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Length-weight Relationship and Condition Factor of the Mangrove Crab *Ucides cordatus* (Linnaeus, 1763) (Crustacea, Brachyura, Ucididae)

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ABSTRACT

The relationship of wet weight (WT) to cephalothorax width (CW) and temporal and seasonal variations in the condition factor were analyzed for each sex of the mangrove crab Ucides cordatus*, using specimens collected monthly from September 1998 through September 2000, at Iguape, state of São Paulo. The WT/CW relationship, determined by the regression analysis and the condition factor were evaluated individually, monthly and seasonally, for each sex. The WT/CW relationship indicated isometric growth in males and negative allometric growth in females. Body weight was higher in males than in females of equivalent size and this difference was associated with the males' faster growth and heavier chelipeds. On the other hand, the means for condition factor were always higher for females than for males; the mean condition factor was lower in spring and summer and higher in autumn and winter.*

Key words: Fattening, Mangrove crab, Mangrove forest, *Ucides cordatus,* Weight increase

INTRODUCTION

The size-weight relationship has been used in fishery analyses for several purposes: to convert one variable to another, to estimate the expected weight for a certain size, or to detect ontogenetic morphological changes related to maturation of crustaceans and fishes (Pinheiro and Fransozo, 1993). The power function ($y=ax^b$), fitted to the empirical points of this relationship, is used in studies of relative growth. The constant "a" represents the degree of fattening (condition factor) of a species. The exponent "b" represents the weight gain, which can be isometric (b=3), negatively allometric (b<3), or positively allometric (b>3) (Hartnoll, 1982).

According to Le Cren (1951), evaluation of the condition factor can provide important information about the "well-being" of a species, indicating its recent feeding conditions (fat content) and degree of adjustment to the environment. Vazzoler (1996) termed this parameter the "isometric condition factor" (or Fulton's condition factor). The condition factor can vary with gonadal development and time of year, and also among different populations. In species with isometric growth, the condition factor is calculated by dividing the total wet weight by the cube of the body size. However, because for most species this

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constant varies between two and four (Vazzoler, 1996), the "allometric condition factor" is used. In this case, the wet weight is divided by the size raised to the constant "b", which is obtained by analyzing the WT/CW relationship (Braga, 1986).

The temporal and seasonal fluctuations of the condition factor are influenced by endogenous parameters (e.g., nutritional aspects, sex, and the state of gonadal maturation) or exogenous parameters (environmental factors) affecting a population (Rodriguez, 1987). Evaluation of these parameters is essential to determine the degree of fattening, and to indicate the season of growth or reproduction of a given species.

The WT/CW relationship and the condition factor have been evaluated for the crabs *Callinectes bocourti*, by Costa et al. (1980); *Callinectes danae*, by Branco and Thives (1991) and Branco et al. (1992); *Arenaeus cribrarius*, by Pinheiro and Fransozo (1993); *Hepatus pudibundus*, by Mantelatto and Fransozo (1993); *Portunus spinimanus*, by Santos et al. (1995); and *Dilocarcinus pagei*, by Pinheiro and Taddei (2005b).

The present study aimed to determine the equations that best expressed the relationship of wet weight (WT) to cephalothorax width (CW), for each sex of *U. cordatus*. This relationship was compared over the seasons of the year. The monthly and seasonal dynamics of the condition factor were also analyzed for each sex and the results were compared with events in the species' life cycle.

MATERIALS AND METHODS

Specimens of *U. cordatus* were collected monthly from September 1998 through September 2000, in mangrove forests near Barra de Icapara (24° 41' S), in the Municipality of Iguape, state of São Paulo. Each animal was identified according to Melo (1996). It was then sexed by abdominal morphology and number of pleopods (Pinheiro and Fiscarelli, 2001), measured with a vernier caliper to the nearest 0.05 mm (CW = greatest cephalothorax width), and weighed on a precision balance to the nearest 0.01 g (WT = wet weight).

The WT/CW relationship was determined for the total number of individuals of each sex, as well as for both sexes by season of the year (Summer = January through March; Autumn = April through June; Winter = July through September; and Spring = October through December). In each case, the empirical points were submitted to regression analysis, using the power function ($y=ax^b$), where WT = the dependent variable (y), CW = the independent variable (x), "a" = the condition factor (Santos, 1978), and "b" = the weight increase (Pinheiro and Fransozo, 1993). The fit was evaluated by the coefficient of determination (R^2). The type of weight increase (isometric, b=3; positively allometric, b>3; and negatively allometric, b<3) was confirmed by the "t" test of the difference from 3, using a 1% significance level.

The equations for the WT/CW relationship were compared among the seasons of the year for each sex separately. The variables WT and CW were log-transformed and analyzed by linear regression (y=a+bx). Student's *t* test (*z*) was used to assess the parallelism or coincidence between the straight lines. The data from the coincident equations were grouped and submitted to a new regression analysis to generate a more reliable equation for interconversion between variables.

The individual condition factor was established for each "i-th" individual, from the equation $a_i = WT_i/(CW_i)^b$, where: WT_i = total wet weight; CW_i = cephalothorax width; a_i = condition factor; and b = allometric growth constant obtained for the WT/CW relationship for each sex. The monthly means for the condition factor were calculated by sex, season, and capture period (Reproductive = October through March; Non-reproductive = April through September). These means were used to construct the graphs and perform the statistical analyses. The data for seasons (four treatments) and collection period (two treatments) were analyzed for each sex separately and assessed by ANOVA in a fully randomized design with variable repetitions. The contrast between the means was evaluated by Tukey's test at 5% significance (Zar, 1999). To assess the possible differences in sex and season between the means for size (CW) and total wet weight (WT), the data for each variable were grouped by sex in the different seasons and were also assessed by ANOVA. The coefficient of variation (CV%) was determined for each of these biometric variables and for the condition factor (a), for each sex separately.

The monthly and seasonal changes in the means for condition factor of each sex were associated with the events of the life cycle of *U. cordatus*, as recorded by Pinheiro (2004) in the same locality and study period. The first event was the Molting Season, which was assessed by the relative frequency of specimens in the pre-molt stage (D) and recent post-molt (A and B), according to Drach and Tchernigovtzeff (1967). The second event was the Reproductive Season, which was assessed by the relative frequency of specimens with mature gonads, recently copulated females (full spermatheca with spermatophores), and ovigerous females (spawning).

RESULTS

A total of 2,979 specimens of *U. cordatus* (1,654 males and 1,325 females) were analyzed. The males were larger than the females in terms of size (50.5±10.9 > 46.4±8.7 mm; F=1.55; p<0.01) (Table 1) and also wet weight (63.9±42.3 g > 46.4±25.8 g; F=2.69; p<0.01) (Tab. 2). For males, the coefficient of variation (CV%) of CW was 21.5%, slightly higher than that for females (18.8%). These coefficients were about one-third smaller than the values obtained for the variable WT (66.2 and 55.6%, respectively).

The seasonal means for size (Table 1) and wet weight (Table 2) showed different patterns in males and females. In spring, the males were significantly larger and heavier than in autumn (F=26.1; p<0.05). For females, this pattern was less pronounced: larger and heavier females occurred in spring and summer, and the inverse in fall and winter (F=16.4; p<0.05).

Table 1 - *Ucides cordatus* (Linnaeus, 1763). Summary statistics for cephalothorax width (CW, in millimeters) for each sex according to season, based on monthly captures from September 1998 through September 2000.

Season	CW_{Males}				$CW_{Females}$			
	N	Min.	Max.	Mean ± SD	N	Min.	Max.	Mean ± SD
Summer	458	23.5	83.4	50.7 ± 11.7 b(1)	414	23.0	78.1	47.3 ± 9.7 b
Autumn	366	29.8	73.1	47.7 ± 7.5 a	270	16.2	64.1	44.2 ± 6.8 a
Winter	464	24.6	81.7	49.6 ± 10.1 ab	307	14.8	66.8	45.1 ± 8.4 a
Spring	366	16.7	82.6	54.4 ± 12.4 c	334	22.3	70.0	48.5 ± 8.5 b
Total	1,654	16.7	83.4	50.5 ± 10.9 B	1,325	14.8	78.1	46.5 ± 8.7 A

(1) For the same sex, the means followed by the same lower-case letter did not differ statistically among seasons of the year; the same obtains for the upper-case letters in comparisons between the sexes (p<0.05).

Table 2 - *Ucides cordatus* (Linnaeus, 1763). Summary statistics for total wet weight (WT, in grams) for each sex by season, based on monthly captures made from September 1998 through September 2000.

Season	WT_{Males}				$WT_{Females}$			
	N	Min.	Max.	Mean ± SD	N	Min.	Max.	Mean ± SD
Summer	458	5.9	232.8	66.3 ± 47.1 b(1)	414	5.1	173.4	50.1 ± 30.6 b
Fall	366	12.2	197.5	51.5 ± 26.1 a	270	1.8	105.8	39.7 ± 17.1 a
Winter	464	24.6	81.7	49.6 ± 10.1 b	307	1.5	126.3	42.9 ± 24.5 a
Spring	366	2.1	215.8	77.8 ± 48.0 c	334	4.5	119.3	50.7 ± 24.7 b
Total	1,654	2.1	232.8	63.9 ± 42.3 B	1,325	1.5	173.3	46.4 ± 25.8 A

(1) For the same sex, means followed by the same lower-case letter did not differ statistically among the seasons of the year; the same obtains for the upper-case letters in comparisons between the sexes (p<0.05).

In all the cases, the WT/CW relationship showed a significant positive correlation between the variables, with a significant fit of the empirical points to the power function (p<0.01) (Table 1). Males showed an isometric increase in weight (b=2.99; t=1.04; p>0.001), whereas females showed a negative allometric increase (b=2.88; t=12.46; p<0.001) (Fig. 1). In males, the equation obtained for winter differed significantly from the equations for the other seasons (p<0.01) (Table 3); Data for the latter could be grouped and represented by a single equation (lnWT=−7.60+2.97lnCW; N=1,190; r^2=0.98; p<0.01). For females, the equations for spring and summer coincided (p>0.01) and were expressed as lnWT=−7.13+2.85lnCW (N=748; r^2=0.98; p<0.01). These differed from the equations for autumn and winter, which also differed from each other (p<0.01). Graphical analysis of the equations obtained for the WT/CW relationship, after the data were grouped (Fig. 2), showed that in the spring-summer-autumn period, the males weighed more for the same reference size.

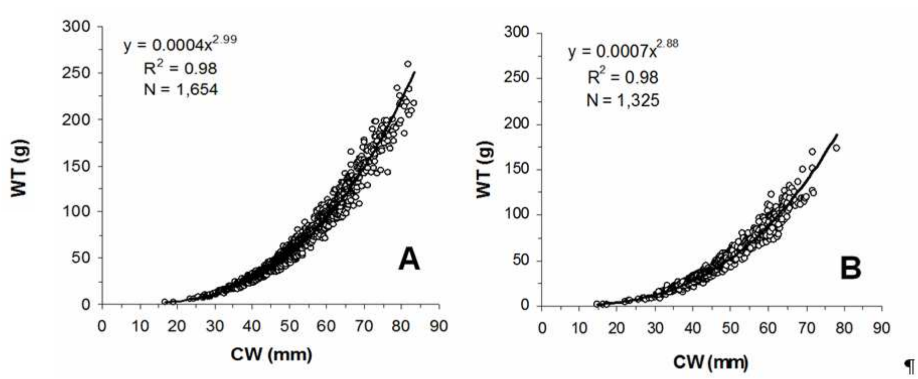

Figure 1 - *Ucides cordatus* (Linnaeus, 1763). Graphs of dispersion of points and the power function fitted to the empirical points of the WT/CW relationship, for males (A) and females (B). The data are based on captures made monthly from September 1998 through September 2000 (WT = total wet weight; CW = cephalothorax width).

Table 3 - *Ucides cordatus* (Linnaeus, 1763). Equations for the relationships of total wet weight (WT) to cephalothorax width (CW), obtained for each sex by season, based on monthly captures made from September 1998 through September 2000.

Season	Males				Females			
	N	Linearized Power Function (*ln y = ln a + b ln x*)		R^2	N	Linearized Power Function (*ln y = ln a + b ln x*)		R^2
Summer	458	*ln WT = - 7.60 + 2.98 ln CW*	Aa(1)	0.99	414	*ln WT = - 7.13 + 2.85 ln CW*	Aa	0.98
Autumn	366	*ln WT = - 7.60 + 2.99 ln CW*	Aa	0.97	270	*ln WT = - 7.26 + 2.88 ln CW*	Ab	0.97
Winter	464	*ln WT = - 8.11 + 3.06 ln CW*	Ab	0.98	307	*ln WT = - 7.82 + 2.98 ln CW*	Ac	0.97
Spring	366	*ln WT = - 7. 82 + 3.01 ln CW*	Aa	0.99	334	*ln WT = - 7.26 + 2.86 ln CW*	Aa	0.98
Total	1,654	*ln WT = - 7.82 + 2.99 ln CW*		0.98	1,325	*ln WT = - 7.26 + 2.88 ln CW*		0.98

(1) For the same sex, means followed by the same upper-case letter did not differ in the linear coefficient (a); the same obtains for the lower-case letters in the case of the angular coefficient (*b*) (p<0.05).

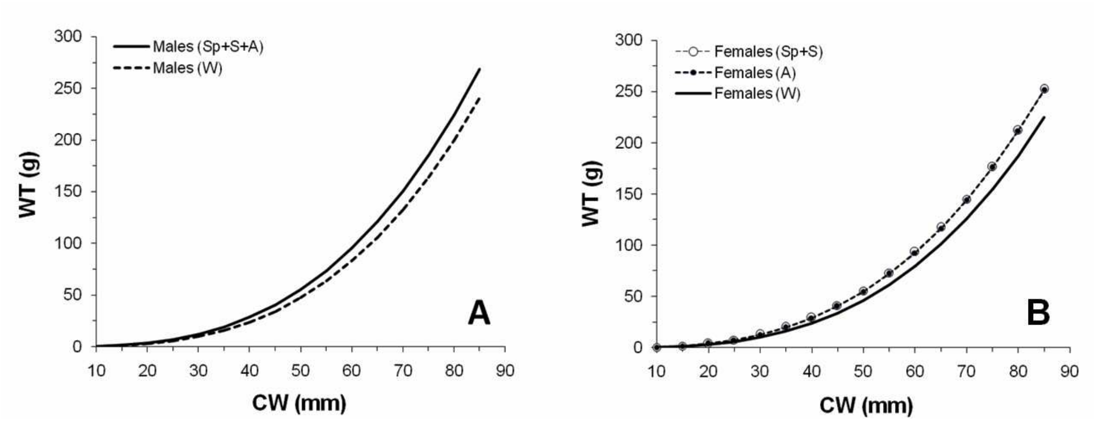

Figure 2 - *Ucides cordatus* (Linnaeus, 1763). Relationship of total wet weight (WT) to cephalothorax width (CW), after statistically similar seasonal equations were grouped for males (A) and females (B) (S = Summer, Jan-Mar; A = Autumn, Apr-Jun; W = Winter, Jul-Sep; Sp = Spring, Oct-Dec).

The spring-summer equation for females indicated the second-largest body weight, with an equation similar to that for females in autumn. In last place was the winter equation for males and females, with females weighing less.

The general mean of the condition factor for females ($6.71\ 10^{-4} \pm 0.57\ 10^{-4}$) was about 1.5 times higher than that for males ($4.53\ 10^{-4} \pm 0.38\ 10^{-4}$; $F=2.26$; $p<0.01$), with similar coefficients of variation (8.4 and 8.5%, respectively). The mean values of "a" for each sex showed a smaller monthly variation, although interannual differences were detected in comparisons between the same month or period (Fig. 3). The seasonal analysis of the means for the condition factor (Fig. 4) also revealed the same pattern for the sexes, with a smaller mean in the spring and a larger one in autumn ($p<0.05$).

In the reproductive season, the means for condition factor were $6.67\ 10^{-4} \pm 0.56\ 10^{-4}$ for females and $4.49\ 10^{-4} \pm 0.39\ 10^{-4}$ for males. In the non-reproductive season, these means were $4.57\ 10^{-4} \pm 0.37\ 10^{-4}$ and $6.75\ 10^{-4} \pm 0.58\ 10^{-4}$, respectively, and were also significantly different from each other ($F=5181.9$; $p<0.01$). In the non-reproductive season, the means for condition factor were always higher than those in the reproductive season, independent of sex ($p<0.05$).

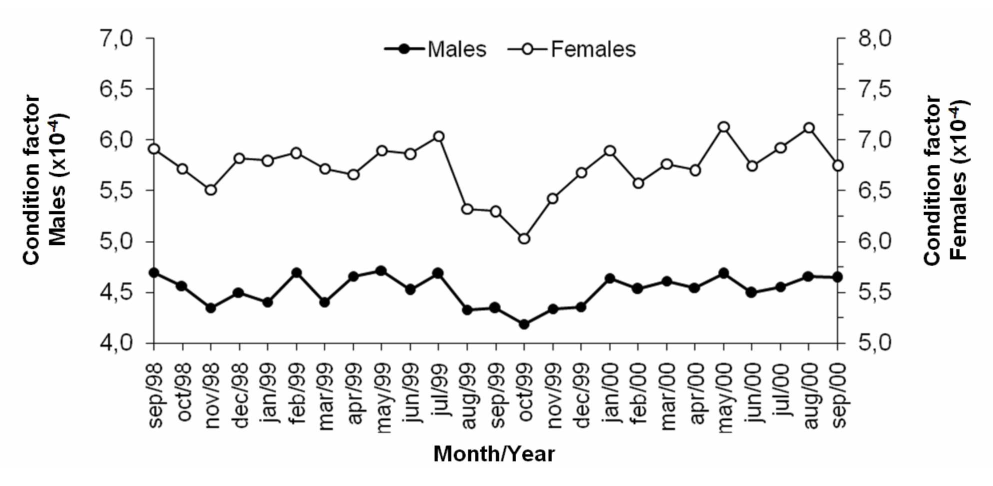

Figure 3 - *Ucides cordatus* (Linnaeus, 1763). Monthly means of the condition factor for each sex, captured from September 1998 through September 2000.

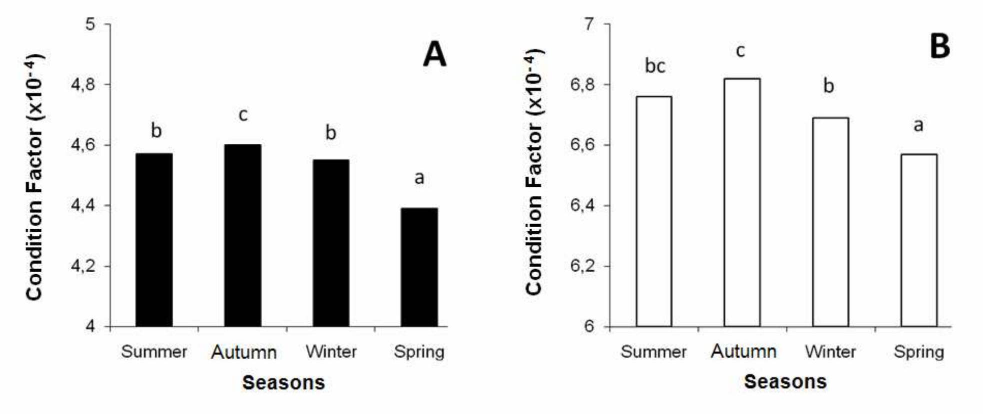

Figure 4 - *Ucides cordatus* (Linnaeus, 1763). Seasonal means of the condition factor for males (A) and females (B), captured from September 1998 through September 2000.

DISCUSSION

Characterization of population structure is essential for effective management and conservation of fisheries stocks. Biometric analysis can help to determine biological patterns, particularly in crustaceans, in which there is an antagonistic relationship between the amounts of energy allocated to somatic growth or reproduction.

The biometry of *U. cordatus* differed from that of other aquatic brachyurans, possibly because it was a semi-terrestrial species. Males of *U. cordatus* were, on average, larger and heavier than females. This is a common characteristic in brachyurans, although Pinheiro et al. (2005) observed that the asymptotic sizes of the sexes of this species were similar (males, 90.3 mm; females, 88.6 mm). Pinheiro and Taddei (2005a) reported similar observations for the semiterrestrial freshwater crab *Dilocarcinus pagei*. In contrast, in aquatic brachyurans, such as the swimming crab *Arenaeus cribrarius* studied by Pinheiro and Hattori (2006a), on average the males grew larger and eventually weighed more than females (Pinheiro and Fransozo, 1993). This difference was seen in the contrasting asymptotic sizes in this species (males, 120.5 mm; females, 100.8 mm). For aquatic brachyurans, the larger size of males in intermolt enables them to better protect the recent-postmolt females during and after copulation (Pinheiro and Fransozo, 1999). The semiterrestrial species copulate in the intermolt and do not show postcopulatory mate-guarding behavior (Hartnoll, 1969; Pinheiro, 1993).

The individual variation in wet weight in *U. cordatus* could be explained by the different degree of stomach fullness and gonadal maturation of the specimens analyzed. In males, the divergence is increased by the positive allometric growth of the chelipeds from the puberty molt onwards (Pinheiro and Hattori, 2006b). The higher coefficient of variation of WT, three times higher than that of CW, could be explained by the isometric cephalothorax dimensions of brachyurans (Hartnoll, 1978, 1982). The lower coefficient of variation of the individual or mean condition factor renders this parameter more appropriate for comparative analyses, because it is independent of size.

The similarity of the seasonal pattern of each sex in regard to size (CW) and weight (WT) is explained by the positive correlation of these variables. However, it does not explain the contrast between the sexes. According to Pinheiro (2004), at Iguape *U. cordatus* reproduced seasonally, with mature and ovigerous females recorded from November through March, whereas mature males occurred year-round. The seasonality of ovarian development explains the occurrence of larger females in spring-summer, although larger males also occur at this time of year. According to Pinheiro and Fiscarelli (2001), these two seasons are the main period for molting and mating (September through November), maturation of the ovaries (November through

December), and spawning and gonadal reorganization (December through March), events which are associated with an increase in size and weight in this species. The lowest means of size and weight were recorded in autumn-winter. This period preceded the months with the highest frequency of ecdysis (nuptial molt), which occurred only once a year after the puberty molt (± 60 mm) (Pinheiro, 2004). The seasonality of growth in the females was confirmed by the higher constant of variation of seasonal growth during spring-summer (Pinheiro et al., 2005), which was about three times higher than that of the males, indicating that the seasonal Von Bertalanffy model was appropriate for this sex.

The life cycle of *U. cordatus* at Iguape can be divided into two distinct seasons. The reproductive season is characterized by the nuptial molt, mating, gonadal maturation, and spawning. In the non-reproductive (or fattening) season, the data suggest an increase in feeding frequency and stocking of energy reserves in the midgut gland (hepatopancreas), as previously described for other brachyurans. The division of the life cycle of *U. cordatus* into two seasons has been mentioned by others also, such as Diele (2000) and Souto (2004), who studied populations of this species in the northern and northeastern regions of Brazil, respectively. There are certain differences in terminology and/or duration of these periods, according to the investigator and geographic locality. However, the data obtained in the present study also indicated that the crabs were "thinner" in the reproductive season (spring-summer), contrasting with the non-reproductive season, termed the "época do caranguejo gordo" (fat-crab season) by Souto (2004). In the review by Pinheiro (2004), crabs in some areas of northern Brazil showed a certain variation and even a temporal delay from these seasons, mainly related to rainfall. For example, Diele (2000) indicated that January-June was the reproductive period and July-December was the non-reproductive period.

The WT/CW relationship indicated that the sexes of *U. cordatus* showed different patterns of weight increase, corroborating previous studies for species of Portunidae (Sumpton, 1989; Branco and Thives, 1991; Branco and Lunardon-Branco, 1993; Pinheiro and Fransozo, 1993) and Trichodactylidae (Pinheiro and Taddei, 2005b). The constants for increase in weight ("b") of the seasonal equations could only be compared when the constants for degree of fattening ("a") were identical or very close, because of the negative correlation between them (Hile, 1936 *apud* Pinheiro and Fransozo, 1993). This was established through graphical comparison of the equations for the WT/CW relationship after the statistically coincident equations were grouped (Fig. 2). In the spring and summer, the nuptial molt, gonadal maturation of the females and spawning occurred. In the autumn, and particularly in the winter, the animals were fatter. According to Branco et al. (1992), gonadal organization and recovery occurred during this period. The condition factor increases because of the rest from reproduction and the stocking of energy reserves. This agreed with the data obtained in the present study, which indicated a higher condition factor in both sexes during the non-reproductive period (fattening phase), compared to the reproductive period.

The condition factor of females of *U. cordatus* was about 1.5 times higher than that of the males. This was similar to the results obtained by Pinheiro and Taddei (2005b) for the red freshwater crab *Dilocarcinus pagei* (2.5 times), and by Pinheiro et al. (1999) for the speckled swimming crab *Arenaeus cribrarius* (1.2 times). The similarity in the month-to-month dynamics of the condition factor between the sexes of *U. cordatus* was a consequence of the reproductive seasonality of the species, as mentioned previously. From July onwards, the condition factor was sharply reduced, possibly because of the beginning of the molting process, when the animals blocked the burrow opening and ceased feeding in preparation for the molt. The lowest condition factor index occurred in October, coinciding with the higher frequency of "caranguejos-leite" or "milk-crabs" (Pinheiro, 2004), individuals in which all the internal organs were milky white because of the retention of carbonates in the hemolymph circulation, derived from the exoskeleton which changed (Pinheiro and Fiscarelli, 2001). From October onwards, the values of the condition factor increased from December through March, corresponding to the beginning of gonadal maturation and the spawning period (Pinheiro, 2004; Pinheiro and Fiscarelli, 2001).

According to Haefner and Spaargaren (1993), female crustaceans can show an increase in weight/volume of the hepatopancreas, the gland responsible for storage and transport of energy reserves to the ovaries during vitellogenesis. The increase in the hepatosomatic index in fish has been used to determine the period of greatest energy mobilization for vitellogenesis, raising the values of individual condition factors (Querol et al., 2002). Similarly, in *U. cordatus*, the condition factors of both sexes increased from November on (gonadal maturation period), particularly in the females, which showed greater regularity in ovarian development and, therefore, a more obvious seasonal pattern.

The condition factor can also be influenced by the availability of food in the environment. For instance, Araújo (2000) showed for the fish *Parauchenipteros striatulus* that the higher values for condition factor found in autumn resulted from better feeding conditions in the preceding months (summer). Similar results were obtained for both sexes of *U. cordatus*.

Alford and Jackson (1993) mentioned that in many organisms, the growth rate varied in relation to intrinsic aspects (genetically determined) or extrinsic aspects (availability of food, temperature variations, etc.). The entire biological cycle of *U. cordatus* is influenced by changes in temperature, rainfall, and tidal amplitude, which can stimulate and/or modulate certain biological events, such as the nuptial molt, mating, gonadal maturation, and spawning. In this context, Barbieri et al. (1985) recommended, whenever possible, that biological information for a species be used to explain the dynamics of the condition factor, as has been done in the present study.

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RESUMO

A determinação da relação do peso úmido (WT) pela largura cefalotorácica (CW) do caranguejo *U. cordatus* e a análise da dinâmica temporo-sazonal do fator de condição foram realizadas com machos e fêmeas coletados mensalmente no período de 1998/2000, em Iguape (SP). A relação WT/CW foi determinada por análise de regressão, enquanto o fator de condição foi determinado individualmente para cada animal, bem como pela média mensal e sazonal para cada sexo. A relação WT/CW evidenciou um crescimento isométrico nos machos e alométrico negativo nas fêmeas, indicando que os machos atingem um peso corpóreo superior ao das fêmeas para um mesmo tamanho de referência. Tal fato está associado ao maior crescimento e peso dos quelípodos do macho. As médias do fator de condição das fêmeas foram maiores que as dos machos. Os menores valores do fator de condição ocorreram durante a primavera e verão, atingindo os maiores níveis durante o outono e inverno.

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