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Research Article

First record and preliminary information on the biology of the deep-sea African crab, *Chaceon gordonae* (Ingle, 1985) (Brachyura: Geryonidae) in Saint Peter and Saint Paul Archipelago, Brazil

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ABSTRACT. Several studies conducted in Brazilian oceanic islands have generated many results of great significance for the understanding of these ecosystems. However, most of these studies have been restricted to shallow waters, not going beyond 200 m depth. In this work, seven exploratory deep-water fishing surveys were carried out with bottom traps at Saint Peter and Saint Paul Archipelago, between 2012 and 2014, at depths ranging from 300 to 700 m. During these surveys the presence of a deep-sea crab, identified as *Chaceon gordonae* was recorded, with 458 specimens being caught. Of the sampled specimens, 252 were males and 206 were females. The carapace length (CL) of sampled crabs measured, on the average, 110.81 ± 14.52 mm for males and 102.00 ± 16.55 mm for females. In general, the β_1 parameter of the length-weight relationship indicates a positive allometric growth. A comparison of linear regression between the carapace length and right chela length and width for males suggested a morphological maturity of 108.90 and 110.10 mm CL, respectively, whereas the regression between carapace length and abdomen width in females indicated a size at morphological maturity of 84.00 mm CL.

Keywords: *Chaceon gordonae*, Decapoda, biology, reproduction, growth, oceanic islands, Brazil.

Primer registro e información preliminar de la biología del cangrejo de profundidad *Chaceon gordonae* (Ingle, 1985) (Brachyura: Geryonidae) en el Archipiélago San Pedro y San Pablo, Brasil

RESUMEN. Varios estudios realizados en las islas oceánicas brasileñas han generado resultados de gran importancia para la comprensión de estos ecosistemas. Sin embargo, la mayoría de estos estudios se han limitado a aguas poco profundas, no más allá de 200 m de profundidad. Se analizan siete campañas experimentales de pesca en aguas profundas efectuadas con trampas de fondo en el Archipiélago de San Pedro y San Pablo, a profundidades de 300 a 700 m, entre 2012 y 2014. Durante estos estudios, se registró la presencia de 458 especímenes del cangrejo de profundidad *Chaceon gordonae*. De los ejemplares analizados, 252 fueron machos y 206 hembras. La longitud de caparazón (CL) midió en promedio 110,81 ± 14,52 mm en los machos y 102,00 ± 16,55 mm en las hembras. En general, el parámetro β1 de la relación longitud-peso mostró un crecimiento alométrico positivo. La comparación de la regresión lineal entre la longitud de caparazón y la longitud y ancho de la chela derecha en los machos indicó una madurez morfológica a 108,90 y 110,10 mm LC, respectivamente, mientras que la regresión entre la longitud y ancho del caparazón del abdomen de las hembras indicó una talla de madurez morfológica a los 84,00 mm CL.

Palabras clave: *Chaceon gordonae*, Decapoda, biología, reproducción, crecimiento, islas oceánicas, Brasil.

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INTRODUCTION

Chaceon is the most numerous genus of the Family Geryonidae, including 28 species, which are widely distributed around the continental slopes and seamounts of the world oceans (Manning & Houlthuis, 1989; Tavares & Pinheiro, 2011). *Chaceon gordonae* (Fig. 1) was previously recorded by Ingle (1985), with a reported distribution from Sierra Leone Ridge, off western Africa, to southern Iceland, based, however, on only two males and two females. Later, Afonso-Dias *et al.* (2008) provided the second record of the species in the North Atlantic Ocean, from São Tomé e Príncipe Archipelago, off western Africa, reporting that *C. gordonae* had been regularly caught there in reasonable quantities, sustaining a small artisanal fishery.

In the South Atlantic Ocean, the first records of geryonid crabs were made by Scelzo & Valentini (1974), which identified individuals from oceanographic expeditions conducted on the continental shelf and slope of Brazil, Uruguay and Argentina. Between 1999 and 2007, *C. notialis* and *C. ramosae* sustained a commercial fishery in Uruguay and southern Brazil (Defeo *et al.*, 1991; Pezzuto *et al.*, 2002, 2006; Perez *et al.*, 2009). In the eastern side of the South Atlantic Ocean, another species of geryonid crab, named *C. maritae*, has been fished off Namibia, Angola and South Africa, contributing, for instance, for approximately 2.5 to 3.5% of Angola´s GNP (gross national product) (Melville-Smith, 1987; Van Roosbroeck *et al.*, 2006). In northeastern Brazil, Sankarankutty *et al.* (2001) and Carvalho *et al.* (2009) reported the occurrence of *Chaceon*, initially reported as *Chaceon fenneri*. In 2011, however, Tavares & Pinheiro (2011) concluded that those specimens belonged to a new species, described as *Chaceon linsi*.

Morphometric information is important for biological studies and in brachyuran crabs the analysis of relative growth is widely used to assess maturity because it may reveal changes along the ontogeny, indicating differences in growth not only between sexes, but also between pre- and post-pubertal molt (Hartnoll, 1974, 1978; Fernández-Vergaz *et al.*, 2000). For this kind of analysis, the dimensions of body structures, which are directly or indirectly used for reproduction, such as the chela for males and the abdomen for females (Hartnoll, 1974), are often used. Data related to sexual maturity are crucial for the study of the reproductive cycle and are thus vitally important to guide the adoption of fisheries management measures required to ensure the conservation of the exploited species.

A research project developed by the Universidade Federal Rural de Pernambuco, around Saint Peter and Saint Paul Archipelago (SPSPA), detected the presence of *Chaceon gordonae*, representing the first record of this Geryonid crab species at the Central-Equatorial Atlantic. The morphological maturity of the species was estimated and its size structure and distribution by depth were described. An evaluation of the sex ratio was also presented. The findings reported here add new information to the few studies available on Geryonid crabs, particularly about *C. gordonae*, in the South Atlantic, contributing thus to its conservation.

MATERIALS AND METHODS

The Saint Peter and Saint Paul Archipelago (Fig. 2) is a small group of rocky islands located in the Mid-Atlantic Ridge, between the northern and southern hemispheres and the African and the American continents (00°55'N, 29°20'W). It is about 510 nm far from the Brazilian coast and 282 nm far from Fernando de Noronha Archipelago (Viana *et al.*, 2009).

Seven research cruises were carried out between January 2012 and April 2014 to explore deep-sea using as fishing gear, three different types of bottom baited traps (big rectangular, 2.0x0.9 m, with 30 cm opening; medium rectangular, 2.0x0.6 m, and 20 cm opening; and circular, with 60 cm diameter and 30 cm opening) at depths ranging from 300 to 700 m. Traps were covered by a 25 mm plastic mesh. At each haul were released three traps, one by each model, deployed alternately (big rectangular, medium rectangular, and circular) with 20 m intervals, and, on average, seven hauls were conducted at each cruise. Specimens caught were labeled and storage in the boat for posterior transport and analysis at the laboratory.

Figure 1. *Chaceon gordonae* (Ingle, 1985). Male with 83 mm carapace length, 110 mm carapace width, collected in Saint Peter and Saint Paul Archipelago, at 330 m depth.

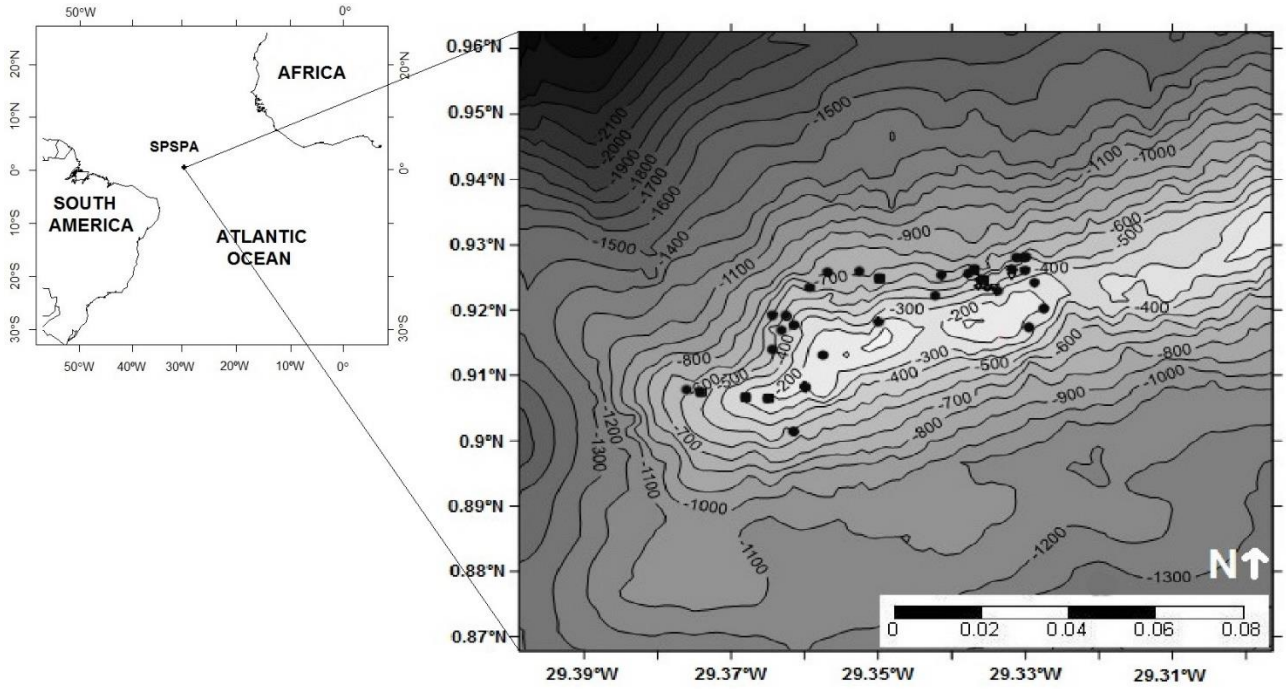

Figure 2. Location of Saint Peter and Saint Paul Archipelago, Brazil. Black dots representing sampling stations.

A vernier calliper with 0.01 mm precision was used to measure the key variables: carapace width (CW), carapace length (CL), left and right chela width (LCHW and RCHW), left and right chela length (LCHL and RCHL), and female maximum abdomen width (AW). The wet weight (W in g) of both males and females was recorded in order to establish a length-weight relationship. The size frequency distribution was obtained by grouping the measurements of carapace length (CL) in 20 mm intervals. Carapace width, carapace length and weight of males and females were compared using a Student t-test. To assess if carapace length of males and females showed significant differences ($P < 0.05$) among surveys (months), Shapiro-Wilk (normality) and Levene tests (homocedasticity) were applied. Because the data showed neither a normal distribution (for males: $W = 0.8898$, and for females: $W = 0.8835$; $P = 0.0001$), nor homocedasticity ($P = 0.0282$), a nonparametric ANOVA (Kruskal-Wallis t test) was used, followed by a Student Newman Keuls (SNK) test for comparison of medians (Zar, 2010).

Due to the loss of appendages in some specimens, only those that were whole were employed to establish the length-weight relationship, using the total wet weight (g) and the carapace length (mm) of the specimens. The standard power function was applied, in which W is the body wet weight of an individual crab of CL, β_0 is the intercept, and β_1 is the growth factor parameter, as follows:

$$W = \beta_0 CL^{\beta_1}$$

The parameters were obtained by logarithmic least square regression. Student-t test was used to establish the type of relative growth (allometric or isometric) by comparing β_1 estimates with the expected value under a null hypothesis (isometry with $\beta_1 = 3$) (Fonteles-Filho, 2011).

The morphometric maturity of *C. gordonae* was studied by analyzing the relative growth pattern of the key variables (RCHL, LCHL, RCHW, LCHW, and AW for females) against carapace length (CL), as an independent variable. The standard power function linearized using logarithmic transformations was fitted to the data by least square regression. The inflexion point on the curve, indicating the occurrence of a significant change in the previous growth pattern, in which the pubertal molt probably occurs, was determined by the maximum difference in intercept (β_0) and angular coefficients (β_1) of the models (Fonteles-Filho, 2011; Shinozaki-Mendes *et al.*, 2012a), in which consecutive values of CL are used as separation points between immature and mature curves, and the highest value is considered the point of maximum inflection. For comparison between coefficients (β_0 and β_1) of the models, the "W" test was used, which is based on maxi-

mum likelihood and uses the chi-squared distribution (Mendes, 1999; Shinozaki-Mendes *et al.*, 2012b). Regenerating chela of males were excluded from the analysis.

RESULTS

Length and weight distributions and sex ratio

Of the 458 crabs measured, 252 were males and 206 were females. Males and females ranged from 40.60 to 137.10 mm and from 41.60 to 139.80 mm CL, respectively. On average, males were larger (mean CL = 110.81 ± 14.52 mm SD) and heavier (650.39 ± 236.26 g SD) than females (mean CL and weight, respectively= 102.00 ± 16.55 mm SD and 387.42 ± 151.89 g SD). According to the Student-t test, differences in measurements between males and females were highly significant, a typical patterns for gerionids (Table 1). The length frequency distribution was unimodal and skewed to the smaller sizes in both sexes (Fig. 3). Carapace length of the crabs differed among the surveys (Kruskal-Wallis ANOVA, H = 65.00; n = 458; $P < 0.001$). Mean lengths tended to be larger in January and smaller in October (Fig. 4). The highest abundance (in number of crabs caught) was recorded in January (127 crabs), while the lowest was recorded in December.

The length-weight relationship of *C. gordonae*, based on a subsample of 284 crabs (127 males and 157 females), revealed a positive allometric growth. However, when individuals were analyzed by sex, the β_1 parameter suggested a negative allometric growth in females and a positive growth in males (Table 2).

The overall sex ratio (M:F) was 1:0.82. When analyzed by month, males revealed to be more abundant in March, June, October and December, whereas females predominated in April and May. In January, the sex-ratio was 1:1.31 and in October just a single female was caught (Table 3). A segregation of sexes by depth intervals was observed in the shallowest and deepest strata (χ^2-test, $P < 0.05$; Table 4), and no ovigerous female were caught at these depth. However, in the middle strata between 400 to 600 m depth, 54 ovigerous females were observed.

Depth distribution

C. gordonae were captured in a depth range from 300 to 700 m. Although the crabs were caught in all depth strata, they were more abundant between 400 and 500 m. Moreover, significant differences were observed in depth distribution by sexes (Table 4). Males were caught more frequently than females over most of their range, except for the 600 m strata, where females predominated. Differences between male and female monthly distribution were not observed.

Morphometric analysis

The comparison between length and width chela measurements for males showed that right chela had a greater increase than the left chela ($P < 0.001$ for length and width) (Table 5). Hence the morphometric maturity for males was calculated with the relationship between right chela measurements against CL, while for females this relationship was calculated between abdomen width (AW) against CL. The maximum inflection points that indicate morphological maturity was estimated at 108.90 mm CL (based on right chela width; $P = 0.0415$; Fig. 5a) and 110.10 mm CL (based on right chela length; $P = 0.0005$, Fig. 5b), and 84.00 mm CL for females, based on the abdomen width ($P = 0.0005$; Fig. 5c).

DISCUSSION

The geryonid crabs are characterized by their hexagonal carapace, longer than wider, with anterolateral margins convex, each one with 3-5 teeth, depending on the genre to which individuals belong, being more distinct in *C. gordonae* and *C. affinis* than in others (*i.e.*, *C. maritae* and *C. fenneri*) (Colosi, 1923; Manning & Holtuis, 1989). Ingle (1985) described *Chaceon gordonae*, previously known as *Geryon gordonae* (Manning & Holtuis, 1989), from only two males (CL 118 and 119 mm) and two females (CL 81 and 89 mm), from a depth of 1,153 m, reporting a distribution for the species from the Sierra Leone Ridge, off West Africa, to southern Iceland. Afonso-Dias *et al.* (2008) reported the occurrence for this species in São Tomé Island, the larger of two islands of São Tomé e Príncipe Archipelago, as well off the west coast of Africa, with a CL range between 77 and 129 mm for males and 75 and 119 mm for females, with a depth between 500 and 1,200 m.

Here, the first occurrence of *C. gordonae* to the Mid-Atlantic Ridge is reported, particularly to the Saint Peter and Saint Paul Archipelago, a rare Brazilian insular ecosystem located on central equatorial Atlantic, which plays a very important role in the life cycle of several species of marine organisms (Viana *et al.*, 2009). Material was deposited in the Museum of Oceanography Petrônio Coelho, located in Federal University of Pernambuco. This is the fourth geryonid crab occurring in Brazilian waters. The goal of the present study was thus to provide biological information on a virgin population of deep-sea crab in the SPSPA that does not have any type of previous exploitation, ensuring data that can be used to develop future management and conservation plans.

Table 1. Sample size (n), range, mean, and standard deviation (SD) of carapace length and weight of males and females of the deep-sea African crab, *Chaceon gordonae* (Ingle, 1985), caught during deep-water fishing surveys carried out in the vicinity of the Saint Peter and Saint Paul Archipelago (differences tested by Student t-test).

Variables		n	Range	Mean ± SD	t-test
CL (mm)	Males	252	40.60 - 137.10	110.81 ± 14.52	t = 6.06
	Females	206	41.60 - 139.80	102.00 ± 16.55	$P < 0.0001$
	Total	458	40.60 - 139.80	106.85 ± 16.06	
Weigth (g)	Males	127	177.00 - 1420.00	650.39 ± 236.26	t = 6.63
	Females	157	19.00 - 675.00	387.42 ± 151.89	$P < 0.0001$
	Total	284	19.00 - 1420.00	505.01 ± 233.93	

Table 2. Length-weight relationship parameters for males and females of deep-sea African crabs *Chaceon gordonae*, caught around Saint Peter and Saint Paul Archipelago. Intercept (β_0), growth parameter (β_1), standard error of the mean (SE), determination coefficient (r^2), sample size (n).

	β_0	β_1	SE(β_1)	r^2	n	*t*-test	*P*	SE estimate
Females	0.0009	2.79	± 0.09	0.85	157	29.99	<0.0001	± 0.235
Males	0.0002	3.17	± 0.17	0.72	127	18.29	<0.0001	± 0.209
Total	0.0003	3.07	± 0.08	0.83	284	37.54	<0.0001	± 0.245

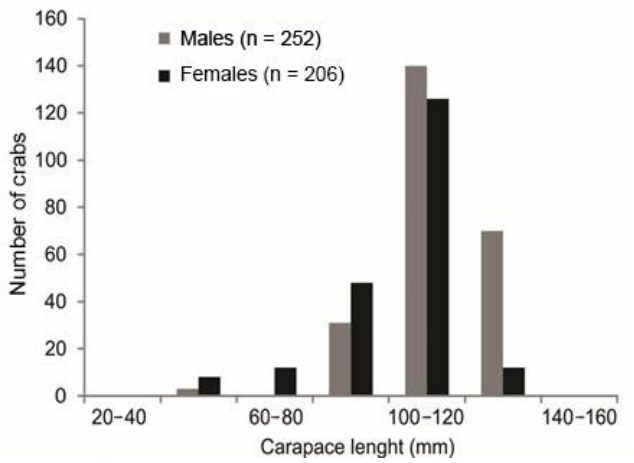

Figure 3. Deep-sea African crab *Chaceon gordonae* (Ingle, 1985). Length-frequency distribution by sex of specimens caught around Saint Peter and Saint Paul Archipelago.

The exploitation of *Chaceon* spp. in Brazil began in 1984 by chartered Japanese vessels based in Itajaí (SC) and Rio Grande (RS), which suspended their activities later on, due to the progressive reduction of the catch per unit of effort (CPUE) (Pezzuto *et al.*, 2002). Between 1999 and 2006, the Brazilian fishing authorities promoted the use of deep-sea fisheries resources by means of a foreign vessel-chartering program. During that time, a new stage of exploitation of deep-water crabs started, based on stocks of two different species, located in southern Brazil: *Chaceon notialis* and *Chaceon ramosae*. Along this period, *C. ramosae* showed a higher catch rate and stock declined steadily along the years than *C. notialis*, which exhibited a marked fluctuation. Both stocks, however, begun to exhibit a downward trend in CPUE from 2002 on, suggesting that fishing mortality levels surpassed the maximum sustainable yield in most years (Perez *et al.*, 2009).

A similar trend was also observed in the fishery for *C. maritae* in western Africa. An increase in fishing effort resulted in an increase in landings, between 1987 and 1998, followed by a period of stability, between 1999-2002, and then a significant decrease in catches (Malheiro, 2011, unpublished data).

The size range of *C. gordonae* found in the present study (40.60 to 137.10 mm CL for males and 41.60 to 139.80 mm CL for females) was wider than those previously described (Ingle, 1985; Afonso-Dias *et al.*, 2008). The unimodal size frequency for both males and females, however, appears to be a general pattern of the Geryonidae. According to López-Abellán *et al.* (2002) and Castro *et al.* (2010), this kind of length-frequency distribution in females may be due to a shorter period of moulting in immature specimens, when compared to those after maturing.

Males were more frequent than females in the present study, concurring with many studies on geryonids (Fernández-Vergaz *et al.*, 2000; Pinho *et al.*, 2001; López-Abellán *et al.*, 2002; Guerrero & Arana, 2009; Pezzuto & Sant'Ana, 2009; Castro *et al.*, 2010),

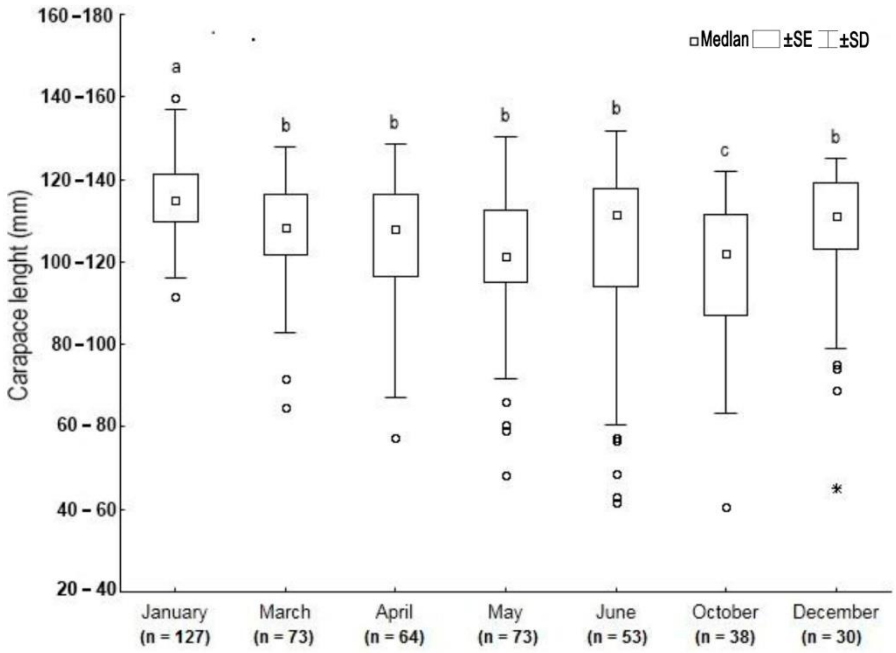

Figure 4. Monthly length-frequency distribution of deep-sea African crab *Chaceon gordonae*, caught around Saint Peter and Saint Paul Archipelago.

Table 3. Monthly sex ratio of deep-sea African crabs *Chaceon gordonae*, caught around Saint Peter and Saint Paul Archipelago (*$P < 0.05$).

Survey	n Males	n Females	Sex-ratio	χ^2
January	55	72	1 : 1.31	2.27
March	57	16	1 : 0.28	23.02*
April	12	52	1 : 4.33	25.00*
May	21	52	1 : 2.47	13.16*
June	42	11	1 : 0.26	18.13*
October	37	1	1 : 0.03	34.11*
December	28	2	1 : 0.07	22.53*
Total	252	206	1 : 0.82	4.62*

confirming this pattern for this zoological group. This trend, however, might be simply a result of the fishing method. The use of traps often results in more males being caught, particularly when females are ovigerous, because of their tendency to avoid traps while brooding eggs (Taggart *et al.*, 2004). Additionally, sampling bias probably also exists with regard to male size, since smaller crabs are less likely to enter traps when large males are present (Taggart *et al.*, 2004).

The bathymetric range of the species in Saint Peter and Saint Paul Archipelago, from 300 to 700 m, this last one being the maximum depth where traps operated, appears to be typical for geryonids, with males also being more abundant in shallower depths (Melville-Smith, 1988; Pinho *et al.*, 2001; Gutiérrez *et al.*, 2011).

Table 4. Sex-ratio of the deep-sea African crabs, *Chaceon gordonae*, caught around Saint Peter and Saint Paul Archipelago, by depth intervals (*$P < 0.05$).

Depth range (m)	n males	n females	Sex-ratio	χ^2
300 - 399	31	7	1 : 0.22	15.15*
400 - 499	77	67	1 : 0.87	0.69
500 - 599	44	43	1 : 0.98	0.01
600 - 699	1	13	1 : 13.00	10.28*
700 - 799	37	1	1 : 0.03	34.11*
Total	190	131	1 : 0.69	10.84*

The bathymetric range of *C. gordonae* in SPSPA, however, was 200 m shallower than previously reported (500 m) by Afonso-Dias *et al.* (2008). The highest abundance in number of crabs caught, found between 400 and 500 m, as well as the different depth distribution for males and females, might be related to both environmental as well as biological factors. Similar differences in bathymetric distribution have been reported for other deep-sea crabs, like *C. affinis*, due to reproductive migrations toward shallower waters and/or the incorporation of recruits from deep to shallow waters (López-Abellán *et al.*, 2002).

In brachyuran crabs, chela and abdomen are considered secondary characters for males and females, respectively, because of their functions in reproduction (Hartnoll, 1978). Male crabs use their chela for territorial defense, combat, mating and courtship, as

Table 5. Sample size (n), mean ± standard deviation (SD), for the key variables (LCHL- left chelae length, RCHL- right chelae length, LCHW- left chelae width, RCHW- right chelae width) of the deep-sea African crab, *Chaceon gordonae* caught during deep-water fishing surveys carried out in the vicinity of Saint Peter and Saint Paul Archipelago.

Variable	Sex	n	Mean ± SD	F-ratio	t-test	*P*
LCHL	Males	243	96.75 ± 15.72	1.8	17.76	<0.0001
	Females	191	72.55 ± 11.72			
RCHL	Males	243	99.11 ± 16.42	1.94	17.57	<0.0001
	Females	189	74.27 ± 11.78			
LCHW	Males	244	33.29 ± 5.72	2.19	19.9	<0.0001
	Females	191	23.69 ± 3.86			
RCHW	Males	243	35.33 ± 6.6	2.56	18.64	<0.0001
	Females	189	25.12 ± 4.12			

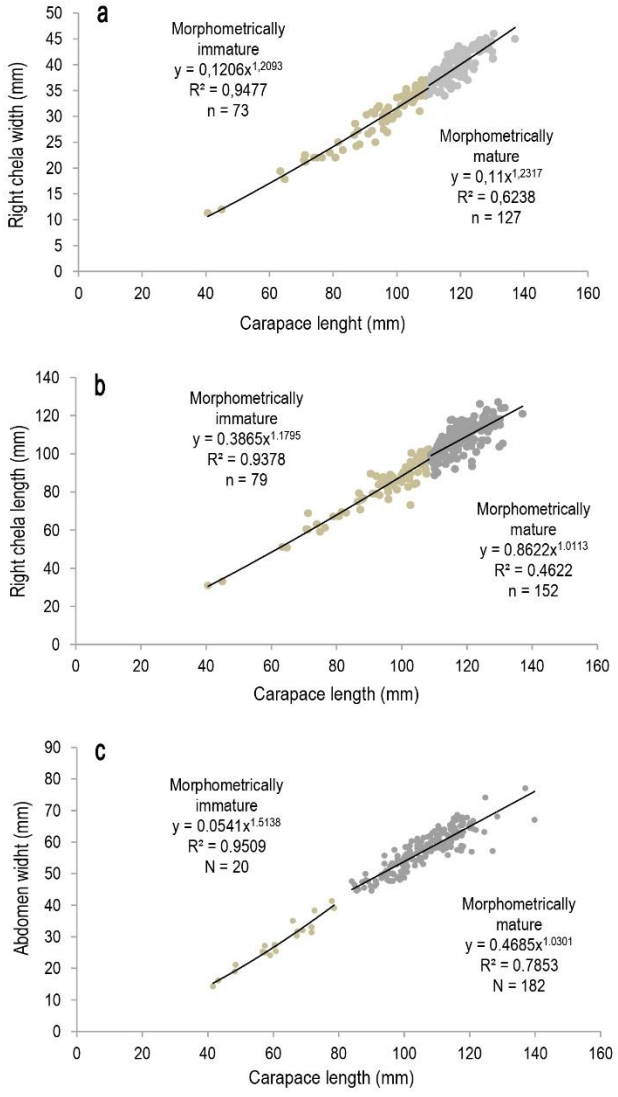

Figure 5. *Chaceon gordonae* bivariate scatter plots of secondary sexual characters and lines fitted to each group of points representing morphometric mature stages of males and females: a) Male right chela width (RCHW), b) male right chela length (RCHL), and c) female abdomen width (AW).

well as for carrying and holding the female during copulation. The abdomen in adult females forms an incubation chamber for the developing eggs, which are attached to the pleopods. The increase in relative growth of the male chela and female abdomen at the puberty molt brings these structures to fully functional size at maturity (Melville-Smith, 1988). Hence, the relative growth of chela and abdomen has been used to determine size at which puberty molt occurs or functional maturity is attained in many other *Chaceon* species, such as *C. affinis*, in Canary Islands (Fernández-Vergaz *et al.*, 2000; López-Abellán *et al.*, 2002), *C. chilensis*, in Robinson Crusoe Island (Guerrero & Arana, 2009), and *C. ramosae* (Pezzuto & Sant'Ana, 2009) and *C. notialis* (Sant'Ana & Pezzuto, 2009), in southern Brazil. The carapace length was chosen to assess morphometric maturity in *C. gordonae* caught in SPSPA, because the fifth anterolateral teeth, due to their long length and sharpness, are prone to wear-off and break during transportation to the laboratory. Therefore, the measure of carapace width may not represent the real size of the animal. To date, no data were available on the size at sexual maturity of *C. gordonae* worldwide. The size at maturity reported here corroborate than those estimated for other *Chaceon* species (Haefner, 1977, 65-75 mm CL for females of *Geryon quinquedens*; Melville-Smith, 1987, 80 mm CW for males and 96 mm CW for female of *G. maritae*; Fernandez-Vergaz *et al.*, 2000, 129 mm CW for males and 113 mm CW for females of *C. affinis*; López-Abellán *et al.*, 2002; Guerrero & Arana, 2009, 100 mm CL for males of *C. chilensis*; Pezzuto & Sant'Ana, 2009, 121 mm CW for males and 127 mm CW for females of *C. ramosae*; Sant'Ana & Pezzuto, 2009, 89 mm CW for males and 88 mm CW for females of *C. notialis*).

This is the first study on *C. gordonae* done in Brazilian waters. In general, the results agreed with several patterns observed in other *Chaceon* studies, in other regions, such as depth and size distribution. However, more effort is required to achieve a better

understanding about the ecology of this important crustacean in the archipelago. Techniques other than traps, such as the use of BRUV's (Baited Remote Underwater Video), may improve the understanding to study the movements, spatial distribution, and life history of this species at Saint Peter and Saint Paul Archipelago.

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