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Sexual maturity and egg production in an unexploited population of the red squat lobster *Pleuroncodes monodon* (Decapoda, Galatheidae) from Central America

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ABSTRACT

The squat lobster *Pleuroncodes monodon* is one of the most common and abundant galatheid species in the deepwater fishery of Pacific coast of America. In contrast with Peru and Chile, the red squat lobster is not commercially exploited in Costa Rica. Here we estimated the size of sexual maturity and analysed egg production in *P. monodon* from the Pacific of Costa Rica; the results might be important for an adequate management strategy when initiating a sustainable fishery of this resource in Costa Rica. Analyses of allometric growth revealed that females and males reached their morphological sexual maturity at 26.9 and 30.4 mm CL, respectively. The percentage of immature females captured in the present study (54%) suggests that almost half of females are able to reproduce before they are caught. Egg production was positively correlated with body size; females that measured between 24.1 and 29.0 mm CL contributed roughly 90% to the offspring production of the population. Females from Costa Rica had a considerably lower average egg volume (0.039 mm^3) and higher fecundity (9810) than females from Chile. In comparison to other American galatheids *P. monodon* from Costa Rica produces numerous but small eggs, a typical strategy of species with a prolonged larval development. An analysis between our results and information published about *P. monodon* from Chile also revealed differences in the size–frequency distribution shape of both populations. The non-exploited character of the Costa Rican *P. monodon* population and a latitudinal (temperature-related) cline in body size might be associated with these differences.
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1. Introduction

The squat lobster *Pleuroncodes monodon* H. Milne Edwards, 1837 is one of the most common and characteristic galatheids along the Pacific coast of the Americas (Haig, 1955; Bahamonde et al., 1986; Roa and Bahamonde, 1993). Its geographical distribution covers a wide range of latitudes, from Chile (~41°S) to southern Mexico (~15°N) (Haig, 1955; Longhurst and Seibert, 1971; Hendrickx and Harvey, 1999), including some scattered reports from Central America (Longhurst and Seibert, 1971; Bianchi, 1991). Although both *P. monodon* and *P. planipes* Stimpson, 1860 seem to co-occur in Central America, recent molecular analysis confirmed that the squat lobsters currently fished in Costa Rica belongs to *P. monodon* (see Section 2).

Several studies along the Chilean coast allowed the compilation of information about different reproductive features of *P. monodon* (e.g. sexual maturity, fecundity, among others: Roa, 1993; Palma and Arana, 1997), which supported the development of management strategies for this species in Chile (Gallardo et al., 1994; Bahamonde et al., 2004). However, life history features might change with latitude in species with a wide latitudinal distribution such as *P. monodon*. This conclusion is supported by different studies relating latitude to body size (Atkinson and Sibly, 1997; Angilletta and Dunham, 2003), sex ratio (Defeo and Cardoso, 2002; Rivadeneira et al., 2010) and reproductive biology (Hernáez, 2001; Lardies and Wehrtmann, 2001).

In Costa Rica, *P. monodon* is an important bycatch component of the deepwater fauna and may occasionally constitute up to 99% of the total catch of individual commercial deepwater hauls (Wehrtmann and Nielsen-Muñoz, 2009). A commercial fishery in Costa Rica has never targeted this squat lobster, and such a situation offers the opportunity to examine life history

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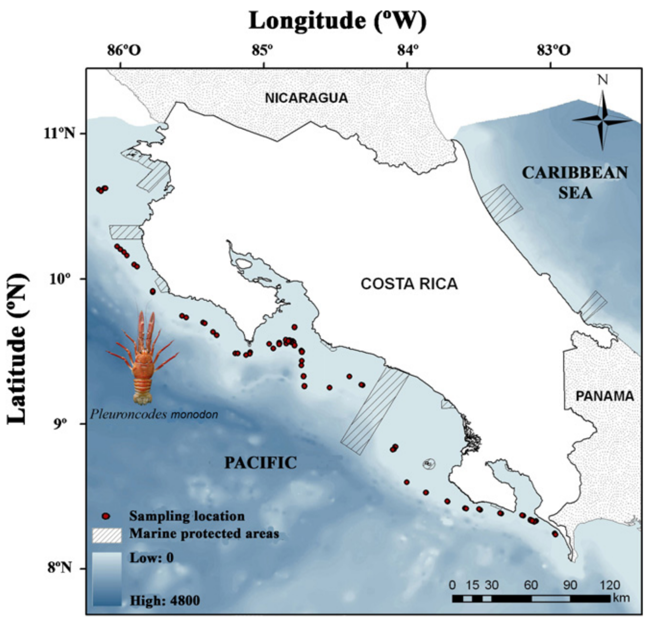

Fig. 1. Geographical distribution of sampling sites along the Pacific coast of Costa Rica. Each point represents a site where *Pleuroncodes monodon* was collected.

aspects of an unexploited population in Central America. Therefore, the present study was designed to analyse sexual maturity and egg production of *P. monodon* for the first time in Costa Rica. The results will be compared to the available information about *P. monodon* from Chile and will provide an insight to the reproductive plasticity of this species along a latitudinal gradient.

2. Materials and methods

2.1. Taxonomic identification

The geographical distribution of both *P. monodon* and *P. planipes* overlaps in Central America (see Hendrickx and Harvey, 1999). Therefore, molecular analyses (COI and 16S) were performed to verify the identification of specimens collected in 2009 with commercial shrimp trawlers along the central Pacific coast of Costa Rica; the obtained results indicated that we were dealing with *P. monodon* (E. Macpherson, unpubl. data).

2.2. Study area

Monthly samples of *P. monodon* were obtained during one year (February 2007–March 2008) along the Pacific coast of Costa Rica (Fig. 1), covering more than 90% of the latitudinal area of Pacific Costa Rica (∼08°S–∼11°N). Specimens were collected by means of standardized 20 min-hauls of commercial shrimp trawlers between 80 and 350 m depth, the typical depth range inhabited by *P. monodon* (Palma and Arana, 1997). Trawling was conducted with commercial nets of 2.2 inch (5.5 cm) mesh size. Three subsamples of approximately 20 kg each were taken from each haul; *P. monodon* specimens were separated from these subsamples and stored independently from ovigerous squat lobsters. Individuals were then frozen and transported to the laboratory of the Unit for Fishery Research and Aquaculture (UNIP) of the Research Center for Marine Science and Limnology (CIMAR), University of Costa Rica, San José, Costa Rica.

2.3. Sexual maturity

The collected specimens were sexed according to the criteria proposed by Baba et al. (2008). Subsequently, the following morphometric measurements (±0.1 mm) were registered: total length (TL: from the posterior margin of the orbital arc to the posterior mid-dorsal region of the telson); carapace (CL: from the posterior margin of the orbital arc to the posterior mid-dorsal region of the carapace); propodus length of the major chelipod (PL: from the anterior region to posterior limit of propodus). Additionally, we measured the width of the fifth abdominal somite (SW: from the left to the right pleuro of the fifth abdominal somite), and recorded the presence of setae on the pleopods.

The size at maturity can be estimated using different criteria (Hernáez and Wehrtmann, 2007). In our study, the physiological maturity refers to the CL at which females carry eggs, and morphometric maturity indicates the size characterized by a change in the allometric growth of the chela. The size at morphological sexual maturity (MSM) in males and females was estimated by analysing the biometric relation between PL and CL. To determine the growth pattern in *P. monodon*, the allometric equation ($y = aX^b$) was adjusted for each growth phase to obtain the allometric constant "*b*" (see Somerton, 1980). The analysis of the allometric growth constant *b* provides information concerning the increment of one biometric dimension in relation to another. We considered growth to be isometric when *b* ranged between 0.90 and 1.10, negative allometric when $b < 0.90$, and positive allometric when $b > 1.10$ (Pinheiro and Fransozo, 1993; Hernáez and Wehrtmann, 2007). The size at physiological sexual maturity (PSM) was estimated only for females, and was calculated from the size where 50% of the females were carrying eggs. We employed a logistic linear function defined by the equation

$$PSM = \frac{1}{1 + e^{(-a-b\times sc)}}$$

where PSM is the size at physiological sexual maturity, *a* and *b* are the intercept and slope obtained from the equation and *SC* is the midpoint of each size class (Kimura, 1974). After adjusting the regression model, we estimated the size at which 50% of the females reached physiological sexual maturity ($CL_{50\%} = a/b$). Only complete individuals were utilized to estimate morphological and physiological sexual maturity.

2.4. Egg production

We detached the entire egg mass from each ovigerous female, and subsequently three subsamples of 100 eggs from each female were prepared. These subsamples were dried together with the remaining egg mass for 48 h at 65 °C; thereafter, all samples were weighed with an analytical balance (Sartorius; ±0.1 mg). The egg's dry weight and the total number of eggs were calculated according to the following equation (Hernáez et al., 2008):

$$E = \frac{S}{100} \quad (1)$$

$$\mathrm{NE} = \frac{\mathrm{WEM}}{E} \quad (2)$$

where E = egg weight, S = average weight of the subsamples; NE = total number of eggs; WEM = weight of the total egg mass.

The eggs of *P. monodon* were divided into three developmental stages (Stages I–III) according to their shape and the development of the abdomen and the eyes (Wehrtmann, 1990). The egg volume (EV) was estimated by arbitrarily separating 20 eggs from each female's egg mass and measuring the length and width of each egg under a microscope equipped with ocular micrometer. This data

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