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RESEARCH NOTE

Occurrence of *Panulirus inflatus* (Decapoda: Palinuridae) pueruli in the southeastern Gulf of California, Mexico

Presencia de puérulos de *Panulirus inflatus* (Bouvier, 1895) (Decapoda: Palinuridae) en el sureste del golfo de California, México

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Abstract.- This study presents results on the collection of *Panulirus inflatus* pueruli in seaweed (GuSi; set at the surface) and crevice (Booth: set on the bottom) collectors from April to December 1998 in waters of the southeastern Gulf of California, Mexico. The collectors were deployed at two sites in Mazatlán Bay. A total of 15 pueruli and 26 post-pueruli were collected, of which 4 postpueruli were found in crevice collectors from 10 inspections. Examination of the crevice collectors was difficult because weather conditions made sampling problematic during the year in this zone. Seaweed collectors caught 37 pueruli in 91 observations. Most of the pueruli from these collectors were caught between April and June, with a peak settlement in May (19) and a mean surface water temperature of 24.4°C. The highest catch per unit of effort was 1.36 pueruli per collector per week in May, followed by April (0.33) and June (0.31). Statistical tests showed no significant differences among the moon phases, although the number of pueruli was higher during the first quarter. This is the first record of *P. inflatus* pueruli in the southeastern Gulf of California on specifically designed collectors.

Key words: Postlarvae, *Panulirus inflatus*, Gulf of California

INTRODUCTION

The spiny lobster is among the most valuable and highly prized seafood in a global context. Annual landings in Mexico are close to 2200 t, worth approximately US$ 11.5 million, which places Mexico among its main producers after Australia, New Zealand, South Africa, Cuba, Brazil, and the United States of America.

Among the species found along the Mexican coastline, *Panulirus inflatus* (Bouvier, 1895) and *P. gracilis* Streets, 1871, are important sources of income from the Pacific Ocean and Gulf of California. Their joint yearly catches are between 500 and 650 t, worth US$ 3.0 million (Pérez-González *et al*. 2002). In Mexico, both species cohabit the southeastern Gulf of California to Oaxaca, although *P. gracilis* extends to Paita, Peru, and *P. inflatus* is endemic to the Mexican coasts. Previous studies carried out on these species were particularly directed at the biology, ecology, and fisheries of the adult populations, with little work undertaken on the phyllosoma larvae, pueruli or juvenile stages. As a result, little is known about the recruitment dynamics of these species.

In particular, little information is available on the stock-recruitment relationship for *P. inflatus*, which is a useful tool in the sustainable management of crustacean fisheries (Caputi *et al*. 1995, Chubb 2000, Butler *et al*. 2006). This is an unfortunate situation for a resource as heavily exploited by an artisanal fishery as the 'prieta' (*P. inflatus*) and 'guera' (*P. gracilis*) spiny lobsters in the southeastern Gulf of California and the central-southern Mexican Pacific coast because the abundance of any adult population is primarily dependent on the recruitment, survival, and growth of its larval and juvenile stages (Little & Milano 1980, Chubb 2000, Phillips & Melville-Smith 2006).

Muñoz-Garcia *et al*. (2000a, b, 2002, 2014) investigated the taxonomy, distribution and abundance of the phyllosoma of *Panulirus* spp. and their relationships with environmental parameters such as salinity, temperature and the moon phase in the southeastern Gulf of California at Mazatlán Bay. *Panulirus inflatus* has an extensive larval phase of between 6 and 11 months that includes 11 pelagic stages (Johnson & Knight 1966). In the XI stage, the phyllosoma undergoes metamorphosis into a natant postlarva called a puerulus.

Artificial collectors have successfully caught the puerulus stage for a range of spiny lobster species (Phillips & Booth 1994). Collectors were developed to obtain animals for study in the laboratory (Witham *et al*. 1968, Phillips 1972, Díaz-

Iglesias *et al.* 2010), to investigate levels of puerulus settlement in relation to subsequent recruitment (Booth & Tarring 1986, Montgomery & Craig 1997, Gardner *et al.* 2006, Arteaga-Rios *et al.* 2007, Booth & McKenzie 2009), and for mariculture purposes (Hirata *et al.* 1988, Gardner *et al.* 2006, Díaz-Iglesias *et al.* 2010).

No research has been undertaken on the puerulus stage of *P. inflatus* in the southeastern Gulf of California, although pueruli have been observed by fishermen in their natural habitat. For this reason, several GuSi (Gutiérrez-Carbonell *et al.* 1992) collectors were deployed in areas within Mazatlán Bay during 1997, but only 2 organisms were caught in 3 examinations (one per week). However, pueruli also had been observed on the bottom in crevices, holes and seaweed by divers (pers. obsv.).

Due to the biological, ecological and commercial importance of *P. inflatus*, researchers deemed it necessary to investigate the settlement trends of this species in 2 types of artificial collectors (i) a seaweed simulation colector, set at the surface; and (ii) a crevice simulation collector, set on the bottom. This is the first time that *P. inflatus* has been reported as captured by artificial collectors in the study area. This work is a project to develop an optimal sampling strategy for collecting information on the biology, ecology, behavior, distribution and abundance of larvae, postlarvae and juveniles of *P. inflatus* and *P. gracilis* in the southeastern Gulf of California.

Materials and methods

Pueruli were collected from 2 areas within Mazatlán Bay, located in the southeastern Gulf of California and extending from 23º11' to 23º15'N and from 106º25' to 106º26'W (Fig. 1). The zone consists of rocky and gravel-sand bottom with some patches of seaweed (*Padina* sp.). During summer and early autumn, the area frequently experiences tropical storms, including strong hurricanes; while in winter and early spring, strong northwest winds are common in the area. Mazatlán Bay is protected in part by Three Islands (Tres Islas) located at the entry of the bay.

GuSi and Booth collectors were used to capture *P. inflatus* pueruli, which are described by Gutiérrez-Carbonell *et al.* (1992) and Booth & Tarring (1986), respectively. The GuSi collector consists of a 20 L plastic bucket covered by 'filastica' (long narrow plastic strips used to protect shrimp trawling gear). Once the collector is assembled, it simulates a seaweed habitat. The Booth collector consists of 8 plywood sheets, each 38 cm square and 0.9 cm thick, fixed to a galvanized steel frame to provide 7 wedge-shaped crevices, each 2.5 cm high at its widest part. This collector simulates the natural crevice environment. Two GuSi collectors and one Booth were deployed in each of 2 stations at Lobos Island and Punta Chile (Fig. 1). To simulate the seaweeds commonly found in this area, which have been observed as natural habitat for these pueruli, in each station,

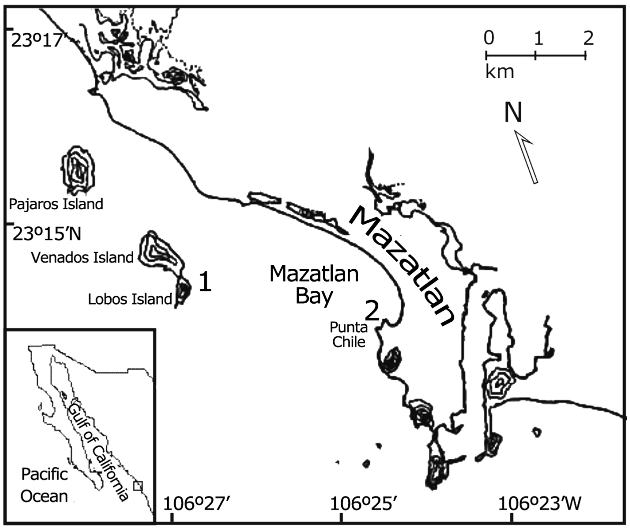

Figure 1. Location of the study area at southeast of the Gulf of California (Bay of Mazatlan) and sampling stations: (1) Tres Islas and (2) FaCiMar / Localización del área de estudio en el sureste del Golfo de California (bahía de Mazatlán) y de las estaciones de muestreo: (1) Tres Islas y (2) FaCiMar

we deployed one collector made of green fiber and one of red fiber. The collectors were deployed during February 1998 in each of the 2 sampling stations (Fig. 1).

The collectors were examined 1 to 2 days after or before the date of each moon phase. The GuSi collectors were examined by retrieving them from the water and shaking them vigorously in a large circular tub. The catch obtained was passed through a mesh sieve and the pueruli and postpueruli were recorded. The Booth collectors were fixed to a steel base, and during hauling, a mesh-based metal box rose to surround the collectors to prevent the escape of pueruli. During each sampling, we recorded the number of pueruli and postpueruli recovered from each collector, the surface water temperature, and the direction of the wind and current. Postlarvae have a dorsoventrally flattened cephalothorax, which may or may not be pigmented, while postpueruli are pigmented, have a rounded carapace with spines, and have hairs on their antennae (Lewis *et al*. 1952). The degree of pigmentation and postlarval development was determined according to the following scale: (1) completely transparent, (2) very lightly or moderately pigmented, and (3) fully pigmented (postpuerulus).

As the Booth collectors only caught 4 pueruli, the data analyzed were based on the numbers captured in the GuSi collectors. The settlement of pueruli was expressed as captch per unit of effort (cpue):

cpue = number of pueruli / number of collectors examined per week

To further test the possible importance of the artificial seaweed color on postlarval settlement, an approximate t-test for sample means with unequal variances was applied to the cpue between the red and green collectors. An ANOVA was also applied to determine if there was any relationship between settlement and the different moon phases.

Results and discussion

A total of 41 postlarvae were caught during the study period, with only 4 collected in the Booth collectors, all of which were postpueruli. Because of the location of the Booth collectors on the bottom, together with the special meteorological conditions during 1998, which represented a strong ENSO (El Niño-Southern Oscillation), sampling of the Booth collectors was difficult. In particular, strong ocean swells made handling the collectors difficult for divers on the bottom. GuSi collectors were sampled on 91 occasions during the entire study period, and a total of 37 pueruli were collected. While *Panulirus inflatus* pueruli have been observed in their natural habitat by fishermen and researchers, this is the first study in which they have been captured using artificial collectors. As a result, more pueruli were caught in the GuSi collectors, which were set at the surface of the water and were thus easier to inspect. We therefore only present results based on the settlement of pueruli on the GuSi collectors.

Of the 37 pueruli collected, 9 were transparent (24%), 6 were pigmented (16%), and 22 were postpueruli (60%). These percentages of postlarvae in each of the 3 degrees of pigmentation or development and in each station are shown in Fig. 2. The 2 sampling stations showed a higher percentage of postpueruli, followed by transparent and pigmented pueruli, in that order. The lower percentage of transparent and pigmented pueruli may suggest a short period at these degrees of pigmentation or development. Most of the pueruli were found between April and June; however, one marked postlarval influx peak during May was evident, and another lower peak was observed in November (Fig. 3). The surface water temperature ranged from 31.7ºC in August to 19.7ºC in December at station 1, and from 31.5ºC in July to 20.7ºC in December at station 2 (Fig. 4). Most of the pueruli were caught in May with a mean surface water temperature of 24.4ºC.

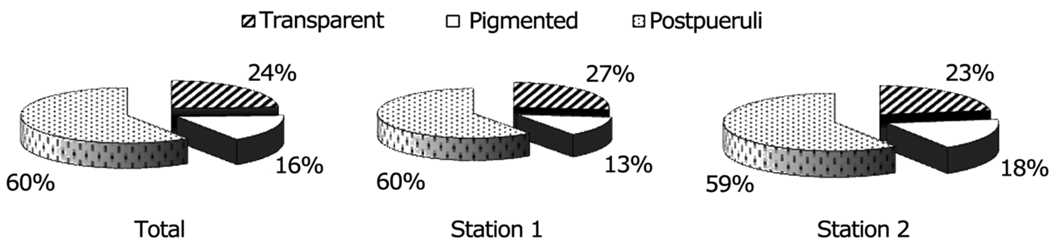

Figure 2. Total percentage and per station of pueruli of *Panulirus inflatus* caught in GuSi collectors from April to December 1998, in each of the 3 pigmentation/development stages (transparent, pigmented, and postpueruli), at southeast of the Gulf of California / Porcentaje total y por estación de muestreo de puérulos de *Panulirus inflatus* capturados en los colectores GuSi de abril a diciembre de 1998, en cada una de las 3 fases de desarrollo (transparente, pigmentado y postpuérulo), en el sureste del Golfo de California

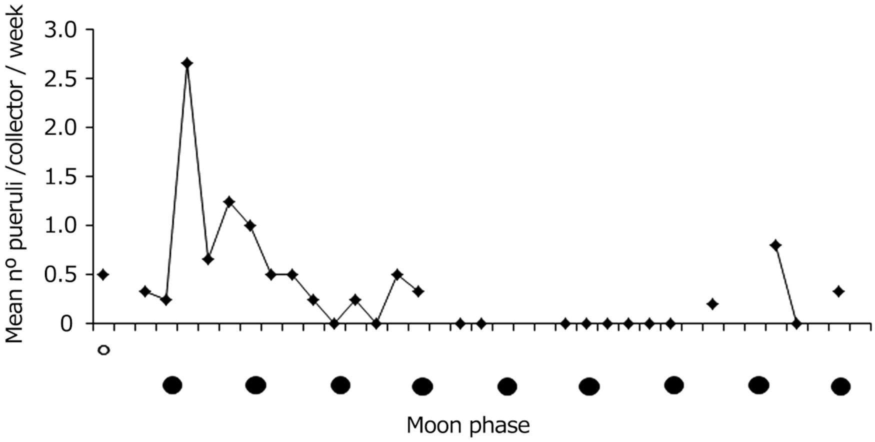

Figure 3. Mean number of pueruli/collector/week in each moon phase of the 2 stations samples from April to December 1998, at southeast of the Gulf of California. ●= new moon / Media del número de puérulos por colector y semana en cada una de las fases lunares en las 2 estaciones de muestreo de abril a diciembre de 1998, en el sureste del Golfo de California. ●= luna nueva

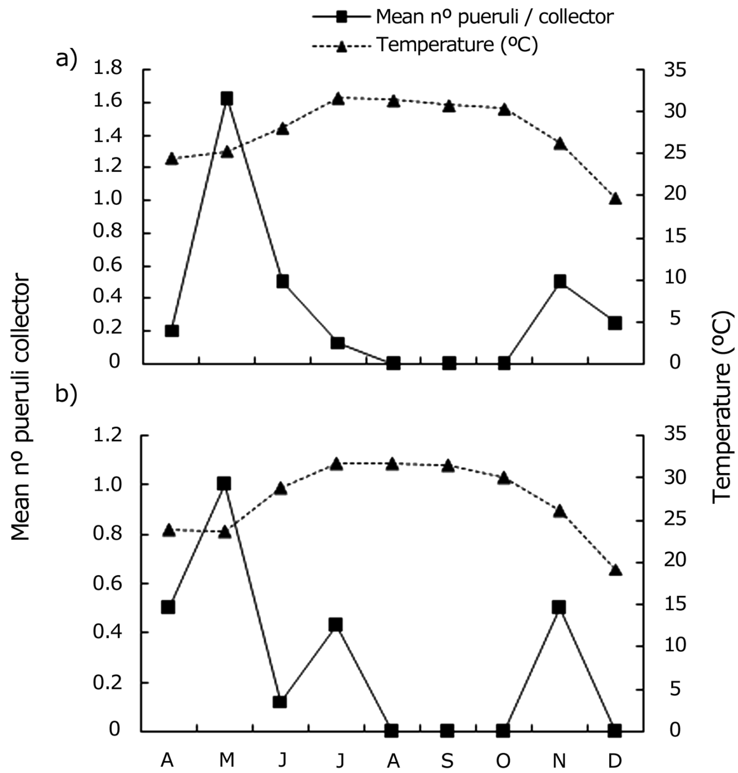

Figure 4. Monthly mean number of pueruli of *Panulirus inflatus* per collector and surface water temperature from April to December 1998 at southeast of the Gulf of California. (a) station 1 and (b) station 2 / Medias mensuales del número de puérulos de *Panulirus inflatus* por colector y de la temperatura del agua de abril a diciembre de 1998, en el sureste del Golfo de California. (a) estación 1 y (b) estación 2

The pueruli cpue was highest in May (1.36), followed by April (0.33) and June (0.31), coinciding with the predominant winds and water currents coming in from the northwest-west and southwest (Peraza-Vizcarra 1986). The t-test showed no significant differences among the red and green colors, although the red collectors caught the most pueruli. Likewise, the statistical analyses showed no significant differences among the moon phases, although the presence of pueruli was higher during the first quarter, followed by the last quarter and new moon (Table 1).

Table 1. Number of pueruli of *Panulirus inflatus* caught per station and moon phase at southeast of the Gulf of California from April to December 1998 (NM= New Moon, FQ= First Quarter, FM= Full Moon, and LQ= Last Quarter) / Número de puérulos de *Panulirus inflatus* capturados por estación de muestreo y fase lunar en el sureste del Golfo de California, de abril a diciembre de 1998 (NM= luna nueva, FQ= cuarto creciente, FM= luna llena y LQ= cuarto menguante)

Date	Moon Fase	Station 1	Station 2	Total Catch	Total Examination
April 02	FQ	0	1	1	2
April 22	LQ	1	0	1	3
April 28	NM	0	1	1	4
May 07	FQ	5	3	8	3
May 12	FM	1	1	2	3
May 19	LQ	5	0	5	4
May 26	NM	2	2	4	4
Jun 04	FQ	1	1	2	4
Jun 11	FM	2	0	2	4
June 19	FQ	1	0	1	4
June 24	NM	0	0	0	4
July 03	FQ	1	0	1	4
July 10	FM	0	0	0	4
July 17	LQ	0	2	2	4
July 24	NM	0	1	1	3
August 10	FM	0	0	0	4
August 17	LQ	0	0	0	1
September 16	LQ	0	0	0	1
September 25	NM	0	0	0	2
September 30	FQ	0	0	0	2
October 06	FM	0	0	0	2
October 15	LQ	0	0	0	2
October 23	NM	0	0	0	5
November 06	FM	1	0	1	5
November 27	FQ	1	3	4	5
December 04	FM	0	0	0	5
December19	NM	1	0	1	3
Total		22	15	37	91

Although no significant differences were observed in the catches of pueruli with the moon phase, the higher cpue during the first quarter has also been reported for *P. inflatus* (Caballero-Fuentes & Torres-Zepeda 2008) and for other species, such as *P. argus* (Little & Milano 1977, Marx & Herrnkind 1985, Monterrosa 1991, Briones-Fourzan & Gutiérrez-Carbonell 1992), *P. cygnus* (Phillips 1972, 1975) and *P. marginatus* (MacDonald 1986). Therefore, investigations of postlarval recruitment may reduce the sampling effort without seriously affecting the catch by examining the collectors only during the second half of the lunar month.

However, Briones-Fourzan (1993) noted that during some months, the catch of *P. argus* pueruli from collectors set in Quintana Roo, Mexico was highly variable. It was therefore suggested that the heterogeneity in the catches of the collectors in a given sampling station may result from the position of the individual collectors as related to the prevailing wind and current direction at a given moment. The higher cpue of *P. inflatus* pueruli was obtained between May and June, when the predominant direction of the wind and current of the water was northwest-north to southeast-south, relating to times when water temperatures were intermediate or rising (April-May) and falling (October-November) (Fig. 4). In contrast, throughout the year, those predominant currents may vary weekly or perhaps daily, and resulting settlement levels may be impacted accordingly. Little information exists on the current patterns and hydrological processes in Mazatlán Bay and adjacent areas. For this reason, we recommend that collectors should be set in other areas to reflect variations in habitats and hydrological conditions.

Settled pueruli of other species have sometimes been recorded in large numbers without the use of collectors. For example, large numbers of *Jasus edwardsii* pueruli were taken from the sea water intake of a thermal power station (Booth 1989, Booth & Mckenzie 2009), and they occur at times in tens to hundreds under stones along the shore at Castlepoint on the North Island of New Zealand (Booth 1979). Pueruli and early juveniles of *P. homarus rubellus* and *P. ornatus* commonly occur on shark nets off Durban, South Africa (Berry 1974), and masses of the red alga *Laurencia* sp. are important habitats for pueruli and early juveniles of *P. argus* (Marx 1986). In the southeastern Gulf of California, pueruli and early and later juveniles of spiny lobsters have been reported by fishermen and students. Researchers and technicians also have observed hundreds of early juveniles of *P. inflatus* in Mazatlán Bay under stones, in crevices, holes, and oyster shells, and in patches of seaweed, especially *Padina* sp. (pers. obs.).

Two species inhabit the study zone (*P. inflatus* and *P. gracilis*), both of which are commercially exploited (Pérez-González *et al*. 1992a, 2002), and their catches consist of later juveniles and adult spiny lobsters. However, despite the co-existence of these species and the fact that both have reproductive activity in similar seasons (Pérez-González *et al*. 1992b), the collectors did not catch *P. gracilis* pueruli during the study period. This suggests that the species may not recruit as pueruli in this zone or that the type of collectors were unsuitable to settlement for these individuals. In contrast, all the pueruli were of the spiny lobster, *P. inflatus*. Most the pueruli caught were kept in an aquarium; almost all molted at least once, and some reached the juvenile stage after the second and third molt, thus confirming the identity. The pueruli did not feed, but the first and second juvenile instars readily consumed food. Some individuals survived for 5 months, during which time they molted 3 or 4 times. Transparent pueruli were immediately introduced into an aquarium with some seaweed (*Padina* sp.). Once exposed to the seaweed, they molted within one or 2 days after their capture, acquiring the coloration of the seaweed.

We recommend that settlement should be monitored to determine the temporal and spatial patterns in puerulus recruitment to assess the possibility of using the recruitment data to forecast lobster production in the Mexican Pacific, including the Gulf of California coast, which is inhabited by 2 species of great commercial importance. Probably, the possible mix of *P. inflatus* and *P. gracilis* phyllosoma in this zone may preclude the use of a stock-recruitment approach in fishery models for each species. Thus, further study of the postlarval settlement in the area could potentially inform resources managers as to the temporal and spatial recruitment dynamics of these commercially important fisheries.

Acknowledgments

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