Condition factor and carapace width versus wet weight relationship in the swimming crab *Callinectes danae* Smith 1869 (Decapoda: Portunidae) at the Santa Cruz Channel, Pernambuco State, Brazil

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Abstract

The present work aims to study the size vs. weight relationship and the condition factor of a commercially important crab, *Callinectes danae*, from an estuarine complex located at Pernambuco State, Northeastern Brazil. After sampled, the specimens were measured on their carapace width (CW; mm) and weighted on their wet weight (WW; g). A total of 1,635individuals of *C. danae* were analyzed, being 881 males (53.8%) and 754 females (46.2%). Males were significantly larger and heavier than females ($p < 0.05$), the expected pattern to many crabs. The relationship WW vs. CW, described through the potency equation, was allometrically positive for both males ($b = 3.12$) and females ($b = 3.02$), a result also observed in other swimming crabs. The mean condition factor of males was $8.0\ 10^{-5} \pm 1.5\ 10^{-5}$, and that of females was $11.5\ 10^{-5} \pm 2.8\ 10^{-5}$, being significantly higher in females ($p < 0.05$), due to the fact that female gonads are heavier than that of males. The condition factor oscillated throughout the sampling year, for both sexes, which was related to the reproductive cycle.
Key words: Allometry, biometry, estuary, relative growth.

Introduction

The Crustaceans are widely used in studies of relative growth, in function of their rigid exoskeleton and discontinuous growth (Du Preez and McLachlan, 1984; Leite *et al.,* 2006). The power function, or Huxley's equation, is the most used to show this relationship, and represented by $y = a.x^b$ (Huxley, 1950). The x is the independent variable, related to other body dimensions of the species (dependent variables, y), that can be the size and the weight, respectively. The b is the allometric constant, which expresses the analogy between these two variables, and the constant *a* represents the degree of fattening of the species, and is called the condition factor (CF).

According to Satake *et al.* (2009), this relationship is an important tool in studies of biology, physiology and ecology, specially of species with commercial value (LeCren, 1951; Froese, 2006; Mohapatra *et al.*, 2010), since it allows the estimation of the weight when only size measures are available and also allows the comparison between different populations (Gomiero and Braga, 2003). This relation can also be used as a quantitative indicator of the healthiness or "well-being" of the species in its environment, through the condition factor (Vazzoler, 1996).

The condition factor is strongly influenced by the environment factors (exogenous parameters) and by the gonad development, the rate of feeding and growth and the degree of parasitism (endogenous parameters) and may vary among seasons and populations (LeCren, 1951; Rodriguez, 1987; Vazzoler, 1996; Froese, 2006; Pinheiro and Fiscarelli, 2009).

Regarding the Portunidae, the relative growth (considering carapace width - CW vs. wet weight - WW relationship) and/or the CF have been studied for *Callinectes bocourti* A. Milne-Edwards, 1879 by Costa *et al.* (1980); *Callinectes danae* Smith, 1869 by Branco and Thives (1991) and Branco *et al.* (1992); *Arenaeus cribrarius* (Lamarck, 1818) by Pinheiro and Fransozo (1993); *Portunus pelagicus* (Linnaeus, 1758) by Dhawan *et al.* (1976); *Portunus spinimanus* Latreille, 1819 by Santos *et al.* (1995); *Callinectes sapidus* Rathbun, 1896 by Olmi and Bishop (1983), Cadman and Weinstein (1985) and Atar and Seçer (2003); and *Callinectes ornatus* Ordway, 1863 by Mantelatto and Martinelli (1999).

The present work aims at improving the actual knowledge on the size vs. weight relationship and the condition factor of these commercially important crab, through the analysis of sexual and seasonal variations of those parameters in the species *Callinectes danae* from a tropical estuary. The results presented here will be important for management plans, to monitor the population through the condition factor and to derive length estimates when the crabs are weighed but not measured. In addition, they will help to fulfill the lack of knowledge on the biology of crabs in the tropical coast of Brazil.

Material and Methods

The study area is included at the Santa Cruz Channel (07°34'00"S - 07°55'16"S and 34°04'48"W - 34°52'24"W), an estuarine complex located at Pernambuco State, Northeastern Brazil. It's an estuary between the Itamaracá Island and the continent, with freshwater input from six rivers that flow into it. The region shows a climate within the As' type of Koeppen system, with a dry season between the months of September and February, and a rainy season between March and August (Cavalcanti and Kempf, 1970). This estuary is considered one of the most productive in the northeast of Brazil, in terms of phytoplanktonic production and biomass (Macedo *et al.,* 2000).

Sampling took place at four stations along the Santa Cruz Channel (Fig. 1): 1 – Congo River mouth (7°46'26"S - 34°53'27"W); 2 – President Vargas bridge (7°46'28"S - 34°53'13"W); 3 – Paripe River mouth (7°48'38"S - 34°51'27"W) and 4 – Coroa do Avião sand bank (7°48'59"S - 34°50'28"W). Samples of *Callinectes danae* were monthly collected from January to December 2009, during diurnal low tides of spring tides. The specimens were attracted with baits and collected with a dipnet. The samplings were performed at four areas to maximize the number of collected individuals, as well as to collect individuals of both sexes, since there is a habitat partitioning at the area according to the sex (Araújo *et al.* 2011; 2012a). These regions were also chosen taking into account the accessibility and the abundance of the species. For the statistical analysis, however, the data were grouped as a single sample.

At laboratory, the specimens have

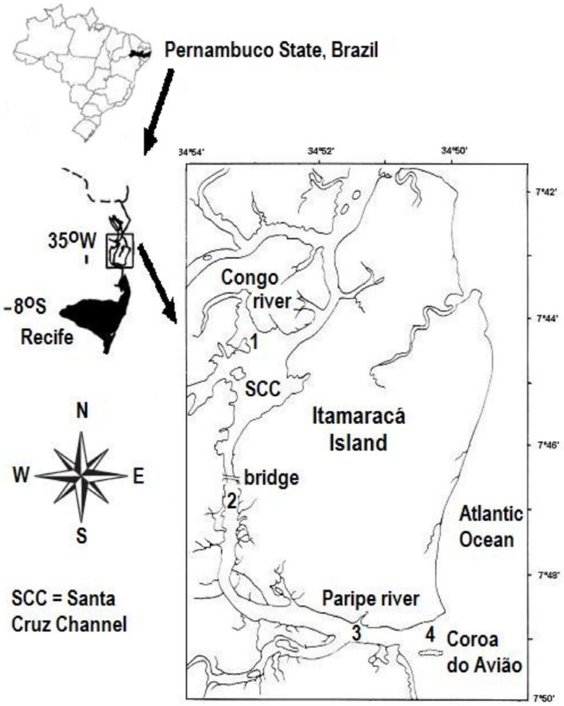

Figure 1. Map of the area of study, the Santa Cruz Channel, Pernambuco State, Northeastern Brazil.

their sex checked to the morphology of the abdomen, measured and weighted at the carapace width (CW) and wet weight (WW), respectively, with a 0.05 mm precision caliper and a 0.1g precision balance.

The minimum, mean ± standard deviation and maximum values of CW and WW were estimated for each sex. All statistical analysis were performed at $\alpha = 5\%$. The normality of the data distribution was tested through the Shapiro-Wilk test. The Mann-Whitney-Wilcoxon test was applied to compare the CW and WW between sexes, since data was heterocedastic.

The relative growth of *C. danae* was described for each sex through the potency equation $WW = a.CW^{b}$, where WW is the wet weight, CW is the carapace width, *b* is the slope, and *a* the intercept. The fit was evaluated by the coefficient of determination (R^2). Subsequently, the data was log-transformed and submitted to a linear regression ($log\ HW = log\ a + b.log\ CW$).

The Box & Cox (1964) procedure was applied to determine the best transformation to obtain the normality of the dependent variable. Subsequently, an Analysis of Covariance (ANCOVA) was used to compare the slopes and intercepts of the lines between sexes, to verify the possibility of grouping males and females by the same equation. The type of weight increase was defined by the coefficient *b* (isometric, b = 3; positively allometric, b > 3; and negatively allometric, b < 3), which had its significance tested by the Student t test.

The total condition factor (CF) was calculated for both males and females (ovigerous and non-ovigerous were grouped) to the values of total samples by the formula $a = WW/CW^{b}$ (LeCreen, 1951). This formula was also applied monthly and seasonally (Summer = January to March; Autumn = April to June; Winter = July to September; and Spring = October to December) for each sex.

The minimum, mean ± standard deviation and maximum values of the CF were estimated for each sex, month and season. The Mann-Whitney-Wilcoxon test was applied to compare the CF between sexes, and the Kruskal-Wallis to compare the CF between seasons, followed by Dunn's *a posteriori* test when significant differences were detected (Zar, 1996; Ayres *et al.,* 2007).

Results

A total of 1635 individuals of *Callinectes danae* were analyzed, being 881 males (53.8%) and 754 females (46.2%). The mean CW of males was 60.85 ± 16.84 mm, and that of females was 55.26 ± 13.03 mm. The mean WW of males was 36.57 ± 29.08 g, and that of females was 24.62 ± 15.84 g. (Table 1). Males were significantly larger and heavier than females ($p < 0.05$).

The slopes and intercepts of the lines differed significantly between sexes ($p < 0.05$), showing sexual dimorphism in the size vs. weight relationship of *C. danae.* The relationship (Fig. 2) was allometrically positive for both males ($b = 3.12$) and females ($b = 3.02$) ($p < 0.05$).

The mean total condition factor of males was $8.0\ 10^{-5} \pm 1.5\ 10^{-5}$, and that of females

Table 1. *Callinectes danae*. Minimum, mean (±SD) and maximum values of Carapace width (CW), Wet Weight (WW) and Condition Factor (CF) of males and females.

Sex	Data	Min	Mean ± sd	Max
Males	CW (mm)	26.30	60.85 ± 16.84	95.90
	WW (g)	2.20	36.57 ± 29.08	121.00
	CF (10^{-5})	3.60	7.97 ± 1.48	22.89
Females	CW (mm)	20.15	55.26 ± 13.03	82.35
	WW (g)	0.90	24.62 ± 15.84	71.90
	CF (10^{-5})	6.87	11.50 ± 2.85	34.89

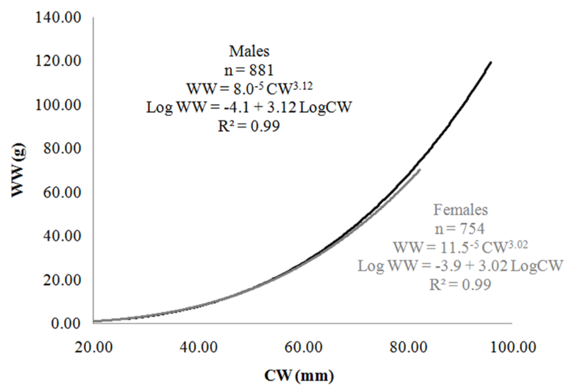

Figure 2. *Callinectes danae*. Comparison of the WW vs. CW between males and females.

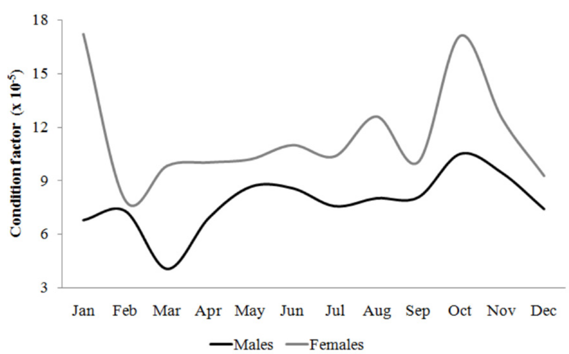

Figure 3. *Callinectes danae*. Monthly variation of the condition factor for both males and females.

was 11.5 10^{-5} ± 2.8 10^{-5}. It varied significantly between sexes, being higher in females ($p < 0.05$).

The condition factor oscillated throughout the sampling year, for both sexes (Fig. 3). In the females, the CF is high in January, and exhibits a sharp decrease in February. In the following months, there is a slight increase of the CF, decreasing again in July, September and December, but with a sharp increase in October. In the males, the CF presented small oscillations when compared to the females. A decrease in the CF can be observed in March and in the following months there is an increase, reaching the higher value in October, as well as observed in females, decreasing again in December. Significant differences could be detected among the seasons, with the condition factor being higher in the spring for both males and females ($p < 0.05$).

Discussion

Males being larger and heavier than females is the expected pattern to many brachyuran crabs (Olmi and Bishop, 1983; Baptista *et al.*, 2003; Baptista-Metri *et al.*, 2005; Pinheiro and Fiscarelli, 2009). It may occur for the differential reproductive effort between sexes. Males present a mate-guarding behavior during and after copulation, providing protection to the recent post-molt female (Pinheiro and Fransozo, 1999). In fact, adult males may have to be stronger to be able of such behavior. On the other hand, females direct a large portion of the energy budget to the eggs production (Kotiaho and Simmons, 2003). Therefore, the somatic growth is reduced in detriment of the reproduction (Ferkau and Fischer, 2006). It's important to state that ovigerous females are usually heavier than non-ovigerous in many species of crabs (Moura and Coelho, 2004; Araújo *et al.*, 2012a), even though in many studies they are commonly grouped as total females (Branco and Thives, 1991; Pinheiro and Taddei, 2005; Pinheiro and Fiscarelli, 2009), as well as in the present paper.

Both males and females presented a positive allometric relationship of weight in function of size. However, Baptista-Metri *et al.* (2005) found an isometric and Branco and Thives (1991) found a negative pattern for the same relationship in *C. danae*. Branco *et al.* (1992) found a negative allometric pattern, but did not differentiated males and females. These differences within the same species may be a result of geographical variation between populations, due to fisheries exploitation (Branco and Fracasso, 2004), and/or differences in the abiotic factors (Hartnoll, 1982; Pinheiro and Fransozo, 1993), as salinity, pH, rainfall, dissolved oxygen and especially temperature, which varies significantly between Northeast and South of Brazil, where these other studies were accomplished. For example, Branco and Masunari (2000) found an amplitude of 15.5ºC in the water temperature at Santa Catarina, South of Brazil, while Araújo *et al.* (2012a) found an amplitude of 4.5ºC at Pernambuco, Northeast of Brazil, less than a third of what was observed by the other authors. In fact, populations inhabiting different latitudes can present divergences on their biological aspects, as growth, population structure and reproduction (Armitage and Landau, 1982; Hartnoll, 1982; Maltby and Calow, 1986; Hines, 1989; Lardies and Castilla, 2001; Abelló *et al.*, 2002; Yoder *et al.*, 2007; Souza-Carvalho *et al.*, 2011). With the results of the present paper and comparing them to others accomplished with the same species (Branco and Thives, 1991; Branco *et al.*, 1992; Baptista-Metri *et al.*, 2005), these latitudinal differences become clear.

In other species of Portunidae, a positive allometry in the WW vs. CW relationship was observed in *Portunus pelagicus* (Dhawan *et al.,* 1976), *Arenaeus cribrarius* (Pinheiro and Fransozo, 1993) and *Callinectes ornatus* (Branco and Fracasso, 2004), while *Liocarcinus depurator* (Linnaeus, 1758) (Mori and Zunino, 1987) and *Callinectes sapidus* (Atar and Seçer, 2003) presented negative allometry for the same relationship. Thus, there is no clear pattern for the Portunidae. While the type of growth can be similar between different species of this family, intraspecific variations may occur. In fact, the type of growth of Crustacea is ontogenetically determined to each species (Hartnoll, 1982), but may vary between sexes, sexual maturity and populations.

The constant of weight increase *b* was different from 3, which evidences that *C. danae* presents ontogenetic changes on its body shape along its development, probably due to sexual maturity, such as observed by Costa and Negreiros-Fransozo (1998) and Araújo *et al.* (2012b). These changes also occur in other swimming crabs, such as in *Arenaeus cribrarius* (Pinheiro and Fransozo 1993) and *Callinectes ornatus* (Mantelatto and Martinelli, 1999), a pattern found among brachyuran crabs (Hartnoll, 1982).

Males presented a higher regression coefficient than females, similar to other brachyuran crabs (Branco and Thives, 1991; Branco and Fracasso, 2004; Myiasaka *et al.*, 2007). This may be a result of the androgen gland improving the weight in the male crab after maturity (Bliss, 1968; Pinheiro and Fiscarelli, 2009).

The condition factor of the females was higher than that of males, what may be due to the fact that female gonads are heavier than that of males, and this fact has been observed in many species of Brachyura, as *C. sapidus* (Atar and Seçer, 2003), *Dilocarcinus pagei* Stimpson, 1861 (Pinheiro and Taddei, 2005) and *Ucides cordatus* (Linnaeus, 1763) (Pinheiro and Fiscarelli, 2009). However, Branco and Thives (1991) and Pinheiro and Fransozo (1993) observed that males presented higher condition factor for *C. danae* and *A. cribrarius,* respectively. It is interesting to note that a small difference in the regression coefficient between sexes could generate great differences in the condition factor. Besides, sexual dimorphism in the metabolic rates, nutritional aspects, stage of maturity, time of recruitment and selective fisheries might also affect sexual differences of the condition factor (Rodríguez, 1987).

Both males and females presented variation of the condition factor comparing months and seasons. This result can indicate an influence of the reproductive period and molt cycle, since the condition factor varies with cyclic activities (Vazzoler, 1996), even though the condition factor appears not to meet the reproductive period in species with continuous reproduction (Branco *et al.*, 1992).

The condition factor of females oscillated along the months of the year, decreasing sharply in February (end of the dry period) and in September (beginning of the dry period), months with the highest frequency of ovigerous females in this population (Araújo *et al.*, 2011). These authors also found ovigerous females in March, but with frequency lower than in February and September. Lower condition factors are associated with the spawning period (Agostinho *et al.*, 1990; Dutil *et al.*, 2003; Pinheiro and Taddei, 2005). The higher condition factor in January may indicate that the females have stored energy, after the decrease of the condition factor in December, to breed in January and also in February. Therefore, February seems to be a suitable period for larval release, which corroborates the hypothesis that biological activities are favored in the summer (Sastry, 1983; Castiglioni *et al.*, 2011), which in tropical areas is the dry period. March, however, may not be as suitable as February due to the end of summer, when temperatures are lower and raining is more frequent. By this, the condition factor in March was not as affected as in February. Besides, the females of *Callinectes* copulate right after the puberty molt, while the carapace is very soft and the gonopore decalcified (Gleeson, 1991; Araújo *et al.,* 2011). The molt leads to low condition factors (Pinheiro and Taddei, 2005), since blue crabs do not feed during the period around the ecdysis (Hines *et al.*, 1987). Therefore, the condition factor is expected to be low (Dutil *et al.*, 2003). In the other months, when the frequency of ovigerous females is low or null (Araújo *et al.*, 2011), an increase in the condition factor occurred due to a higher energy intake of the females to the reorganization of the gonads to the next period of spawning (Pinheiro and Taddei, 2005). The seasonal variation of the condition factor in females also confirms the observed among months. It was higher in the spring, probably due to a preceding higher energy intake as a preparation to the spawning period, and low values from summer to winter.

Regarding males, the condition factor showed a sharp decrease in March, closely to the peak of reproduction of this species in this population (Araújo *et al.*, 2011), probably due to the deflation of the gonads after the copula. There might be an influence of the molt period as well. Since the condition factor was relatively stable in the following months, males of *C. danae* may not present another marked period of molt. The seasonal oscillations in the condition factor of males were very similar to that of females, showing a synchronicity, as also observed by Branco and Thives (1991): it was higher during the spring, before the intensification of reproduction; lower in the summer due to the copula and molt, and intermediate from autumn to winter, period of recovery after the molt period and preparation to the next reproductive period.

As mentioned for other brachyurans previously studied, we conclude that the condition factor of both males and females from this estuary region is related to the reproductive period of *Callinectes danae*, being an important factor to help the understanding of the reproductive behavior and to the management of this commercially exploited species.

Acknowledgments

The authors are deeply thankful to professor Gabriel Omar Skuk Sugliano (*in memorian*) for being an example of human, researcher, and lover of the nature; and to anonymous reviewers for their criticism and suggestions on an early version of the manuscript. The first author is also thankful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES, for the fellowship granted.

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Submitted 21 November 2011
Accepted 17 June 2012