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Morphometry and sexual maturity of the tropical hermit crab *Calcinus tibicen* (Crustacea, Anomura) from Brazil

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Ontogenetic changes in relative growth were studied in the hermit crab *Calcinus tibicen* in order to determine its growth phases with sexual maturity. Specimens were collected at 2-month intervals for two consecutive years. A total of 570 individuals was collected and analysed. Total mean animal size in terms of shield length was 5.14 ± 1.23 mm for males, 4.23 ± 0.79 mm for females and 4.53 ± 0.60 mm for ovigerous females. Sexual dimorphism in chela dimensions was stronger in males than in females. Differences between males and females were found in left propodus length (LPL) and height (LPH) versus shield length (SL) and wet weight (WW) versus SL relationships. Males showed a high positive allometry, while juveniles and adult females were isometric for the LPL/SL relationship. Negative allometry was observed in adult females in the LPL/SL relationship. The size at which a differentiation occurred in the growth of the chelipeds and in the weight gain of males and females was between 3.0 and 3.2 mm SL, suggesting that sexual maturity occurs in small-sized individuals in the life cycle of *C. tibicen*.

KEYWORDS: Diogenidae, relative growth, sexual dimorphism, hermit crab.

Introduction

The tropical hermit crab *Calcinus tibicen* (Herbst, 1791) inhabits shallow waters, up to 30 m deep, of the western Atlantic Ocean from the Bermudas, Florida, Gulf of Mexico and Antilles to northern South America (Panama, Colombia and Venezuela) and Brazil including Fernando de Noronha, and from Ceará to Santa Catarina State (Rieger and Giraldi, 1997; Melo, 1999). Several aspects of the biology and behaviour of *C. tibicen* have been studied: Lewis (1960) characterized its reproductive period in Barbados; Provenzano (1962) described its larval development under laboratory conditions; and Hazlett (1966, 1967, 1972, 1984) studied several

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aspects of behaviour and reproduction. With respect to its ecology, Bertness (1982) investigated some aspects of predation; Hazlett (1984) checked the utilization of shells infested by epibionts in the Jamaica area; Hazlett and Baron (1989) analysed the effect of the shell on the reproductive biology of this hermit crab; and Hazlett (1992, 1995) studied the influence of shell during copulation and the behaviour associated with shell occupation.

The infraorder Anomura is represented by 45 hermit crab species recorded in Brazilian waters (Melo, 1999). Twenty-one of these were registered on the northern coast of São Paulo State, 14 of them belonging to the family Diogenidae (Mantelatto *et al*., 2001). Despite the few reports about Brazilian shore populations of hermit crabs, they represent promising material for studies of comparative population biology and ecology of individuals from different areas (Fransozo and Mantelatto, 1998). In this sense, *C. tibicen* has been investigated in the Ubatuba region as part of a long-term effort undertaken to study the life cycle of this population. Fransozo and Mantelatto (1998) studied the seasonal abundance, seasonal size-frequency distribution, sex ratio and reproductive period of this species, and, more recently, Mantelatto and Garcia (1999) studied the fecundity and the influence of shell type on these parameters, and Mantelatto and Garcia (2000) investigated the shell utilization pattern associated with gastropod shell availability.

Despite the relative abundance of studies on the general biology of hermit crabs, the relative growth aspects of these crustaceans have been poorly investigated (Mantelatto and Martinelli, 2001). The objective of the present study was to determine the changes in the relative growth of the hermit crab *C. tibicen* in order to obtain morphological criteria to establish sexual maturity in a population from an intertidal area in the Ubatuba region (São Paulo State, Brazil), an important zone of faunal transition between Patagonia and tropical regions.

Material and methods

The hermit crab population, located in Praia Grande (23°27′98″S and 45°03′49″W), Ubatuba, São Paulo State, was studied at 2-month intervals for two consecutive years (from January 1993 to November 1994). The animals were collected by hand at low tide from depressions in the intertidal part of the rocky shore area. The animals were caught by three persons over a period of 1 h over the same area of about 750 m^2. Almost all hermit crabs were located in groups in small subtidal pools that were regularly searched during the study. The characteristics (tidal period, abiotic factors such as temperature and salinity, ecological importance, wave conditions) of this area have been described by Fransozo and Mantelatto (1998).

The animals were frozen and transported to the laboratory where they were thawed just before analysis, and carefully removed from their shells, weighed (WW = wet weight) and measured on the basis of shield length (SL = from the tip of the rostrum to the V-shaped groove at the posterior edge of the shield), left propodus height (LPH = greatest height of the major chela) and left propodus length (LPL = greatest length of the major chela). Sex was determined based on gonopore position. Measurements were performed by stereoscopy with an ocular micrometer. Damaged hermit crabs or individuals with regenerating or otherwise anomalous limbs were discarded.

Morphometric relations were used to apply the power function ($Y = aX^b$), which was fitted to the data, and the pattern of allometry was established for each parameter by the b value ($b=1$: isometry; $b<1$: negative allometry; $b>1$: positive allometry). To detect the b-difference from unit, an interval of 0.90–1.10 was used for b (Kurata, 1962; Kuris et al., 1987; Clayton, 1990; Mantelatto and Martinelli, 2001). The logarithmic transformation ($\log y = \log a + b \log \mathrm{SL}$) of the power function was used. The equations and coefficient of determination (r^2) obtained were compared to each other while observing modifications during growth. Analysis of variance was performed for all regressions (Sokal and Rohlf, 1979).

Results

A total of 570 specimens was collected (219 males, 175 non-ovigerous females and 176 ovigerous females). Animal size (minimum, maximum, mean shield length $\pm$ SD, respectively) was 2.05, 8.13, 4.82 ± 1.23 mm for males; 2.38, 6.75, 4.23 ± 0.79 mm for non-ovigerous females, and 3.20, 6.50, 4.53 ± 0.60 mm for ovigerous females. No significant differences in mean size were detected between sexes over the 2-year collection period and therefore the data were pooled for analysis. Additional information on population aspects, i.e. seasonal distribution, size-frequency information and sex ratio have been reported by Fransozo and Mantelatto (1998).

The regression equations applied to the data, coefficient of determination and level of allometry are presented in table 1. All regressions showed significant differences (ANOVA, $P<0.05$) (table 2).

A single regression equation was obtained for males because no differences in the growth rate of the chelae were detected between juveniles and adults. To classify the females into juveniles and adults, we used the size of the smallest ovigerous female collected (3.2 mm SL). Females smaller than this size were considered juveniles (table 1, figure 1).

Males and juvenile females showed isometric growth in almost all of the relations involving chela dimensions. The regressions involving WW versus SL showed isometry for males, negative allometry for adult females and positive allometry for juvenile females (table 1).

The size at which a differentiation occurs in the growth of the chelipeds and in the weight gain of males and females was 3.0–3.2 mm SL, as can be seen in the LPH versus SL, LPL versus SL, and WW versus SL relations in figure 1.

Discussion

In the Ubatuba region, *C. tibicen* has an annual reproductive cycle, with the spawning period lasting from September (spring) to May (autumn), with discontinuation of reproduction during the winter months (Fransozo and Mantelatto, 1998). The fecundity of this species is influenced by the number of spawnings and by the female's condition (primiparous or multiparous) during the same reproductive cycle, associated with a short (4–8 weeks) incubation period (Mantelatto and Garcia, 1999). Probably these life cycle strategies are favourable to the occurrence of sexual maturity in small-sized individuals of *C. tibicen* as observed in the present study. Graphic analysis of the body dimensions of hermit crabs and also of the smallest ovigerous females collected suggests that morphological sexual maturity occurs in small-sized individuals (at about 3.0–3.2 mm of SL) in the life cycle of *C. tibicen.*

In general, the juveniles of *C. tibicen* showed isometric growth until they reach sexual maturity, the time when sexual dimorphism occurs (positive allometry starting from 3.0 mm SL) in terms of type of growth.

Table 1. *Calcinus tibicen* regression equations.

Variables	Groups	N	$Y = aX^b$	$\ln Y = \ln a + b \ln X$	r^2	A
	JF	20	$LPL = 0.85.SL^{1.08}$	$\ln LPL = -0.16 + 1.08.\ln SL$	0.40	=
LPL × SL	FE + OF	314	$LPL = 1.20.SL^{0.74}$	$\ln LPL = 0.18 + 0.74.\ln SL$	0.54	–
	MA	205	$LPL = 0.90.SL^{1.02}$	$\ln LPL = -0.11 + 1.02.\ln SL$	0.88	=
	JF	20	$LPH = 0.77.SL^{1.03}$	$\ln LPH = -0.26 + 1.03.\ln SL$	0.39	=
LPH × SL	FE + OF	314	$LPH = 0.79.SL^{0.96}$	$\ln LPH = -0.24 + 0.96.\ln SL$	0.54	=
	MA	205	$LPH = 0.70.SL^{1.11}$	$\ln LPH = -0.36 + 1.11.\ln SL$	0.89	+
	JF	22	$WW = 0.0006.SL^{4.73}$	$\ln WW = -7.42 + 4.73.\ln SL$	0.56	+
WW × SL	FE + OF	328	$WW = 0.007.SL^{2.68}$	$\ln WW = -4.96 + 2.68.\ln SL$	0.63	–
	MA	216	$WW = 0.005.SL^{2.92}$	$\ln WW = -5.30 + 2.92.\ln SL$	0.88	=

SL, shield length; LPL, left propodus length; LPH, left propodus height; WW, wet weight.
N, number of individuals; r^2, coefficient of determination; ln, neperian logarithm.
A, allometry: (=) isometric, (+) positive allometry, (–) negative allometry.
JF, juvenile females; FE, adult females; OF, ovigerous females; MA, males.

Table 2. *Calcinus tibicen*: analysis of variance carried out to test the significance of regression using the data in figure 1.

Source of variation	SS	df	MS	*F*	*F* critical
SL × LPL					
Regression	83.90	1	83.90	86.91	3.85*
Residual	1070.59	1109	0.97		
Total	1154.49	1110			
SL × LPH					
Regression	262.17	1	262.17	281.26	3.85*
Residual	1033.72	1109	0.93		
Total	1295.89	1110			
SL × WW					
Regression	4687.30	1	4687.30	8913.57	3.85*
Residual	597.90	1137	0.53		
Total	5285.21	1138			

SL, shield length; LPL, left propodus length; LPH, left propodus height; WW, wet weight. SS, sum of squares; df, degree of freedom; MS, mean squares; *F*, *F*-test (*$P<0.0001$).

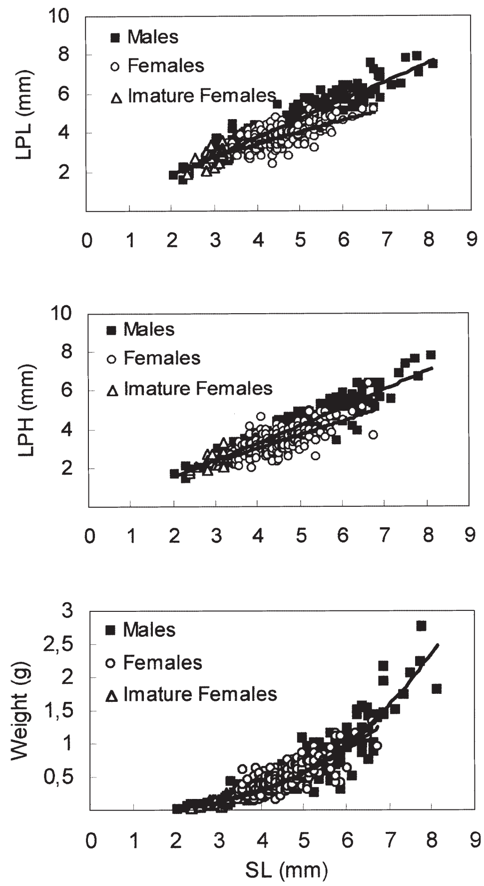

Fig. 1. *Calcinus tibicen.* Relative growth of left propodus (LPL, left propodus length; LPH, left propodus height) and weight in relation to shield length (SL). The regression equations are given in table 1.

The weight relations showed a different pattern between males and females (adults and juveniles). In adult females the negative allometry for this relationship can be related to the energy deviation that might occur due to reproduction, which prevents the use of this resource for growth, justifying the smaller size reached. The isometric and positive allometric growth for the males and juveniles, respectively, demonstrated the energy investment in somatic growth in different levels, i.e. positive allometry may indicate high energy investment in somatic growth, in order to attain sexual maturity.

A clear sexual dimorphism in crab size was found in *C. tibicen*, with males reaching larger dimensions than females, mainly in terms of chela size. These differences in chela size between males and females have been considered to play an essential role in the behaviour of the various species. *Calcinus tibicen* males presented a growth pattern (isometric and positive allometry for the chelae not regarding if it is the right or the left one) similar to that recorded for other hermit species such as *Anapagurus hyndmanni* (Bell, 1846), *Anapagurus alboranensis* Garcia-Gomez, 1994, *Pagurus longicarpus* Say, 1817, *Cestopagurus timidus* (Roux, 1930), *Dardanus insignis* (Saussure, 1858), *Petrochirus diogenes* (Linnaeus, 1758) and *Loxopagurus loxochelis* (Moreira, 1901), respectively studied by Blackstone (1986), Manjón-Cabeza and Garcia Raso (1996), Fernandes-Góes (1997), Bertini and Fransozo (1999) and Mantelatto and Martinelli (2001).

The sexes showed different patterns of relative growth, with allometric changes between the juvenile and adult females. The juvenile females presented isometry in chela dimensions, and the adult females negative allometry (LPL $\times$ SL), while the males displayed positive allometry (LPH $\times$ SL). This dimorphism can be explained by the use of the males' chelar propodus for territorial defence, interspecific fights, courtship behaviour (Hartnoll, 1974; Gherardi and Nardone, 1997) and appropriate shell choice. The chela plays an important role in the choice of shells by these animals, probably acting as an estimator of its size and conditions for occupation. According to Abrams (1988), the crab size dimorphism originates from character displacement due to inter-sexual competition for shells.

The population of *C. tibicen* demonstrated synchrony between morphological and physiological maturity process, according to the graphic analyses of size relationships (morphological) and the size of the smallest ovigerous female (physiological). However, only histological and/or macroscopic analysis of the gonads compared to biometric studies will permit a more precise definition about this process in these animals.

Although some authors are less favourable to the use of relative growth in determining the size at the sexual maturity in hermit crabs (Bertness, 1981; Lancaster, 1988), we may conclude that this is an accessory tool in determining such condition, mainly for hermit species with a clear chelar dimorphism, such as those in the family Diogenidae.

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