JOURNAL OF CRUSTACEAN BIOLOGY, 14(4): 665–669, 1994

RECRUITMENT OF THE SQUAT LOBSTER *PLEURONCODES MONODON* ON THE CONTINENTAL SHELF OFF CENTRAL CHILE

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ABSTRACT

A benthic megafaunal study off Concepción Bay, central Chile (36°32′S, 73°W), provided abundance and bathymetric distribution data of the newly recruited squat lobster *Pleuroncodes monodon* (Decapoda, Galatheidae). The megafauna was surveyed 8 times between July 1991 and April 1992, with an Agassiz trawl at depths of 40, 64, and 96 m along a transect across the continental shelf. Recruits of *P. monodon* (carapace length (CL) 3–10 mm) were first sampled in all depth strata in early March, and then in April. April density (1 ind/m^2) and mean size (6.1 mm CL) were significantly higher than March density (0.07 ind/m^2) and mean size (5.3 mm CL). Depth did not affect abundance and its significant effect on mean size was conditional on month effect. We interpret these results as evidence that the main pulse of recruitment occurred simultaneously across the continental shelf transect in April, and that larvae settling in April have a larger size than larvae settling in March. Recruitment appears to be associated with late summer development of the giant sulfur bacteria *Thioploca* spp., suggesting an ecological relationship. Moreover, the observed recruitment occurred in late summer to early fall when the oceanographic regime in the area shifts to a postupwelling regime.

Remnants of a previously widespread population of the heavily overfished Chilean squat lobster *Pleuroncodes monodon* (H. Milne Edwards, 1837) are now found on the continental shelf off Concepción Bay, central Chile, in the southern border of the preexploitation distribution (Bahamonde *et al.*, 1986; Roa and Bahamonde, 1994). Despite this, it is the most representative species of the soft-bottom megabenthic community of the area. During the spring and summer this area is affected by seasonal upwelling processes, typical of midlatitude Eastern Ocean Boundary Current systems, and by variable oxygen minima of the Peru-Chile Undercurrent (Ahumada, 1989; Summerhayes *et al.*, 1992).

Muddy bottoms of the shelf are rich in organic matter and in summer are characterized by well-developed bacterial mats dominated by giant sliding filamentous sulfur bacteria (*Thioploca* spp.; Gallardo, 1977; Arntz *et al.*, 1991). These prokaryotes thrive where there is low oxygen and high H_2S and where potential grazers are few (Cohen *et al.*, 1984). These and previous incidental observations on the benthos of the same general area concerning the occurrence of small individuals of *P. monodon* (see Gallardo *et al.*, 1993) lead us to suggest that this area, and the concurrent bacterial mats, could serve as refugial habitats for benthic recruitment. This suggestion was reinforced by another study (Roa and Bahamonde, 1994), which showed that the main squat lobster patch of abundance has a clear spatial structure of ages/sizes, with small individuals (15–20 mm carapace length, CL) located to the south, closer to our transect, and the larger ones to the north.

Despite the commercial importance of *P. monodon* and a long history of study, the early stages of its life cycle have received little attention. Previous sampling and analysis of the population age structure have covered only late juvenile and adult ages (Roa, 1993). In this megafaunal survey, we found a recruiting period and site, and obtained data on the abundance and depth distribution of early recruits (CL = 3–10 mm) in a transect off Concepción Bay (36°32′S, 73°00′–73°10′W), central Chile. We present circumstantial evidence for the refugial role of bacterial mats.

MATERIALS AND METHODS

This study was carried out between July 1991 (except September) and April (except February) 1992, in a transect located off Concepción Bay, central Chile (Fig. 1). Along this inner shelf transect 3 sampling stations

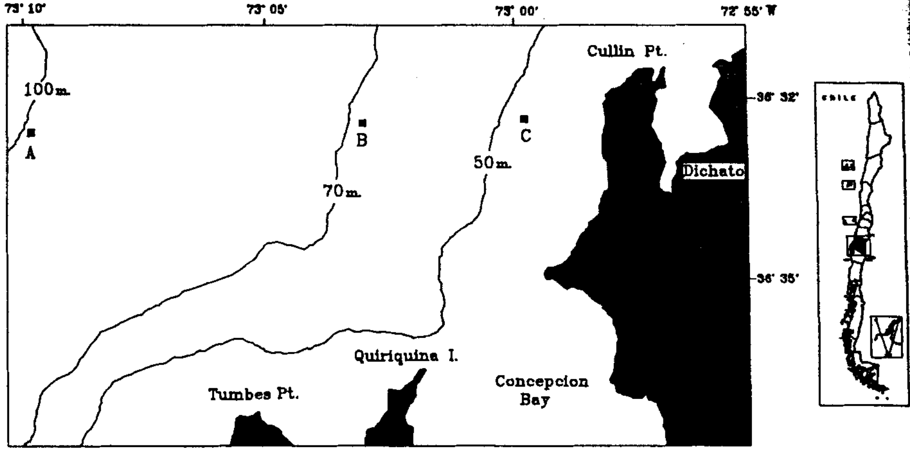

Fig. 1. Map with the location of sampling stations for *Pleuroncodes monodon* off Concepción Bay, central Chile, and geographical points mentioned in the text.

(at depths of 40, 64, and 96 m) were visited and each sampled 5 times with 10-min hauls with a 1-m mouth opening Agassiz trawl (Voss, 1988). The shelf is here widest in the country north of about 40°S and consists of a muddy inner shelf and a so-called "non-trawlable" outer shelf. All cruises were carried out on board the 17-m long R/V *Kay Kay* of the University of Concepción.

Navigation and positioning were assisted by means of a GPS Trimble Transpack I satellite-positioning equipment with a ±30-m precision. At each sampling station the position and direction of the ship was recorded at the beginning and end of the haul, made at approximately 1 m/s. The estimated swept area was approximately 605 m^2 for each trawl haul.

Bottom samples were washed through a 4-mm mesh sieve and the biological material retained was considered megafauna (Burd *et al.*, 1990). Samples were fixed with 10% Formalin-sea-water solution and later transferred to 70% ethanol. Individuals of *P. monodon* were separated, counted, and measured. Small individuals were considered recruits because the CL was similar to that of planktonic megalopae collected in another study in progress. The CL was measured from the posterior edge of the ocular concavity to the center of the posterior edge of the carapace, as commonly used to describe size/age relationship in this species (Roa and Bahamonde, 1994; Roa, 1993).

A Smith-McIntyre 0.1-m^2 grab haul was taken at each station to obtain information on the substratum (oxidized or reduced state, color, smell, type, presence or absence of a well-developed mat of *Thioploca*, grain-size composition, and total organic matter content measurements). The grain analysis was performed by wet sieving and the organic matter by weight difference after calcination at 500°C (Holme and McIntyre, 1984). Moreover, at each station Hydro-Bios bottles equipped with reversing thermometers were cast to obtain water samples at 3 depths: surface, middepth, and near bottom to measure temperature, salinity, dissolved oxygen, and total organic matter.

Statistical comparisons of abundance and size distribution between months and depths were performed using 2-way factorial ANOVA, with month and depth strata as factors. Abundance data were transformed to $\ln(x_{ijk} + 1)$, where i, j, and k index month, depth, and replicate, respectively, to increase normality and variance homogeneity. Robustness of ANOVA comparisons for size distributions were confirmed using the nonparametrie Kruskal-Wallis test on ranks. Graphical inspection showed that observations on size distribution were normal on each cell (see Fig. 2), and that variance varied between narrow limits for each combination of depth and month (see Table 1). Statistical comparisons were restricted to months in which individuals were observed at all depths (no empty cells). All statistical analyses were done using the module MGLH of SYTSAT (Wilkinson, 1988).

Results

During the 10 months of the sampling period (July 1991 to April 1992), *P. monodon* (CL = 3–10 mm) were found only in March and April 1992, and in negligible numbers in January. These recruits had mean sizes between 5.3 and 6.4 mm CL (Table 1, Fig. 2), corresponding to newly recruited individuals.

Statistical comparisons of sizes between both months and the three depth strata (2-way factorial ANOVA) yielded significant differences in all treatments. In particular, the month–depth interaction term was significant ($F(2, 827) = 11.343$, $P < 0.001$),

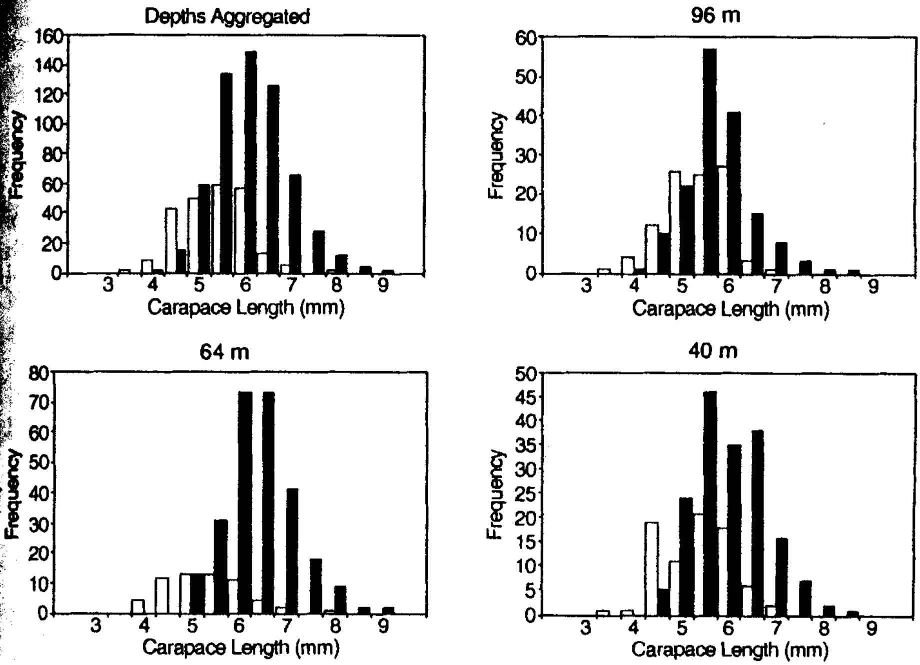

Fig. 2. Size distribution of early-recruiting squat lobsters. Empty bars = March; filled bars = April.

reflecting the fact that only in April differences between depth strata were apparent (Table 1). The significance of the month main effect ($F(1, 827) = 140.189$, $P < 0.001$) was related to the greater sizes in April (Table 1). Kruskal-Wallis U statistic (U = 34,835.5, approximate Chi-square(1) = 131.697, $P < 0.001$) yielded similar results for the month main effect.

Log-transformed abundance data were compared for the three depth strata and March and April. Results show a highly significant effect of the month main effect ($F(1, 24) = 48.862$, $P < 0.001$) and no evidence for a depth-related effect ($F(2, 24) = 2.085$, $P = 0.160$), although the month–depth interaction term was significant ($F(2, 24) = 9.719$, $P = 0.001$). Table 1 shows that the significant month effect was due to greater abundance of newly settled recruits in April at the intermediate depth stratum.

During this late summer-early fall recruitment period, mats of the giant sulfur bacteria *Thioploca* spp. at the surface of the sediments were well developed at all strata, forming a highly textured "tissue" ±0.5 cm in thickness. This differs from the situation in winter when dispersed bacterial filaments were found at both 64 and 96 m between July and December.

During recruitment months, mean environmental conditions close to the bottom at 64-m depth were typical of the Perú-Chile Undercurrent: 11.6°C, 34.691 ppt salinity, and 0.87 ml $O_2 l^{-1}$. Substrate at the shallower station contained approximately 28% mud and 72% sand and 3% organic matter, while intermediate and deep station substrates had approximately 100% mud and 7% organic matter.

Discussion

This is the first contribution on the recruitment of the squat lobster *P. monodon*, a megabenthic sublittoral species of central Chile. Despite the limited spatial coverage of our sampling, the abundance of newly settled individuals only in the late summer–early autumn postupwelling oceanographic

Table 1. Mean carapace length (CL) and abundance of recruits of *Pleuroncodes monodon* collected in three depth strata between March and April 1992 and on the continental shelf off Concepción Bay, central Chile. Both parameters were calculated from five replicates per depth (*N* = number of recruits measured; SD = standard deviation).

Month/depth	Mean CL (mm)	SD	Mean abundance *N* per m²	SD
March 1992				
40 m (*N* = 79)	5.37	0.73	0.046	0.045
60 m (*N* = 60)	5.34	0.83	0.023	0.011
90 m (*N* = 99)	5.35	0.65	0.128	0.156
Depths aggregated	5.36	0.72	0.066	0.099
April 1992				
40 m (*N* = 173)	5.99	0.77	0.880	1.257
60 m (*N* = 262)	6.40	0.74	2.074	0.561
90 m (*N* = 159)	0.73	0.71	0.145	0.095
Depths aggregated	6.10	0.79	1.033	1.105

regime (March and April) indicates that this is the period of recruitment of *P. monodon.*

April recruits were significantly larger than March recruits (Table 1). This could be interpreted as growth during the first month of benthic life. However, the fact that recruit abundance was also greater in April indicates that more important than benthic growth of early-settling larvae is their pelagic growth, as evidenced by the larger average size of April recruits.

According to Palma and Arana (1990), larval hatching occurs in the southern-hemisphere spring (October–November). Given that recruitment to the benthos occurs in late summer and early fall, larval life in nature should last at least five months. This is in contradiction with Fagetti and Campodónico's (1971) laboratory results, which indicate a larval life of only two months. In other words, laboratory conditions may not be useful to understand the life cycle of this species in the highly dynamic conditions of coastal upwelling ecosystems.

Recruitment of the squat lobster appears to be associated with the seasonality in the development of the bacterial-mat habitat, which may be providing a source of food (as evidenced by the high organic matter content of the substrate) and shelter (bacterial mat texture) for the small recruits, although specific information on bacterial biomass is needed to understand this apparent association.

Environments that could facilitate early growth of the squat lobster are the "non-trawlable" bottoms (sandstone cobbles, stones, and rocks) of the outer shelf, which we have not yet examined. Such habitats have been found important for *Homarus americanus* (see Wahle and Steneck, 1991). On the rare occasions when we have collected this rock material it has been found to contain juvenile and adult individuals of *P. monodon.*

Acknowledgements

We thank FONDECYT (National Fund for Scientific and Technological Research, Project 91/334), Center EULA-CHILE (Center Europe-Latin-America for Environmental Science Research and Education) and the Department of Oceanography (both of the University of Concepción, Chile) for financial and logistic support, respectively. We also acknowledge W. Arntz (Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany), N. Bahamonde (Faculty of Sciences, University of Chile, Santiago), and I. Campodónico (Subsecretariat of Fishing, Valparaíso, Chile), for their critical revision of an earlier draft. The second and fourth authors thank the German Service of Academic Exchange (DAAD) for the Graduate fellowships awarded to carry out studies at the University of Concepción. Our special recognition goes to the crew of our brave little R/V *Kay Kay.*

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RECEIVED: 14 September 1993.
ACCEPTED: 23 December 1993.

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