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Research Article

Morphometric sexual maturity and allometric growth of the crab *Sesarma rectum* Randall, 1840 (Crustacea: Sesarmidae) in an impacted tropical mangrove in northeast Brazil

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ABSTRACT. The size at sexual maturity and the allometric growth of the semi-terrestrial crab *Sesarma rectum* were studied in an impacted tropical mangrove in northeast Brazil. Crabs were monthly collected during spring low-tide periods, from October 2009 through September 2010. A catch-per-unit-effort (CPUE) technique was used to sample the crab population, with two-hour sampling periods, by two people. A total of 492 crabs were obtained, being 262 males and 230 females. The specimens were measured at carapace width (CW), the left and right propodus length and height (RPL, RPH, LPL and LPH), and the gonopod length of males (GL), and abdomen width (AW) of females. In males, the inflection point was at 27.14 mm CW in the relationship between CW and the length of right propodus (LRP), considering the morphological size at the onset of maturity. Based on the relationship between CW and AW, the size at sexual maturity in females was 22.97 mm. In spite of living in an impacted area, this population attained the maturity onset at a bigger size than other localities.

Keywords: *Sesarma rectum*, sexual maturity, allometric growth, tropical mangrove, northeast Brazil.

Madurez sexual morfométrica y crecimiento alométrico del cangrejo *Sesarma rectum* Randall, 1840 (Crustacea: Sesarmidae) en un manglar tropical impactado en el noreste de Brasil

RESUMEN. La madurez sexual morfométrica y el crecimiento alométrico del cangrejo semiterrestre *Sesarma rectum* fueron estudiados en un manglar tropical modificado en el noreste de Brasil. Los cangrejos fueron colectados mensualmente durante los períodos de marea baja desde octubre 2009 a septiembre 2010. Para obtener una muestra representativa de la población se utilizó la técnica de captura por unidad de esfuerzo (CPUE), con períodos de dos horas de captura realizada por dos personas. Se obtuvo un total de 492 cangrejos: 262 machos y 230 hembras. Se realizaron mediciones del ancho del caparazón (AC), longitud y altura del propodio izquierdo y derecho, longitud del gonopodo de los machos (LPI, API, LPD, APD e LG), y ancho del abdomen (AW) de las hembras. En los machos, el punto de inflexión se determinó en 27,14 mm CW en la relación entre CW y la longitud del propodio derecho (LPD), considerado el tamaño morfológico al inicio de la madurez. Basado en la relación entre el CW y AW, el tamaño de madurez sexual de las hembras fue de 22,97 mm. A pesar de vivir en una zona afectada, esta población alcanza el inicio de la madurez sexual a un tamaño mayor que en otras localidades.

Palabras clave: *Sesarma rectum*, madurez sexual, crecimiento alométrico, manglar tropical, noreste de Brasil.

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INTRODUCTION

Growth can be expressed by the increase of size, volume, wet weight or dry weight over time. Organisms that do not have an exoskeleton present a continuous growth, but in Crustacea, which have a rigid and inextensible exoskeleton, growth becomes an essentially discontinuous process. There is a succession of molts or ecdyses, separated by an intermolt period (Hartnoll, 1982).

According to Huxley (1932), the allometric equation is the most utilized method for analysis of growth during the ontogeny. The relationship between the size of a body part (y) compared with another body part (x), generally the carapace width (CW), can be expressed by the equation $y = a.x^b$, where the exponent b is the measure of the different rates of growth of the two body parts. To estimate the coefficients of allometric equation, the data are usually logarithmized and a linear regression is fitted, and represented by the equation $\log y = \log a + b \cdot \log x$, where the allometric exponent b is the slope of the resulting linear equation (Teissier, 1960).

In crustaceans, the allometric relationships between body size and various organs are used to estimate the sexual maturity, assuming that the secondary sexual characteristics appear and grow at different rates in mature and immature stages (Leme, 2005). The transitional phase in Brachyura involves morphological changes that can be detected by inflections or discontinuities in a series of linear or curvilinear relationships using a bivariate analysis (Haefner Jr., 1990).

Studies of relative growth in crustaceans allow to define the type of allometry in the growth of different body parts, such as chelae, locomotor appendages, abdomen and pleopods, and to relate them to their specific functions. One responsible factor for these changes in the allometric growth is the sexual maturity (González-Gurriarán & Freire, 1994).

The allometric relationships are powerful tools used by taxonomists and ecologists in the analysis of intraspecific and interspecific variation among different populations and to estimate the average size at sexual maturity, also related to environmental conditions (Costa & Soares-Gomes, 2008).

Several studies related to allometry in Brachyura have been conducted, mainly in Brazil and especially regarding mangrove crabs of the genus *Uca* (Negreiros-Fransozo *et al*., 2003; Benetti & Negreiros-Fransozo, 2004; Masunari *et al*., 2008). Sesarmid crabs are very abundant in mangrove forests (Priyadarshani *et al*., 2008), and the species *Sesarma rectum* Randall, 1840, that builds burrows in shaded areas or along the edge of the mangrove, and feeds on detritus and leaves (Prado, 1999), is very numerous in these environments. There are few studies about sexual maturity and allometric growth of sesarmid crabs (Leme, 2005; Castiglioni *et al.,* 2011).

The human impacts, such as residential development in mangrove or estuarine areas drastically change this environment, preventing the establishment of certain organisms like crabs (Silva *et al*., 2007). The present contribution aimed to elucidate some aspects of the growth and sexual maturity of *S. rectum,* in an impacted tropical mangrove in the State of Ceará, northeast Brazil, contributing to generate information for the conservation of this area.

MATERIALS AND METHODS

The study site is an impacted mangrove situated in the Cocó River Ecological Park in the municipality of Fortaleza, Ceará (3°45’07’’S, 38°29’05’’W) (Fig. 1). The Cocó River Ecological Park is the largest urban park in South America, with an area of 379 hectares. Almost the entire park shows advanced degradation of its ecosystem, with major consequences especially from city expansion promoted by real-estate speculation, and also from slum areas around the park (SEMACE, 2006).

Monthly sampling (CPUE, 2 people for 2 hours), took place during spring low-tide periods, from October 2009 through September 2010. Specimens were obtained manually, some exposed on the surface of the mangrove substrate, and others captured by digging.

In the laboratory, specimens were identified and sexed according to secondary sexual characters (abdomen morphology and number of pleopods). The following variables were measured in the laboratory to the nearest 0.1 mm using a vernier caliper: carapace width (CW), carapace length (CL), the left and right propodus length and height (RPL, RPH, LPL and LPH), and gonopod length of males (GL), and abdomen width (AW) of females (Fig. 2).

The morphometric relationships CW/RPL for males and CW/AW for females were tested to estimate the size at sexual maturity, based in changes of these structures. The examined variables were subjected to a regression analysis, considering two ranges of amplitude of CW corresponding to the two stages of reproductive development (immature and mature) in both sexes, based solely on morphology. The allometric technique was employed to distinct adults (matures) from juvenile crabs (immatures) and

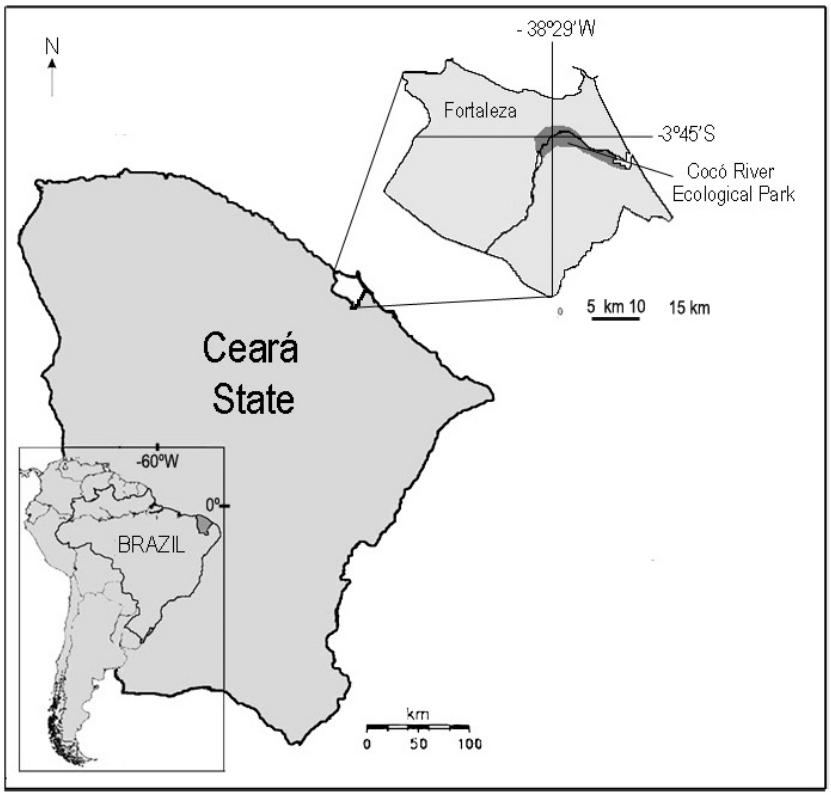

Figure 1. Sampling area in the Cocó River Ecological Park, municipality of Fortaleza, Ceará State, Northeast Brazil.

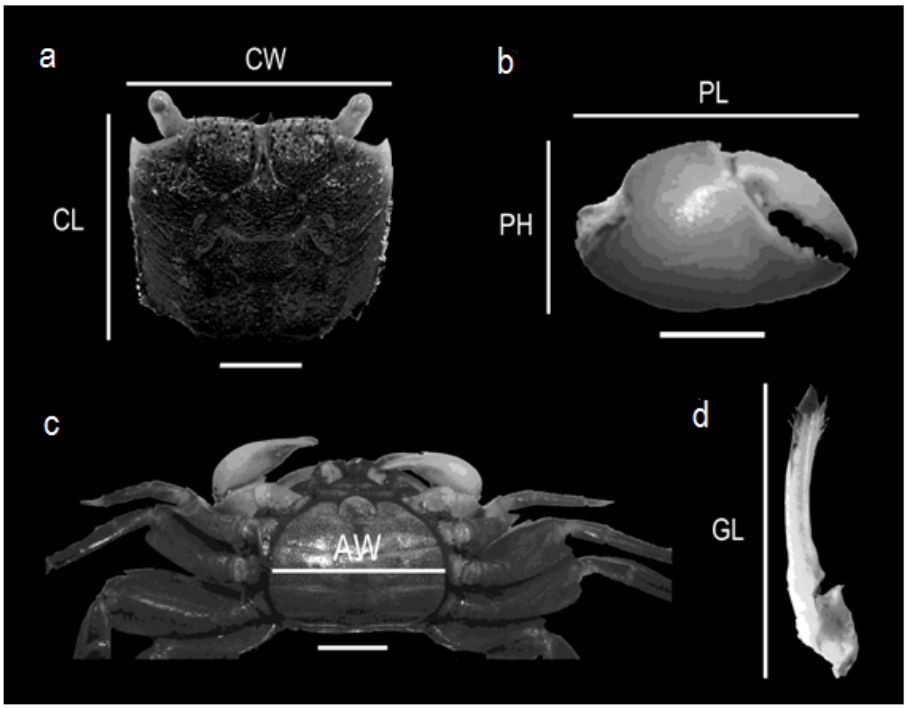

Figure 2. *Sesarma rectum.* Body measurements. a) Carapace in dorsal view, CW: carapace width; CL: carapace length, b) male chelipod, PL: propodus length; PH: propodus height, c) female abdomen CW: abdomen width, d) male gonopod, GL: gonopod length (12.77 mm). Scale = 1 mm.

to estimate the size at the onset of morphologic sexual maturity using the Interactive Process for the Determination of the Transition Point routine of the software Regrans (Pezzuto, 1993). The data set of linear regression divides in two subsets, the inflexion point corresponding to the puberty molting.

In the allometric growth, the carapace width (CW) was used as the independent variable *x*, since it is the most representative dimension of the overall size of the animal (Hartnoll, 1982), related to other body dimensions, the dependent variables *y,* in males, the gonopod length (GL), the carapace length (CL), the height and length of right propodus (RPH and RPL) and the height and length of left propodus (LPH and LPL) and in females, the carapace length (CL) and abdomen width (AW).

Aiming to investigate the occurrence of allometry between the morphometric variables, specifically those related to secondary sexual characteristics, their values were logarithmized ($log\ y = log\ a + b\ log\ x$) and the function $y = a \cdot x^b$, where x is the independent variable (CW), *y* is the dependent variable, *a* is the intercept (value of *y* when $x = 0$), and *b* the slope of the regression line.

The *b* value indicates the growth patterns of the analyzed variables, considering three possibilities: $b = 1$ (isometry), $b < 1$ (negative allometry), $b > 1$ (positive allometry) (Hartnoll, 1982; Fonteles-Filho, 1989). The statistical significance of *b* was tested by Student t-test.

RESULTS

A total of 492 crabs, being 262 males and 230 females, were analyzed in the present study. The CW of males ranged from 15.03 to 36.18 mm, while in females ranged from 13.43 to 32.92 mm. The RPL of males ranged from 8.95 to 31.31 mm and the AW of females ranged from 7.34 to 25.57 mm.

In the ontogenesis of males, the RPL showed an inflexion point in 27.14 mm CW, having 64 individuals in the subset of data at the left of the regression graphic and 198 at the right (Fig. 3). The data both at the right and at the left of the inflexion point showed a positive allometric growth. The equations that represent the relation CW/RPL in juveniles and adults, and the significance test of slope can be visualized in Table 1.

Among females, the dispersion graphic of empiric points showed an inflexion point at 22.97 mm CW (Fig. 4), having 35 individuals in the subset of data on the left of the regression graphic and 195 on the right. The growth of AW was positively allometric in the beginning of development and, after the puberty molt, it became slightly positive, pratically isometric (Table 1).

Males and females showed positive allometry between CW and all dimensions analyzed. In relation to reproductive stage (juvenile and adults), the allometric relations showed different levels of growth, that can observed for the different values of the coefficient *b* in each relation analyzed, but all the relations showed a positive allometric growth (Table 1).

DISCUSSION

In Brachyura, after puberty molt some morphometric changes related to morphological and functional sexual maturity occur. Males can be considered functionally mature when they are able to manipulate the female during the courtship process to achieve pre-copulatory mate successfully. Females are considered mature when they are able to copulate and to lay eggs (Gonzalez-Gurriarán & Freire, 1994).

The relationship between RPL and CW in the present study resulted in the morphological sexual maturity for males of *S. rectum*, at a size larger than that observed in other population from northeast of Brazil, in Arinquindá River mangrove (Pernambuco State) (Castiglioni *et al*., 2011). The present contribution reports a positive allometry of cheliped for both juvenile and adult individuals of *S. rectum*, which is consistent with the predictions made by Hartnoll (1974), who compared the growth related to secondary sexual characteristics in 26 species of Brachyura. This author proposes that although there is a great variation in growth rates of cheliped from species to species, this growth follows a similar pattern.

However, other authors found that the relation CW/GL as a better way to estimate the sexual maturity for male crabs: *i.e.*, Silva *et al*. (2007) for *S. rectum* from Ubatuba (= 18.5 mm CW) and Leite (2005) for *Ucides cordatus* (Linnaeus, 1763) (= 40.0 mm CW). Moreover, the allometric analysis of the chelipeds was not the best one to estimate the size at sexual maturity in *Goniopsis cruentata* (Cobo & Fransozo, 1998) and *Portunus spinimanus* Latreille, 1819 (Santos *et al*., 1995).

The level of allometric growth of gonopods changes after the puberty molt in the American ghost crab *Ocypode quadrata* (Haley, 1969). In the portunid crab *Ovalipes catharus* (White, 1843), the growth of this appendage in immature animals was significantly higher than in mature ones (Davidson & Marsden,

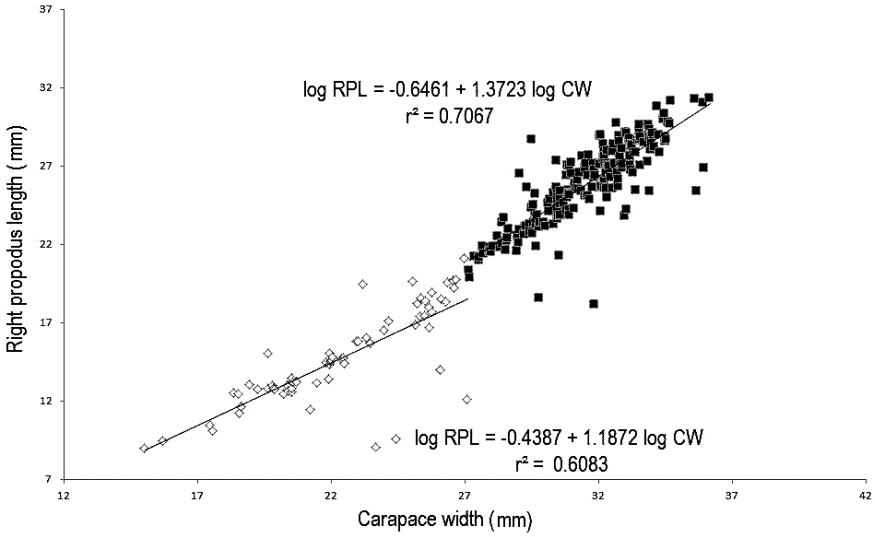

Figure 3. *Sesarma rectum.* Dispersion points between the dimensions RPL and CW of males to determine the morphological size at onset of maturity, in a population living in the mangrove of the Ecological Park of Cocó River, Fortaleza, Brazil. White points: juveniles, black points: adults. RPL: Right propodus length, CW: carapace width.

1987). In the "stone-crab" *Menippe nodifrons* Stimpson, 1859 the morphometric relationship CW/GL showed positive allometry in juveniles and isometry in adults (Bertini *et al*., 2007). These diverse data show that the gonopod growth is more pronounced in juvenile organisms than in adults. In the present study, males also showed a positive allometric growth for juvenile and adults individuals in the relationship CW/GL and the gonopod had a higher growth rate (*b*) in juvenile organisms.

In brachyuran crabs, the female abdomen has a role related to the protection and hatching of eggs that are adhered to the pleopods. Changes in allometric growth of this structure occur at the beginning of sexual maturity (Hartnoll, 1974). The sexual dimorphism of abdomen is related to differences in the function of male and female pleopods. In male crabs, the pleopods (gonopods) do not need to increase much in size in relation to carapace width. Finney & Abele (1981) also confirm this information, stating there is no reproductive advantage in rapid growth of gonopods. On the other hand, females have a marked increase in abdomen size, due to the function of the pleopods to hold the egg mass and act as an incubation chamber for developing eggs.

According to Finney & Abele (1981), the abdomen growth rate decreases slightly as a result of the sexual maturity, a fact that was observed in this study, in which a high positive allometric growth occurred in juvenile females, and a practically isometric growth in adult females. In *S. rectum* females from Ubatuba, studied by Leme (2005), the general pattern of Brachyura was not found. Individuals collected were divided into five phases of abdomen growth. In phase 1, the crabs were considered immature (12-15 mm CW) and abdomen showed isometric growth. For the phases 2 (12-18 mm CW) and 3 (18-21 mm CW), the allometric growth was positive. In phases 4 (21-24 mm CW) and 5 (>24 mm CW), growth was again isometric.

The inflection of the straight line in the dispersion graphic of AW/CW clearly demonstrated the point at which sexual maturity is attained by females of *S. rectum*. Thus, the discontinuity of the lines indicated that the morphometric maturity was reached at 22.97 mm CW.

Interestingly, three ovigerous females with sizes smaller than 22.97 mm CW were found during the study period, two in January 2010 and one in February 2010. This may be because some females may reach maturity early than most population. It is noteworthy that maturity should be considered as a long process rather than a specific moment (Luppi *et al*., 2004), since the functional, gonadal and morphometric maturities are not always synchronized, and they can be reached at different stages of growth (López-Greco & Rodríguez, 1999).

Some examined measures as CW/CL for males and females, CW/AW for adult females and CW/GL for adult males showed that the allometric growth is biologically isometric, even that the significance of Student's t-test has indicated that it was slightly

Table 1. *Sesarma rectum*. Regressions for body dimensions. (A, adult; *a* and *b* constants; AW: abdomen width; allometry = positive (+), negative (-), isometry (0); CL: carapace length; CW: carapace width; F: females; GL: gonopod length; J: juvenile; LPL = left propodus length; LPH: left propodus height; M: male; N: number of crabs; r^2 = determination coefficient; RPL: right propodus length; RPH: right propodus height, t = *t* test for the slop *b*). * Significant level for the t-Student test, $\alpha = 0.05$.

Relationships	Sex	N	Linearized equation		r^2	t (b = 1)	Allometry
			log y = log a + b log x				
CW *vs* CL	M	262	log CL	= - 0.0810 + 1.0202 log CW	0.9499	70.3022*	+
	F	230	log CL	= - 0.1125 + 1.0346 log CW	0.9754	95.4675*	+
	JF	35	log AW	= - 1.3257 + 1.9271 log CW	0.9055	17.7905*	+
CW *vs* AW	AF	195	log AW	= - 0.1047 + 1.0084 log CW	0.8153	29.2666*	+
	MJ	13	log GL	= - 0.9064 + 1.4160 log CW	0.8037	6.7112*	+
CW *vs* GL	MA	249	log GL	= - 0.4071 + 1.0103 log CW	0.8538	37.9549*	+
	MJ	64	log RPL	= - 0.4387 + 1.1872 log CW	0.6083	9.8113*	+
CW *vs* RPL	MA	198	log RPL	= - 0.6461 + 1.3723 log CW	0.7067	21.7444*	+
	MJ	35	log RPH	= - 0.8825 + 1.3660 log CW	0.7051	8.8825*	+
CW *vs* RPH	MA	227	log RPH	= - 0.7850 + 1.3105 log CW	0.6515	20.5111*	+
CW *vs* LPL	M	262	log LPL	= - 0.9886 + 1.5999 log CW	0.8578	39.5880*	+
CW *vs* LPH	M	262	log LPH	= - 1.2222 + 1.5375 log CW	0.8481	30.0811*	+

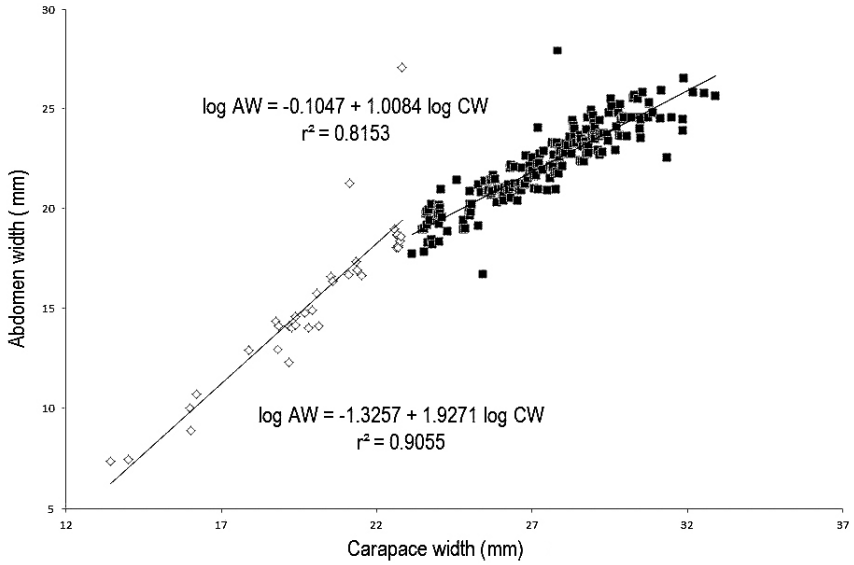

Figure 4. *Sesarma rectum.* Dispersion points between the dimensions AW and CW of females to determine the morphological size at onset of maturity, in a population living in the mangrove of Cocó river Ecological Park, Fortaleza, Brazil. White points: juveniles, black points: adults. AW: abdomen width, CW: carapace width.

positive; the value of *b* was not so different from isometric levels.

There are few studies of allometric growth for populations of *S. rectum*. Allometric analyses performed by Leme (2005) to females of a population of *S. rectum* from Ubatuba (State of São Paulo), did not reveal a point of inflection of the curve. Thus, sexual maturity was estimated based on the analysis of the gonad development, which revealed that they reached sexual maturity at about 17.42 mm CW. Silva & Chacur (2002) reported a morphological sexual maturity of 13.3 mm CW for females and of 14.4 mm

CW for males, for a population of *S. rectum* from Itamambuca Mangrove (São Paulo). On the other hand, for the population of *S. rectum* studied by Silva *et al*. (2007) in Paraty (State of Rio de Janeiro), sexual maturity is suggested to be 17.4 mm CW for females and 18.5 mm CW for males. Recently, Castiglioni *et al.* (2011) studying a *S. rectum* population in Arinquindá River, Pernambuco State, northeast Brazil reported a morphological sexual maturity of 16.71 mm CW for females and 15.73 mm CW for males. These values are lower than those obtained in the present study: 27.14 mm CW for males and 22.97 mm CW for females. These variations in the required size to reach sexual maturity could be due to abiotic factors, acting locally and seasonally (Wenner *et al*., 1974). In general, populations of degraded areas reach sexual maturity at smaller sizes when compared to those of undisturbed areas, investing much more energy to reproduction instead of somatic growth as a way of perpetuating the population (Silva *et al*., 2007). But, in this contribution, the crabs reached sexual maturity at larger sizes. This suggests that this *S. rectum* population is adapted to the habitat, although this place is located in a heavily urbanized area and has been the target of recent human impacts.

Allometric analysis contributes to a better understanding of many biological events that occur in the life cycle of animals (Gould, 1996). Carapace width is the body dimension most used as the independent variable in the analysis of relative growth of crabs, because it fully represents the physiological changes that occur throughout their life history (Castiglioni & Negreiros-Fransozo, 2004). The type of growth found in this study is consistent with predictions for Brachyura, according to Hartnoll (1978, 1982).

Our results showed that the population of *S. rectum* from Cocó River Ecological Park reaches the morphometric sexual maturity at greater sizes than those reported in other localities. In spite of living in an impacted area, the allometric growth of this population follows the general patterns of Brachyura.

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