir. Gral. de Pesca e Industrias Conexas, Sría. de Marina, México, D.F., 87 p.

[2] Loesch, H., and Q. Avila. 1966. Observaciones sobre le pesquería de camarones juveniles en dos esteros de la costa de Ecuador. Bol. Cient. y Tecn. INP del Ecuador. 1, 30 p.

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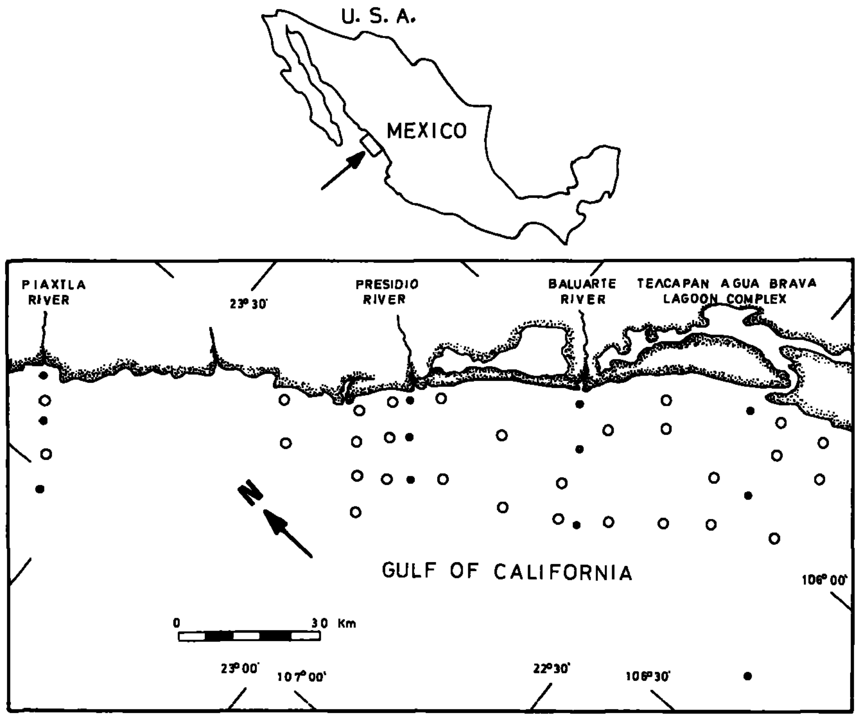

Figure 1

Study area (1981–86) located off the mouths of the Piaxtla River and the Teacapan-Agua Brava lagoon complex, Mexico. Twenty-nine stations from the CRIP-INP cruise series are denoted by empty circles. Stations from the BIOCAICT series are indicated with solid circles.

Seventeen survey cruises were made by the Centro Regional de Investigaciones Pesqueras of the Instituto Nacional de la Pesca (CRIP) on board commercial shrimp trawlers during the years 1981, 1982, 1984, 1985, and 1986, and four cruises were made by the Universidad Nacional Autonoma de Mexico between November 1985 and August 1986 on board the vessel *MARSEP XI* (BIOCAICT cruises). On all cruises, a pair of 22.9-m otter trawl nets was used. The nets have a progressively reducing mesh size from 6.4 cm on the body of the net to 3.8 cm at the cod end. Eleven sampling stations of the BIOCAICT series were located on four transects perpendicular to the coast line off the mouths of Piaxtla, Presidio, and Baluarte rivers and off the Teacapan-Agua Brava lagoon complex. Sampling depth varied from 9 to 90 m. Data from the more extensive CRIP cruises were selected to match the location of the BIOCAICT series (Fig. 1).

In all BIOCAICT cruises, surface, mid-water, and bottom water samples were taken with 8-L niskin bottles. Temperature was measured in situ with reversing thermometers to the nearest 0.1°C. Dissolved oxygen (DO) was determined by using a modification of the Winkler method (Strickland and Parson, 1972). At each sampling station, shrimps were sorted, identified, and counted for each catch. Color in fresh animals (Chapa-Saldaña[1]) proved to be a very reliable character for species identification.

CRIP monthly samples from 29 stations within a depth span of 9–80 m were averaged at intervals of 18 m (10 fathoms), except for the initial interval of 9 m (9–18 m), and pooled across years into four bimonthly periods. The term sample refers to the number of shrimp per twin net haul divided by the number of hours (ind./h) at each station. The first period (April–May) had a total of 87 samples (April 1985, May 1981, 1982 at 29 stations [Fig. 1], distributed in five depth intervals [9–18 m, 19–36 m, 37–54 m, 55–72 m, and 73–80 m]). June–July had 203 samples (June 1981, 1982; July 1981, 1982, 1984, 1985, and 1986) while August–September had 145 samples (August 1981, 1985, 1986; September 1982, 1985), and there were 87 samples for October–December (October 1981; December 1985, 1986). The sampling periods between June and September had higher numbers of samples because the CRIP cruises were primarily intended to sample the closed season that, in those years, was imposed for that period. Catch data were averaged by period and depth interval and are reported as mean number of individuals per hour (ind./h ±SE) of trawling. Seasonal abundance data from BIOCAICT cruises, on the other hand, are reported for only three depth intervals: 9–15 m, 40–45 m, and 70–90 m. Catch figures were averaged for every 2.0°C interval of temperature and 0.5 mL/L interval of dissolved oxygen within the observed ranges and are presented as the average number of individuals per hectare (ind./ha ±SE).

Nonparametric single factor analysis of variance by ranks (Kruskal-Wallis test for tied ranks) was used to test for differences in shrimp abundance between the five depth intervals in each of the four bimonthly periods and between four dissolved oxygen levels. A nonparametric multiple range test (NMRT) was used in cases where Kruskal-Wallis test were significant (α=0.05, Zar, 1974).

Results and discussion

Penaeus brevirostris specimens were collected over a wide depth range, although generally higher catches were taken between 50 and 80 m. The depth distribution varied throughout the sampling period (Fig. 2). Most catches were monospecific, except in August 1986, when both *P. brevirostris* and *P. californiensis* were sampled at 80 m on the Piaxtla transect. During the period April–May, shrimp were more abundant between 9 and 18 m (5.8 ±3.6 ind./h) but specimens were also caught at most depth intervals except at 73–80 m (Fig. 2A). Differences in mean abundance between the five depth intervals were not significant (Kruskal-Wallis, P>0.05). During June-

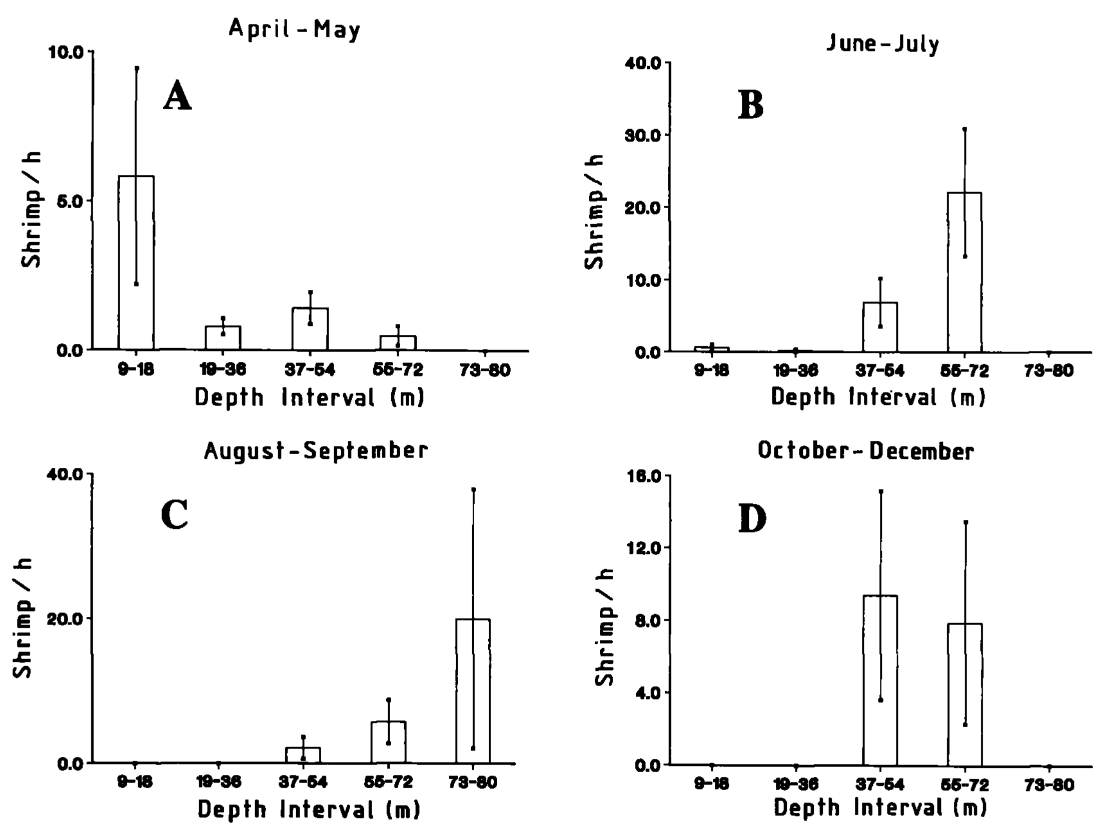

Figure 2

Mean abundance (shrimp/h ±SE) of crystal shrimp, *P. brevirostris*, at five depth intervals. Data combined from CRIP cruises in 1981, 1982, 1985, and 1986. (**A**) April–May 1981, 1982, and 1985; (**B**) June–July 1981, 1982, 1984, 1985, and 1986; (**C**) August–September 1981, 1982, 1985, and 1986; and (**D**) October–December 1981, 1985, and 1986. Abundance refers to mean number of shrimp caught at stations located within each depth interval in one hour trawling (paired 22.86-m otter trawl).

July, higher catches were obtained between 55 and 72 m (22.1 ±8.855), but abundance was also considerable at 37–54 m (6.9 ±3.3) (Fig. 2B, Kruskal-Wallis test, $P<0.001$). Mean abundance was significantly different between depth interval 55–72 m and all other intervals (NMRT, $P<0.01$), between depth interval 37–54 m and the remaining three intervals (NMRT, $P<0.01$), and was not significantly different between depth intervals 9–18, 19–36, and 73–80. In August–September, red shrimp was found only at depths beyond 55 m (Fig. 2C, Kruskal-Wallis, $P<0.025$). Mean abundance was significantly different between depth interval 55–72 m and all other depth intervals (only three categories were considered, as three intervals with zero abundance were regarded as one; NMRT, $P<0.005$). Abundance between depth intervals 9–18 m, 19–36 m, 37–54 m, and 73–80 m was not significantly different. During the October–December period, *P. brevirostris* catches were taken mainly at depth intervals 31–40 and 41–50 m (Fig 2D, Kruskal-Wallis, $P>0.05$). Although there appears to be a distinct difference in abundance between depth intervals, the test was not significant because the number of zero catches was high (79 cases out of 84), making the sum of ranks very similar in all intervals. The high standard error indicates the extent of data dispersion.

These results suggest that although *P. brevirostris* is generally found at greater depth intervals in the summer and autumn, its presence at mid-depths and shallower waters in spring may be an indication of seasonal changes in bathymetric distribution, i.e. onshore in spring and offshore in summer and autumn.

The distribution and abundance of *P. brevirostris* observed during the BIOCAICT cruises (Fig. 3) were very similar to those described earlier, i.e. the shrimp were mostly distributed in deeper waters except for the capture of some individuals at a depth of 10 m in June 1986 (Presidio and Baluarte transects). In November 1985 (Fig. 3A) and January 1986 (Fig. 3B), most individuals were caught at the deepest stations (70–90 m; 11.47 ±3.99 and 53.07 ±18.01 ind./ha,

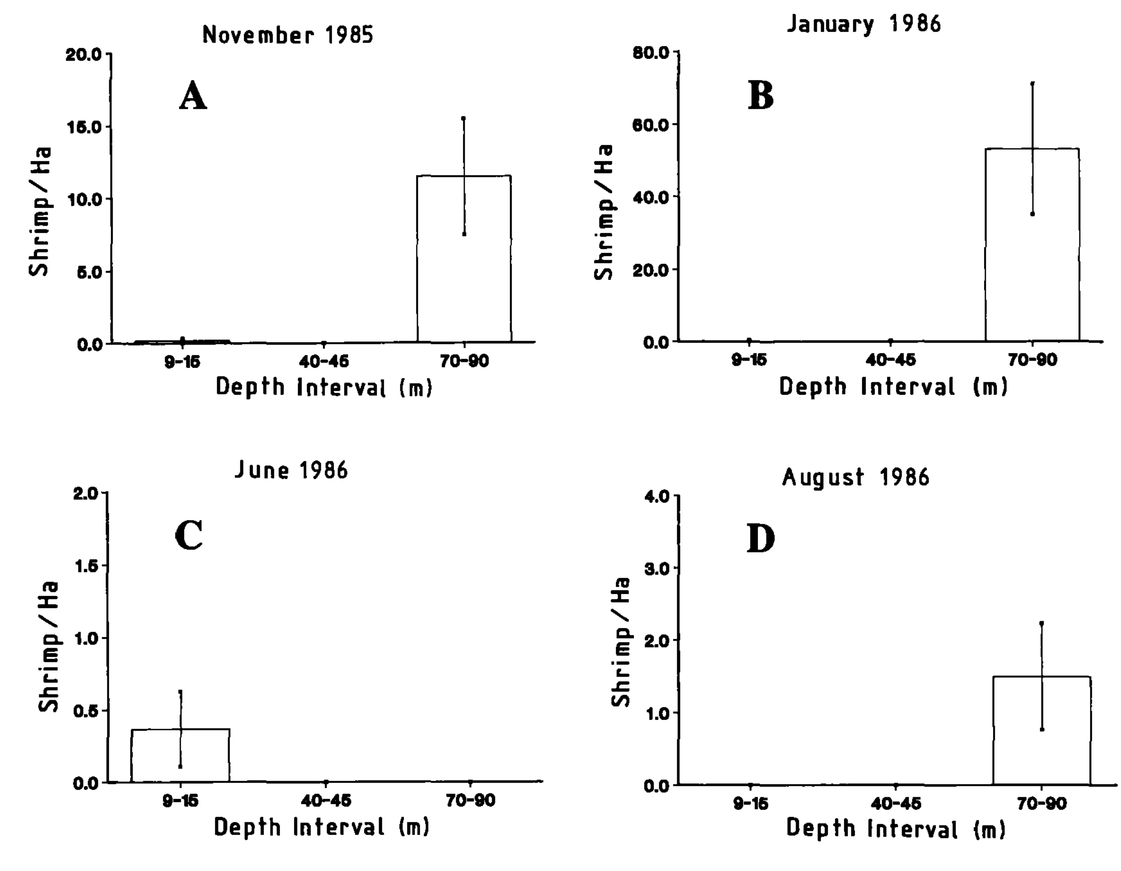

Figure 3

Mean abundance (shrimp/ha ±SE) of crystal shrimp, *Penaeus brevirostris*, at depth intervals observed during the BIOCAICT cruises in (**A**) November 1985, and (**B**) January, (**C**) June, and (**D**) August 1986.

respectively), except for a small catch in the former at the 9–15 m depth interval (0.13 ±0.19 ind./ha). In mid-June, very few specimens were collected (0.37 ±0.26 ind./ha), all in the Presidio and Baluarte transects at depths of about 10 m (Fig. 3C). During the summer cruise (August 1986) all individuals were caught at the deeper stations, (>70 m, 1.50 ±0.73 ind./ha; Fig. 3D).

The distribution of *P. brevirostris* observed during the BIOCAICT cruises, at all the stations, appeared to be limited to a narrow temperature range. The majority of individuals were caught at temperatures between 14.1 and 18.0°C and, although some individuals were also found at about 24.0°C, the average mean abundance at this temperature was rather low (0.1 ind./ha; Fig. 4).

Similarly, the main distribution of *P. brevirostris* appears to be limited to a narrow bottom dissolved oxygen range (Fig. 5). Mean shrimp densities were highest at the DO levels of 0.9–1.5 mL O_2/L while at higher (2.9–4.1 and 4.2–6.0 mL O_2/L) and lower levels (0.1–0.8 mL O_2/L), mean shrimp abundance was lower (Kruskal-Wallis test, $P<0.005$). Crystal shrimp abundance was significantly higher at the DO interval 0.9–1.5 mL/O_2 than at the other DO intervals (NMRT, $P<0.005$. Abundance differences among other DO intervals were not significant.

The former suggests that *P. brevirostris* occupies waters with lower oxygen content than do the other members of the genus. Most studies emphasize their distinct avoidance of hypoxic water and the negative consequences of exposure to it. Renaud (1986) found that *P. aztecus* and *P. setiferus* were able to detect and avoid hypoxic water below 2 ppm (1.4 mL O_2/L) and 1.5 ppm (1.05 mL O_2/L), respectively. Broom (1971) found a slightly higher threshold for the latter species (2 ppm, 1.4 mL O_2/L). Rubright et al. (1981) and Bassanesi-Poli (1987) reported surface oriented movements of *P. vannamei* when dissolved oxygen in culture ponds dropped below 2 mL/L. Egusa and Yamamoto (1961) observed stress in *P. japonicus* for oxygen concentrations below 2 mL/L and evacuation of their burrow at a DO level of 0.7 ppm (0.5 mL O_2/L). Regarding prolonged effects of hypoxia, Clark (1986) reported that *P. latisulcatus* showed molt inhibition and increased mortality under the hypoxic conditions of 2 ppm (1.4 mL O_2/L).

The disappearance of *P. brevirostris* from traditional fishing grounds in the summer may be due to the occurrence of temperature and dissolved oxygen levels outside its tolerable range. The population may move to deeper regions where low temperature and DO conditions, to which they are better adapted, prevail. Calderon-Perez[3] found a substantial number of shrimps of this species 120 m deep in June 1992 but none in shallower areas where temperature and DO were higher.

Thus, the seasonal variation in depth distribution of *P. brevirostris* in the eastern Pacific ocean may be due to bathymetric movements which, for most animals (Figs. 4 and 5), seem to be determined by seasonal changes in environmental parameters.

[3] Calderon-Perez, J. A. 1992. Data from the *BIOCAPESS VI* cruise on board the B/O (R/O) *El Puma*, carried out between 24–30 June 1992. Estación Mazatlán, Instituto de Ciencias del Mar y Limnología, U.N.A.M., apdo. Postal 811, Mazatlán, Sinaloa, México, CP 82000.

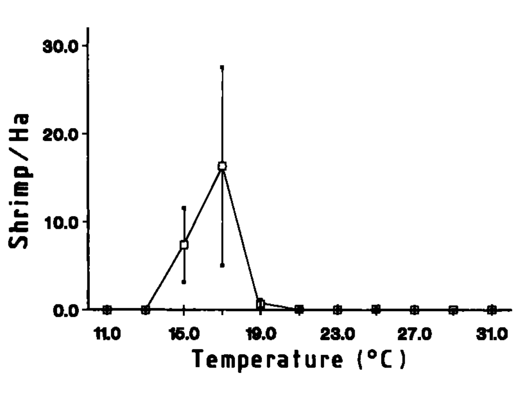

Figure 4

Mean abundance (shrimp/ha ±SE) of crystal shrimp, *Penaeus brevirostris*, in relation to bottom temperature (°C). Vertical lines represent standard error of the mean for each 2°C interval.

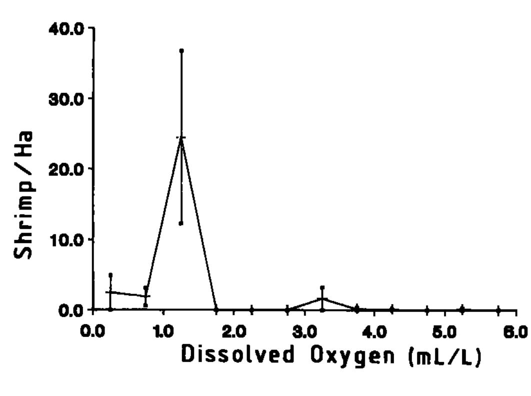

Figure 5

Mean abudance (shrimp/ha ±SE) of crystal shrimp, *Penaeus brevirostris*, in relation to dissolved oxygen (DO) concentration. Vertical lines represent standard error of the mean calculated for each DO interval of 0.5 mL/L.

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