

Sexual maturity and relative growth of the porcellanid crab *Petrolisthes armatus* (Gibbes, 1850) from a remnant mangrove area, southern Brazil

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Abstract

Both relative growth and sexual maturity of a *Petrolisthes armatus* population from a remnant mangrove area in southern Brazil were described. Samples were carried out at two-month intervals in a rocky intertidal area of Araçá mangrove, from March 2005 to July 2006. The carapace width at sexual maturity was estimated between 3.5 to 4.5 mm for both males and females, based on the measurement of nine different morphological characters. The best results were obtained from the analysis of the relationship involving carapace length and cheliped size. Male weight increased more than their body size, a condition that was not found in females. This is probably related to the large energy allocation in females from growth processes to the production of nutritive elements for their offspring. The first pleopods did not grow proportionally to carapace width in males, as opposed to the females, in which pleopod growth seemed to be synchronized to body size. In general, males and females presented similar growth pattern and the differences found between them were related to the distinct reproductive roles performed by both sexes in the population. Expected size differences at maturity from another population living in a non-impacted region were not confirmed. The growth features found here allowed us to infer that this population of *P. armatus* is well established in the impacted mangrove by virtue of its growth strategy.

Key words: Araçá mangrove, growth, reproduction, sexual maturity, *Petrolisthes*.

Introduction

Variability in the size of individuals represents important information to access the population fitness, particularly from growth perspectives. In population approaches, knowledge about an individuals' growth rate is essential to infer the reproductive role of that individual in the population (Hepper, 1967).

Despite the existence of an ecdysis process that involves changes in the calcified and chitinous exoskeleton promoting a discontinuity in the growth, the presence of this body covering in crustaceans supports accurate measurement of an individuals' size, which further allows one to perform morphometric studies in order to

infer some aspects related to growth (Hartnoll, 1978).

The growth of a body part or organ in relation to the whole is called relative growth (Teissier, 1960; Hartnoll, 1985). During life, some phases are crucial to the success of the reproductive process, such as the transition from the juvenile to the adult. Many decapod species when reaching their sexual maturity present essential and important morphological changes (Petriella and Boschi, 1997) and some of these changes can be observed or detected by the analysis of the relative growth. Therefore, studies on the relative growth of decapod crustaceans have been considered an important tool in characterizing sexual dimorphism, heterochely, size at sexual maturity,

systematics and physiological and behavioral patterns (see Biagi and Mantelatto, 2006 for literature review).

Considering body dimensions, Hartnoll (1982) postulated that the first dimension, usually represents the individuals' size, and is the independent variable (x), while the other dimension – the dependent variable (y) – is the focus of the relative growth studies. The formula $y = a \cdot x^b$ and its logarithmized form $\log y = \log a + b \cdot \log x$ is used to represent relative growth, in which b is considered the relative growth rate, since it defines the kind of allometric growth.

In this context, Huxley and Teissier (1936) defined different patterns of relative growth when variables of the same greatness are considered. If $b = 1$ (or 3, when talking about three dimensional variables, e.g. weight), there is an isometric relation, where the increase in the dependent variable is parallel to the increase in independent variable. If $b \neq 1$, there is an allometry and the increase of the two variables occurs at different speeds. When $b > 1$, the allometric relation is positive and the dependent variable increases faster than the independent variable; when $b < 1$, the allometric relation is negative and the dependent variable increases slower than the independent variable.

Despite the undisputed efforts to study the relationships of growth in decapods (see Hartnoll, 2001 for review), the prominence of the Anomura in an evolutionary context (Cunningham *et al.*, 1992) and the large number (about 280) of described porcellanid crab species worldwide (Rodríguez *et al.*, 2005), there is clearly a lack of studies with respect to sexual maturity and dimorphism in anomuran members (Biagi and Mantelatto, 2006), including the porcellanid crabs. The only available similar report on a member of the family Porcellanidae has been on *Petrolisthes politus* (Gray, 1831) by Scelzo (1985), and one on juveniles of *Petrolisthes armatus* (Gibbes, 1850) obtained under laboratory conditions by Brossi-Garcia and Moreira (1996). Both justify the necessity of more investigations. This study improves the knowledge on the *P. armatus* group by describing the relative growth of different demographic categories, using a large sample and a large range of body sizes. It aims to verify growth variability and to estimate the sexual maturity size interval during ontogeny in a southern population living in an impacted mangrove area.

Material and Methods

Species sampling

The remnant mangrove of Araçá region (23°48'S; 45°24'W) is localized near São Sebastião Channel in the north coast of São Paulo State. This channel separates São Sebastião city (continental edge) from Ilhabela (São Sebastião Island) (Poffo, 2000). This region is subject to accidental oil spills, receives domestic-sewage discharge and supports extensive tourist activities (Zanardi *et al.*, 1999). The effects of these events are easily seen in the studied area, such as a reduced number of mangrove trees, oil spreading over mud sediment and remains of domestic garbage. These impacts have resulted in an area with decapods that show specific characteristics that are understood as environmental adaptations (Vergamini and Mantelatto, 2008a; Miranda and Mantelatto, 2009).

Samples were taken from a rocky intertidal area near the water line in the Araçá region, during low tide at two-month intervals, from March 2005 to July 2006. Specimens were collected by hand, during an hour and a half by two people moving all rocks in order to catch crabs of all possible sizes. This methodology was previously tested in the area and proved to be efficient in capturing small juveniles and adult crabs (see Vergamini and Mantelatto, 2008b and Miranda and Mantelatto, 2009 for details).

The animals were frozen and transported to the laboratory, where they were thawed just before analysis. Individuals were counted and sexed through analysis of the presence, position and number of pleopods. All dimensions were measured to the nearest 0.1 mm using a caliper rule or under a light stereomicroscope, with the aid of a camera lucida when necessary. The following dimensions were obtained: CL = carapace length; CW = carapace width; WW = body wet weight; LLP = greatest length of the left chelae propodus; LRP = greatest length of the right chelae propodus; WLP = greatest width of the left chelae; WRP = greatest width of the right chelae; PL = first pleopod length; ASL = second abdominal somite length. Individuals with injured or missing appendage and unsexed ones were excluded.

In the study of relative growth, isometry of size dimensions ($H_0: b = 1; H_1: b \neq 1$) and weight ($H_0: b = 3; H_1: b \neq 3$) were tested using the Student's t-test on the obtained slope values. Student t-tests were performed to verify if slopes and in-

tercepts from the obtained straight lines differed among various allometric relationships. To discriminate juveniles from adults, slopes and intercept values were tested by ANCOVA, adopting as a starting reference the size of the smallest ovigerous specimen (CW = 4.0 mm). All statistical tests were conducted according to Zar (1996) by adopting the significance level $\alpha < 0.05$.

All specimens were preserved in 80% ethyl alcohol and deposited in the Crustacean Collection of the Department of Biology, Faculty of Philosophy, Sciences and Letters of Ribeirão Preto (CCDB/FFCLRP/USP) under the sequence of numbers 1832 to 1844.

Results

During the study period 775 specimens were collected, including 333 males (43.0%), 157 non-ovigerous females (20.3%), 228 ovigerous females (29.4%), and 57 individuals (7.4%) in which sex was unable to be determined. The number of animals collected ranged from 55 (July 2005) to 137 (November 2005) and all demographic categories were present during the study period, except in July and in September. The size of individuals varied from 0.8 (non-determined sex) to 14.1 mm (male) CW.

Generally, we observed that males were larger (CL and CW), heavier, had longer chelae (WP) and longer first pleopods than females, while females had the abdomen width larger than males ($P < 0.001$) (Table I). Allometric indexes differing from 1 (positive) were obtained in all relationships, except for carapace length vs. carapace width and the first pleopod length vs. carapace width (Table II).

Different growth patterns were observed in the females. Isometric growth of the characters LRP and WLP were present only in the juvenile females, while adult ones presented positive allometry for those characters (Table III). Within males, juveniles had isometric growth rates of WLP and WRP in opposition to the positive allometry presented by the adults. In general, juveniles (both males and females) could be separated from adults in all relationships involving cheliped measurements, as the "a" and/or "b" constants of the tested straight lines were statistically different.

The size at sexual maturity of *Petrolisthes armatus* males and females occurred between 3.5 to

4.5 mm CW, which can be verified by the distribution of empirical points in the relationships involving size and cheliped measurements (Fig. 1). This size interval includes the smallest ovigerous females captured (CW = 4.0 mm).

Discussion

Despite sexual maturity being estimated at the same size for both sexes, sexual dimorphism in *P. armatus* is evidenced by differences in individuals' size and growth pattern, especially when involving the pleopods. This is correlated with the differing functions of the pleopods between the two sexes. The present study is one of the first to use pleopod morphometry to determine sex and sexual dimorphism in natural populations of porcellanid crabs.

In decapod crustaceans, growth is followed by a size and weight increment almost instantaneously after the molting process, which implies the abandonment and degradation of the old skeleton and the synthesis of new tissues (Petriella and Boschi, 1997). This verified abrupt size increment is the result of a high absorption of water that occurs before the stiffening of the new tegument over the incorporation of calcium salts present in the hemolymph and in other storage places (Stevenson, 1985).

Patterns of growth depend on sex and life stages and could vary between different populations according to habitat and geographic regions (Hartnoll, 1982). Anomurans are highlighted among other crustaceans due to their observed high diversity of growth patterns. However, this kind of information is scarce since studies on this group's growth patterns are infrequent, possibly because of their morphological pattern heterogeneity, which makes it difficult to construct generalized growth models (Hartnoll, 1985; Biagi and Mantelatto, 2006; Fantucci *et al.*, 2009).

The differences found between growth patterns of *P. armatus* males and females are related to the distinct roles performed by both sexes in the population, and those differences have already been reported in other decapods. Despite the positive allometry of chelipeds, in relation to the carapace width, males reached larger sizes than the females from the same size class ($P < 0.001$). This was probably related to the importance of the males cheliped in territorial defense, intra- and interspecific fights and to cohort behavior (Hazlett, 1966).

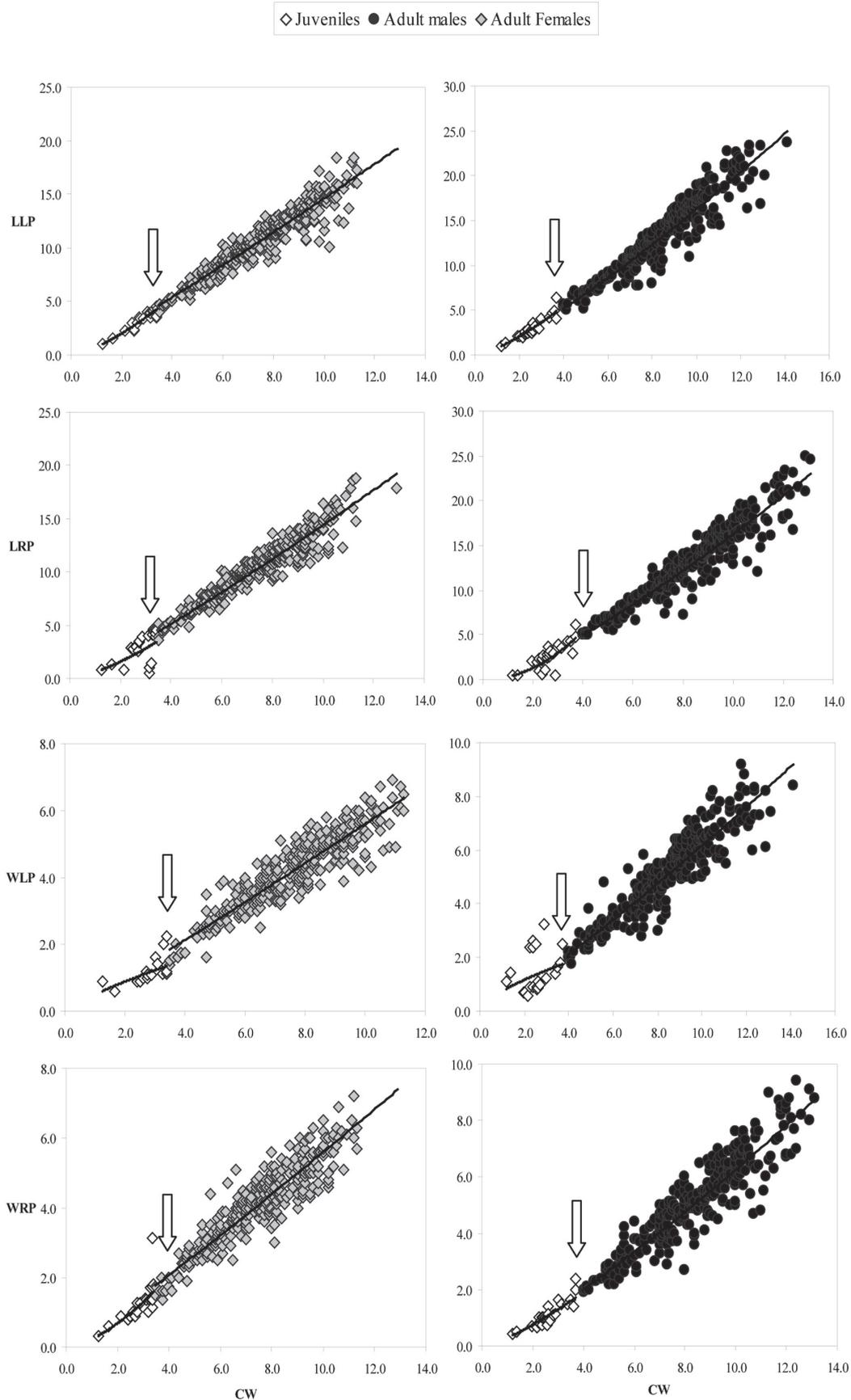


Figure 1. *P. armatus*. Dispersion diagrams of the relationships between carapace width (CW) and propodus measures: length left (LLP) and right (LRP), width left (WLP) and right (WRP), evidencing the interval of sexual maturity (white arrows). Juveniles of each group (males and females) are represented on respective graphics.

Table I. *Petrolisthes armatus*. Mean, minimum and maximum values (mm) of the analyzed dimensions of males and females (n = number of individuals; X = mean values; sd = standard deviation; CL = carapace length; CW = carapace width; WW = body wet weight (g); LLP = greatest length of the left chelae propodus; LRP = greatest length of the right chelae propodus; WLP = greatest width of the left chelae; WRP = greatest width of the right chelae; PL = first pleopod length; ASL = second abdominal somite length).

Variables	Group	n	X ± sd	Minimum	Maximum
CL	♂	333	8.48 ± 2.73	1.30	15.10
	♀	385	7.59 ± 2.09	1.40	12.90
CW	♂	333	8.00 ± 2.60	1.20	14.10
	♀	385	7.27 ± 2.07	1.30	12.90
WW	♂	296	0.91 ± 0.82	0.04	9.30
	♀	338	0.60 ± 1.39	0.03	2.20
LLP	♂	286	12.76 ± 5.06	0.90	23.70
	♀	336	10.45 ± 3.40	1.00	21.10
LRP	♂	300	12.46 ± 5.14	0.40	25.00
	♀	334	10.05 ± 3.42	0.50	18.80
WLP	♂	294	1.49 ± 0.50	0.60	9.20
	♀	337	4.08 ± 1.30	0.60	8.10
WRP	♂	300	1.46 ± 0.56	0.40	9.40
	♀	333	3.97 ± 1.32	0.30	7.20
PL	♂	264	3.15 ± 0.82	0.30	4.90
	♀	134	0.96 ± 0.70	0.10	3.70
ASL	♂	333	5.94 ± 3.95	0.10	12.40
	♀	372	6.21 ± 2.01	0.50	10.70

Table II. Regression equations of the total individuals analyzed (n = number of individuals; r = correlation coefficient; A = allometry; CL = carapace length; CW = carapace width; WW = wet weight; LLP = greatest length of the left chelae propodus; LRP = greatest length of the right chelae propodus; WLP = greatest width of the left chelae; WRP = greatest width of the right chelae; * = significant correlation; ns = non-significant correlation; ● = b ≠ 3, P < 0.05).

Relation	n	Power function y = ax ^b	r	A	b ≠ 1
CL x CW	775	CL = 1.179CW ^{0.946}	0.990	-	286.410*
WW x CW	632	WW = 0.001CW ^{3.070}	0.899	+	69.923*
LLP x CW	664	LLP = 0.855CW ^{1.266}	0.973	+	121.887*
LRP x CW	676	LRP = 0.658CW ^{1.382}	0.908	+	57.790*
WLP x CW	670	WLP = 0.373CW ^{1.211}	0.872	+	54.655*
WRP x CW	678	WRP = 0.289CW ^{1.327}	0.944	+	78.673*
PL x CW	398	PL = 0.1911CW ^{0.909}	0.065	-	0.909(ns)
ASL x CW	705	ASL = 0.6117CW ^{1.111}	0.063	+	1.111*

A negative allometric relationship was found between carapace width and length for the overall individuals analyzed. This can be attributed to the morphological adaptations that allow them to live in the typical habitat where they were found (under rocks). This pattern does not fit those commonly observed among decapods, but the same condition was observed in the hermit crab *Dardanus insignis* (de Saussure, 1858) studied by Branco *et al.* (2002).

Growth and reproduction are competitive processes during the lifecycle of Crustacea. They are mutually influenced in different ways and energy is their main connecting factor, due to its available quantity to allow those processes, as well as to

Table III. Regression equations of each group of interest (n = number of individuals; r = correlation coefficient; A = allometry; CL = carapace length; CW = carapace width; WW = wet weight; LLP = greatest length of the left chelae propodus; LRP = greatest length of the right chelae propodus; WLP = greatest width of the left chelae; WRP = greatest width of the right chelae; PL = first pleopod length; ASL = second abdominal somite length; J = juveniles; * = significant correlation; ns = non-significant correlation; P < 0.05).

Relation	n	Group	Power function y = ax ^b	r	A	b ≠ 1
CL x CW	333	♂	CL = 1.116CW ^{0.978}	0.985	-	150.537*
		♀	CL = 1.196CW ^{0.934}	0.982	-	155.316*
WW x CW	296	♂	WW = 0.001CW ^{3.172}	0.886	+	42.145*
		♀	WW = 0.001CW ^{2.938}	0.982	-	57.914*
LLP x CW	19	♂J	LLP = 0.769CW ^{1.346}	0.962	+	3.745*
		♂A	LLP = 0.917CW ^{1.237}	0.950	+	1.979*
		♀J	LLP = 0.738CW ^{1.410}	0.965	+	4.762*
		♀A	LLP = 1.193CW ^{1.082}	0.956	+	4.339*
LRP x CW	19	♂J	LRP = 0.322CW ^{2.318}	0.734	+	3.016*
		♂A	LRP = 0.835CW ^{1.289}	0.952	+	11.942*
		♀J	LRP = 1.078CW ^{1.059}	0.937	=	0.119*
		♀A	LRP = 0.609CW ^{1.073}	0.167	+	4.078*
WLP x CW	26	♂J	WLR = 0.748CW ^{0.743}	0.360	=	0.638*
		♂A	WLP = 0.422CW ^{1.150}	0.925	+	5.415*
		♀J	WLP = 0.507CW ^{0.803}	0.670	=	0.916*
		♀A	WLP = 0.490CW ^{1.058}	0.921	+	2.266*
WRP x CW	23	♂J	WRP = 0.295CW ^{1.238}	0.912	=	1.737*
		♂A	WRP = 0.365CW ^{1.231}	0.920	+	8.280*
		♀J	WRP = 0.229x ^{1.574}	0.884	+	3.086*
		♀A	WRP = 0.456x ^{1.089}	0.914	+	3.236*
PL x CW	264	♂	PL = 0.485CW ^{0.899}	0.880	-	5.200*
		♀	PL = 0.029CW ^{1.658}	0.224	=	0.120(ns)
ASL x CW	333	♂	ASL = 0.485CW ^{0.898}	0.787	+	30.67*
		♀	ASL = 0.029CW ^{1.658}	0.860	+	39.51*

its needed time for being metabolized (Hartnoll, 1985). We have found that *P. armatus* male weight increased more than their body size, a condition that was not found in females, which could probably be related to the distinct strategies of growth and reproduction developed by the sexes. Females allocate a great part of their energy from growth processes to the production of nutritive elements for their offspring. In contrast, males can channel their energy into somatic growth (Sastry, 1983). Being larger may also be advantageous, because it influences sexual selection, where larger males are more successful in fights for mating pairs (Abrams, 1988; Mantelatto and Martinelli, 2001; Fransozo *et al.*, 2003). Similar aged males that were heavier than females were also found in *Petrolisthes politus* populations (Scelzo, 1985).

Regarding the Brachyura, it is well established that the size of the male chelipeds and the female abdomen width are among the variables used to estimate the size at maturity (Pinheiro and Fransozo, 1993; Mantelatto and Fransozo, 1994). In our study, dispersion graphics involving male and female cheliped size were more useful to show

the evidence of changes in the data distribution pattern related to carapace width. We estimated graphically the interval between 3.5 and 4.5 mm as the size where the maturity transition may occur – an interval that also includes the size of the smallest ovigerous female captured (4.0 mm).

The range estimation of 3.5 to 4.5 mm CW for *P. armatus* size at maturity is in agreement with Oliveira and Masunari (1995) who considered mature specimens those with CW > 4.5 mm, in another southern region of Brazil and to Scelzo (1985) who considered mature females of *P. politus* in Venezuela. According to them, male or female specimens with 2.5 mm CW could be distinguished due to sexual dimorphism of the male appendage (gonopod). In our study it was possible to detect that difference between males and females, in agreement to the above mentioned authors. Contrary to life expectations in an environment under constant pollution stress such as the Araçá area, we observed that the studied population of *P. armatus* presented a growth pattern similar to another population living in a non-impacted region.

By analyzing the first pleopods, we found that their size did not increase proportionally to carapace width in males, in opposition to females, in which the growth seemed to be synchronized. Despite this fact, the final size of the appendage in males was greater than in females. Brossi-Garcia and Moreira (1996) studied the biometry and morphology of *P. armatus* juvenile stages and verified that until the first juvenile stage both males and females had presented four pairs of pleopods on the second, third, fourth and fifth segments of the pleon, while from the second juvenile stage on, males kept only the first pair of pleopods. All the female pleopods were maintained, but they became rudimentary – very similar to small protuberances – in the subsequent juvenile stages. Conversely, the unique male pleopod had a marked development, acquiring the biramous condition from the fourth juvenile stage onward. In the adult phase, the first female pleopods had a reduced size, whereas the others became larger, for the purpose of carrying the egg mass during the ovigerous condition.

When morphometric parameters are utilized to describe growth in crustaceans, it is important to analyze them in individuals of different sizes in order to distinguish the patterns in adults and juveniles (Hartnoll, 1982). In this sense, it is possible to infer that the negative allometry found in the present study did not show the real increase in this

variable. This situation can be explained by the small number of individuals included in the range that Brossi-Garcia and Moreira (1996) had applied to describe the pattern change of *P. armatus* pleopod development (CW = 1.56 mm) and where it had been possible to analyze the gonopod (n = 2).

According to Hartnoll (1982), young individuals present higher growth rates than adults and these rates may reduce as the body size increases. Therefore, it is possible that the first pleopod grows faster on males during young ages and this growth could then be lower in subsequent phases, allowing us to find a negative allometric relationship that could have contributed to our difficulty in identifying the gender of small individuals; thus generating a large number of animals that could not have their sex identified (*see* Miranda and Mantelatto, 2009). This study demonstrates that males and females of *P. armatus* present similar patterns of growth. Males reach larger sizes, although in the majority of the studied relationships they showed a similar pattern, differing only according to the weight and the growth of the first pleopod.

Considering that *P. armatus* presents a known geographic distribution that covers a wide range of latitudes (Melo, 1999; Stillman and Reeb, 2001) and that some unusual characteristics are detected in the population that lives in an impacted area (Miranda and Mantelatto, 2009; present study), this species represents an ideal candidate for future and comparative studies of other non-impacted populations and populations inhabiting other latitudes, in order to test the growth process characteristics and peculiarities described here.

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