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Condition factor and carapace width versus wet weight relationship in the blue swimming crab *Portunus segnis*

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Abstract

The size-weight relationship of a species allows for estimating the expected weight based on size. The present contribution aims at evaluating the body weight vs. carapace width relationship and the condition factor of the blue swimming crab *Portunus segnis*. These characteristics were analyzed for each sex using specimens collected monthly from April 2012 through to March 2013, at the Persian Gulf (Hormozgan Province, Iran). The size of each specimen was measured (carapace width) and weighed (total body wet weight). A total of 302 individuals of *P. segnis* were analyzed. The body weight-carapace width relationship indicated positive allometric growth in males and isometric growth in females. Body weight was higher in males than females of equivalent carapace width, and the means for condition factors were always higher in females than in males, due to the heavier gonads in the former, an expected pattern for many crabs. In both sexes, the lowest condition factor was detected in winter with an ascending trend in the next seasons. The oscillation in condition factor throughout the sampling year was more prominent in females and related to the reproductive cycle. The information reinforces data to define fishing closed seasons for this portunid that is used in many places in the world.

Keywords

Biometry; body size; condition factor; crab; gonad; reproduction; weight

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Introduction

Many crab species are economically important, so it is important to have detailed knowledge about their biology. *Portunus segnis*, known as the blue swimming crab, is a pelagic species that lives in a wide range of inshore and continental shelf areas, including sandy, muddy and sea grass habitats, from the intertidal zone to at least 50 m depth. This species is restricted to the western Indian Ocean from Pakistan to South Africa, and is a Lessepsian migrant into the Mediterranean from the Red Sea (Lai et al., 2010). Because of its large size and good flavor, this crab is considered as one of the economically important species with high demand in the market (Safaie et al., 2013a). The global capture production of this crab was more than 200 000 tons in 2013 (FAO, 2015).

The size-weight relationship assumes an important prerequisite in studies of biology, physiology and ecology, especially in species with commercial value (Froese, 2006; Mohapatra et al., 2010). This relationship allows converting one variable to another, estimating the expected weight for a certain size, or detecting ontogenetic morphological changes related to maturation of crustaceans and fishes (Pinheiro & Fransozo, 1993). Such knowledge can be useful for further studies on the life history of the species and in the development of its fishery, resource management, and culture.

The regression model most used to evaluate this relationship is the power function $Y = aX^b$ (Huxley, 1950) that is fitted to the empirical points of this mathematic equation, also known as the allometric growth equation. The 'X' (independent variable) is related to body size of the species, while 'Y' (dependent variable) is expressed by the total wet weight. The exponent 'b' represents a constant exhibiting the weight growth rate of body size, which can be isometric ($b = 3$) or allometric (positive, $b < 3$; or negative, $b > 3$; Hartnoll, 1982). Therefore, constant 'a' represents the degree of fattening (also referee to as the condition factor) of a species, commonly used as a quantitative indicator of their general status or 'well-being' (Vazzoler, 1996). This is based on the assumption that a higher weight at a given size reflects a better condition. The condition factor is strongly influenced by exogenous (e.g., environmental factors) and endogenous parameters (e.g., rate of feeding and growth, degree of parasitism, sexual cycle, etc.), and may vary among seasons and populations (Froese, 2006; Pinheiro & Fiscarelli, 2009).

The total body weight-carapace width relationship and the condition factor have been previously evaluated for some Portunids such as *Callinectes bocourti* (Costa et al., 1980), *Callinectes danae* (Branco & Thives, 1991; Branco et al., 1992), *Callinectes sapidus* (Atar & Seçer, 2003), *Charybdis helerii* (Mantelatto & Garcia, 2001), *Arenaeus cribrarius* (Pinheiro & Fransozo, 1993), *Portunus spinimanus* (Santos et al., 1995), *Portunus pelagicus* (Josileen, 2011; Efrizal, 2014), *Portunus sanguinolentus* (Sumpton et al., 1989; Sukumaran & Neelakantan, 1997) and *Portunus segnis* (Safaie et al., 2013b). Almost in all the studies, the relationship between body weight and carapace width was not compared seasonally in detail, but were rather restricted to comparisons between the sexes.

The present work aims to evaluate the biometric relationship between total body weight and carapace width of the blue swimming crab, *Portunus segnis* fitted using a power function. This relationship was evaluated for each sex during a year and compared among seasons, as well as analyzed month and seasonally, to improve knowledge about this species' condition factor. This study will provide useful information for interpretation of this relationship among growth-related traits, management plans and monitoring populations of this species. In addition, the results will help to understand the reproductive cycle of this fishery resource, and aid to complete information about the biology of crabs in the Persian Gulf coast of Iran.

Material and methods

Study area and specimens sampling

Specimens of *Portunus segnis* (Lai et al., 2010) were captured monthly from April 2012 to March 2013, except during two months (August 2012 and January 2013), by gill net in the Persian Gulf, near the shore of Bandar Abbas (27°9′51″N-56°14′47″E), in Hormozgan Province, Iran. After capture, crabs were placed in plastic bags over a layer of ice in a cooler and transported back to the laboratory for further examination. The specimens were sexed according to abdominal morphology and number of pleopods (two pairs in males and four pair in females).

Morphological measurement procedures

In the laboratory, each specimen was weighed (BW, total body wet weight) to the nearest 0.01 g using a precision balance (A&D, FX-400, Japan), after dried on a tissue paper. The carapace width (CW) was measured with a digital vernier caliper (IP67, Guanglu, China) to the nearest 0.01 mm.

To estimate the BW-CW relationship, the empirical points were submitted to regression analysis using the allometric growth power function ($Y = aX^b$), according to Ricker (1973), where 'Y' is the total expected body weight (g), 'X' is the carapace width (mm), 'a' is the Y-intercept (called condition factor), and 'b' is the slope (or weight growth coefficient). These parameters are easily estimated by linear regression analysis based on logarithmic transformation (Ln) of variables with a fit equation ($\mathrm{Ln}\,Y = \mathrm{Ln}\,a + b\,\mathrm{Ln}\,x$) that was evaluated by the coefficient of determination (R^2). The type of weight increase (growth) was defined by the value of the coefficient 'b', which had its equality to 3 tested by the Student t-test at a 5% significance level.

The Fulton's condition factor (CF) was estimated for each sex using the formula $CF = (100BW)/CW^b$, where CF is condition factor, BW is mean body weight (g), CW is mean carapace width (mm), and 'b' is the weight increase (growth) coefficient from the weight-carapace width relationship. This formula was applied by month and season (spring, April to June; summer, July to September; autumn, October to December; and winter, January to March) for each sex.

Statistical procedures

The equations obtained for the *BW-CW* relationship were compared among the seasons of the year for each sex separately. The variables *BW* and *CW* were log-transformed and fitted by a linear regression ($\text{Ln}\, Y = \text{Ln}\, a + b\, \text{Ln}\, X$), corresponding to power function evaluation. Student's t-test was used to assess the parallelism or coincidence between the straight lines. When equations do not have statistical difference among the intercept and slope constants, their data were grouped and again submitted to regression analysis to obtain a more reliable equation. Because multiple comparisons between the straight lines among seasons are conducted, a Bonferroni-adjusted significance level of 0.012741 was calculated. This correction accounts for the increased possibility of a type-I error, to keep the overall α equal to 0.05.

Values were presented as mean ($\pm$ standard error), minimum, and maximum for each sex and season. All statistical analysis were performed at $\alpha = 0.05$. The normality of the data distribution was tested through the Kolmogorov-Smirnov test. Differences between seasons were determined using one-way analysis of variance (ANOVA) followed by Tukey post hoc test. Student's t-test was used for analyzing the differences between the sexes. The Mann-Whitney-Wilcoxon test and the Kruskal-Wallis test were applied to compare the variables between sexes and seasons, respectively, since data were heterocedastic (Zar, 2010).

Results

In this study, a total of 302 individuals of *Portunus segnis* were analyzed, comprising 154 females (51%) and 148 males (49%). The mean *CW* of males (118.69 $\pm$ 1.23 mm) was statistically similar to that of females (121.90 $\pm$ 1.31 mm; $t_{300} = 1.775$, $P = 0.077$; table 1). The same was seen when *BW* means where compared between sexes (males: 135.70 $\pm$ 4.74 g; females: 131.51 $\pm$ 4.66 g; $t_{300} = -0.633$, $P = 0.529$; table 2). For females, the coefficient of variation (CV%) of *CW* was 13.4%, slightly higher than that for males (12.6%). These coefficients were about one-third smaller than the values obtained for the variable *BW* of females and males (44.0 and 42.5%, respectively).

The seasonal means for *CW* (table 1) and *BW* (table 2) showed different patterns in males and females. In summer, the males were significantly heavier than in winter ($U = 86$, $N = 36$, $P < 0.05$), while for females a uniform pattern with similar means of both variables was observed during the year (*BW*: $X^2 = 2.060$, $N = 154$, $P = 0.560$ and *CW*: $X^2 = 4.521$, $N = 154$, $P = 0.210$).

An overall analysis of the *BW-CW* relationship of each sex showed a significant positive correlation between the variables, with the empirical points fit to the power function ($R^2 > 0.93$) (fig. 1). The 'b' value for the *BW-CW* relationship was distinct between the sexes with an isometric growth pattern in weight for females ($b = 3.03$, $t_{153} = 0.39$, $P > 0.05$; fig. 1A), and a positive allometric pattern identified for males ($b = 3.45$, $t_{147} = 7.81$, $P < 0.05$; fig. 1B). In males there were no significant

Table 1.
Statistical summary for carapace width (in millimeters) for each sex of *Portunus segnis*, according to season based on monthly captures from April 2012 through March 2013.

Season	CW_{males}					$CW_{females}$				
	N	Min.	Max.	$\bar{x} \pm$ SE		N	Min.	Max.	$\bar{x} \pm$ SE	
Spring	58	85.82	141.90	118.41 ± 1.69	a	60	84.54	161.84	121.85 ± 2.14	a
Summer	18	80.75	146.23	123.83 ± 4.06	a	20	96.44	144.15	117.98 ± 2.48	a
Autumn	54	86.55	146.84	118.69 ± 2.21	a	59	92.92	158.47	122.17 ± 2.05	a
Winter	18	99.34	148.96	114.49 ± 3.42	a	15	89.77	163.42	126.23 ± 5.84	a
Total	148	80.75	148.96	118.69 ± 1.23	a	154	84.54	163.42	121.90 ± 1.31	a

Abbreviations: *CW*, carapace width; *N*, number; Min., minimum; Max., maximum; $\bar{x}$, mean; SE, standard error; different letters indicate significant differences ($P < 0.05$) between seasons.

difference between the equations obtained for each season ($P > 0.05$; fig. 2), a fact verified between the sexes ($P < 0.05$). Data obtained for males during the sampling year could be grouped in a single equation, the same occurring for females despite a slight difference between autumn and winter in the '*a*' constant (table 3). For females, the equation was $\text{Ln}\,BW = -9.72 + 3.03\,\text{Ln}\,CW$ ($N = 154$, $R^2 = 0.93$, $P < 0.05$) and for males $\text{Ln}\,BW = -11.64 + 3.45\,\text{Ln}\,CW$ ($N = 148$, $R^2 = 0.96$, $P < 0.05$; fig. 2).

The mean total condition factor of females ($0.61 \times 10^{-2} \pm 0.005 \times 10^{-2}$) differed significantly when compared with that of males ($0.09 \times 10^{-2} \pm 0.001 \times 10^{-2}$), with coefficients of variation of 10.9 and 8.9%, respectively. This mean differed significantly between the sexes, being higher in females ($t_{157} = 96.034$, $P < 0.05$). The condition factor (*CF*) fluctuated throughout the sampling year for both sexes (fig. 3). In females, *CF* was highest in the autumn and exhibited a sharp decrease in winter and a slight increase in the following seasons (fig. 4). Otherwise,

Table 2.
Statistical summary for total body weight (in grams) for each sex of *Portunus segnis*, according to season, based on monthly captures made from April 2012 through March 2013.

Season	BW_{males}					$BW_{females}$				
	N	Min.	Max.	$\bar{x} \pm$ SE		N	Min.	Max.	$\bar{x} \pm$ SE	
Spring	58	41.01	247.95	132.92 ± 6.24	ab	60	40.68	300.42	128.77 ± 7.79	a
Summer	18	34.15	269.00	159.46 ± 15.57	b	20	66.06	210.42	115.02 ± 7.75	a
Autumn	54	36.26	273.02	138.02 ± 8.65	ab	59	58.84	265.00	135.59 ± 6.81	a
Winter	18	66.75	269.66	113.93 ± 13.14	a	15	48.40	331.11	148.42 ± 22.35	a
Total	148	34.15	273.02	135.70 ± 4.74	a	154	40.68	331.11	131.51 ± 4.66	a

Abbreviations: *BW*, body weight; *N*, number; Min., minimum; Max., maximum; $\bar{x}$, mean; SE, standard error; different letters indicate significant differences ($P < 0.05$) between seasons.

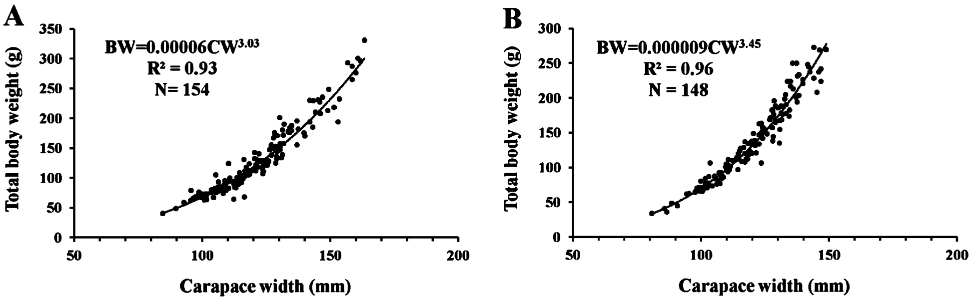

Figure 1. Scatter plot of empirical points of the total body weight vs. carapace width relationship fitted by power function for females (A) and males (B) of *Portunus segnis*. The data are based on captures made monthly from April 2012 through March 2013.

males presented a small *CF* oscillation when compared to females, with a decrease in winter and higher values in spring maintained at the same level during summer and autumn. The value of *CF* did not differ significantly between the spring, summer and autumn in each sex (fig. 4). In females there was no significant difference between the spring and summer when compared with the winter ($F_{2,92} = 0.464$, $P = 0.630$), whereas in males the value was significantly lower in the winter in comparison to the rest of the sampling year ($X^2 = 9.270$, $N = 148$, $P = 0.026$).

Discussion

In the present study, a sexual dimorphism in the relationship between body weight (*BW*) and body size (*CW*) was detected. The value of exponent '*b*' of *BW-CW* relationship in this study demonstrates that males of *Portunus segnis* are heavier than females at a given size. The power function fitted to the empirical points of this relationship suggests a direct correlation between biometric variables independent of the sex. The sexual dimorphism in weight that was recorded in the present study is

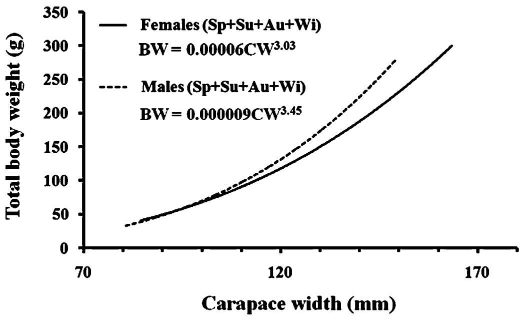

Figure 2. Relationship of total body weight vs. carapace width represented after statistically analysis of similar seasonal equations clustered for females (solid line) and males (dotted line) of *Portunus segnis*. Abbreviations: Sp = spring, April-June; Su = summer, July-September; Au = autumn, October-December; and Wi = winter, January-March.

Table 3.
Equations for the relationships of total body weight to carapace width, obtained for each sex of *Portunus segnis*, by season, based on monthly captures from April 2012 through March 2013.

Season	Males					Females				
	N	Linearized power function ($\text{Ln}\, y = \text{Ln}\, a + b\, \text{Ln}\, x$)	‘a’	‘b’	R^2	N	Linearized power function ($\text{Ln}\, y = \text{Ln}\, a + b\, \text{Ln}\, x$)	‘a’	‘b’	R^2
Spring	58	$\text{Ln}\, BW = -11.37 + 3.39\, \text{Ln}\, CW$	a	a	0.96	60	$\text{Ln}\, BW = -9.64 + 3.01\, \text{Ln}\, CW$	ab	a	0.92
Summer	18	$\text{Ln}\, BW = -11.73 + 3.47\, \text{Ln}\, CW$	a	a	0.99	20	$\text{Ln}\, BW = -9.47 + 2.97\, \text{Ln}\, CW$	ab	a	0.95
Autumn	54	$\text{Ln}\, BW = -11.80 + 3.49\, \text{Ln}\, CW$	a	a	0.96	59	$\text{Ln}\, BW = -9.38 + 2.96\, \text{Ln}\, CW$	b	a	0.93
Winter	18	$\text{Ln}\, BW = -10.92 + 3.29\, \text{Ln}\, CW$	a	a	0.93	15	$\text{Ln}\, BW = -10.84 + 3.25\, \text{Ln}\, CW$	a	a	0.98
Total	148	$\text{Ln}\, BW = -11.64 + 3.45\, \text{Ln}\, CW$	a	b	0.96	154	$\text{Ln}\, BW = -9.72 + 3.03\, \text{Ln}\, CW$	b	a	0.93

Abbreviations: BW, body weight; CW, carapace width; N, number; ‘a’, linear coefficient; ‘b’, angular coefficient; $P < 0.05$.

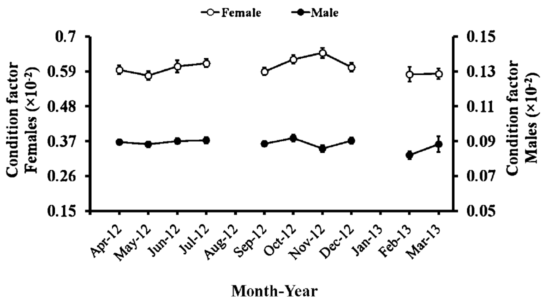

Figure 3. Monthly means of the condition factor for females (○) and males (●) of *Portunus segnis*. The data are based on captures made monthly from April 2012 through March 2013.

a typical pattern for many brachyuran crabs (Pinheiro & Fiscarelli, 2009; Araújo & Lira, 2012). The tendency of males to be heavier than females is also in accordance with previous studies on portunids such as *P. pelagicus* (Sukumaran & Neelakantan, 1997), *P. sanguinolentus* (Sukumaran & Neelakantan, 1997) and *Scylla serrata* (Prasad et al., 1989).

This sexual dimorphism can be explained by a reproductive behavior that differs according to crab family. In most aquatic brachyuran families (especially Portunidae and Cancridae), the sexual dimorphism in size and/or weight is more marked when compared to semiterrestrial and terrestrial ones (Pinheiro et al., 2005). Males in these latter crab species exhibit a mate-guarding behavior of the females before and after copulation, avoiding male competition and providing protection to the recent post-molt females, respectively (Pinheiro & Fransozo, 2002). These behaviors ensure mating success in these crab families and are considered as a reproductive strategy, where stronger adult males take advantage by developing this behavior (Jivoff, 1997). In fact, males should be heavier and stronger to be able to perform such reproductive behavior. In contrast, females allocate a large portion of energy to their gonad development and oocyte production (Kotiaho & Simmons, 2003).

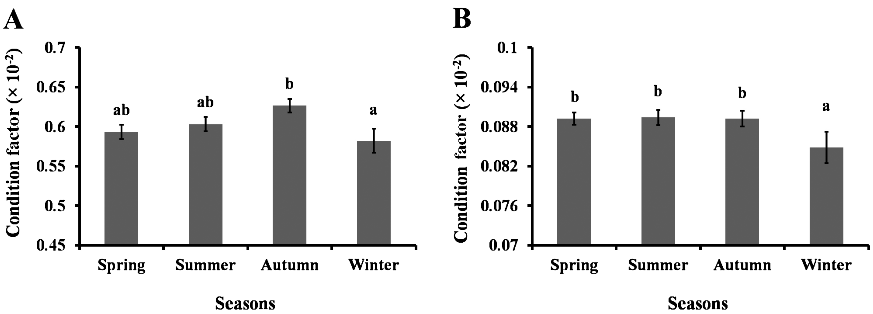

Figure 4. Seasonal means (bars) and standard error (vertical lines) of the condition factor for females (A) and males (B) of *Portunus segnis*. The data are based on captures made monthly from April 2012 through March 2013. Lower case letters added to bars in a same graph do not have statistical difference ($P > 0.05$).

Therefore, due to an antagonistic interaction between growth and reproduction in crustaceans (Hartnoll & Gould, 1988), the somatic growth is reduced during the reproductive period (Ferkau & Fischer, 2006).

The *BW-CW* relationship between males and females of *P. segnis* indicated a different allometric pattern. The former demonstrates a positive allometric growth while the latter exhibited an isometric growth pattern. Results corroborated the finding in *Callinectes ornatus* (Branco & Lunardón-Branco, 1993). However, in some studies in other Portunids, such as *P. sanguinolentus* (Sukumaran & Neelakantan, 1997), an isometric growth was found in both males and females. Whereas in other portunids, like *P. pelagicus* (Sukumaran & Neelakantan, 1997; Josileen, 2011) and *Callinectes danae* (Araújo & Lira, 2012), positive allometry was demonstrated in both sexes. This interspecific variation may be the result of species-specific characteristics. In fact, the type of crustacean growth is a genetically-related trait determined for each species. Beside biological factors, including behavior like guarding and protecting the mate during the reproductive cycle, abiotic factors (e.g., water salinity, pH, dissolved oxygen and especially temperature) can influence growth. When comparing the present results with others obtained with related species, it becomes evident that there is no clear pattern for the Portunidae in these biological differences.

Comparing the weight rate coefficient '*b*' in a seasonal evaluation by sex indicated no difference. This is maybe due to the size of the studied animals, where adults were in the majority in the samples, while only a narrow range of juveniles was included. In contrast, in the mangrove crab, *Ucides cordatus*, studied by Pinheiro and Fiscarelli (2009), a wide range of animals was sampled and results showed different weight increase between seasons in each sex. There is a negative correlation between two constants for increase in weight ('*b*') and degree of fattening ('*a*'), and comparisons among seasons by sex are only valid when '*a*' values were identical or very close (Pinheiro & Fransozo, 1993).

Females have a lower constant of increase in weight than males during the spring, summer and autumn. Only in winter this value was the same between males and females. This crab can be considered as a year-round spawner, in the studied area, based on the gonadal development and gonadosomatic index, with the winter as the main season of reproduction (Safaie et al., 2013a). Reproduction needs plenty of energy to progress, so the constant '*b*' of both sexes was reduced in winter, and in the rest of the year the individuals prepare for another major reproductive activity. As oocyte development and growth in females requires much more energy than gonadal development in males, the reason for the lower value of the constant '*b*' in females is explained. After winter, recovery and energy storage to renew the reproductive cycle caused an increase in the value of constant '*b*'. As a consequence, in the spring, summer, and particularly in the autumn, the animals were fatter. Gonadal organization and recovery occurred during this period. The condition factor also increases because of the rest from reproduction and the stocking of energy reserves. This agrees with the data obtained in the present study, which indicate a higher condition factor in both sexes during the non-reproductive period (fattening phase), compared to the reproductive season. However, the condition factor by itself cannot be used as a single parameter for the determination of the reproductive period, but it is recommended to be used in association with the other factors, including the data obtained from the microscopic observation of the gonads (Choy, 1988). Besides, the gonadosomatic index may be used for this purpose, since it also considers the weight of the developing ovaries (Magalhães et al., 2012).

The higher regression coefficient in males is similar to other brachyuran crabs (Miyasaka et al., 2007). This may be the result of the androgen gland improving the weight in the male crab after maturity (Pinheiro & Fiscarelli, 2009), as well as the growth of their chelipeds that shows a positive allometric pattern from the puberty molt onwards (Pinheiro & Fransozo, 1998).

The hepatopancreas (also named midgut gland) is considered as the major source organ responsible for storage and transport of energy reserves to the developing oocytes during the vitellogenic stage. Therefore, females in decapod crustaceans have an increase in weight and/or volume of this organ during vitellogenesis (Haefner & Spaargaren, 1993). In fishes, the increase in the hepatosomatic index is used to determine the period of greatest energy allocation for vitellogenesis, raising the values of individual condition factors (Querol et al., 2002). Similarly, in *P. segnis*, the condition factors of both sexes increased from spring onwards. In females this increase is more prominent, which showed greater regularity in ovarian development and, therefore, a more obvious seasonal pattern (Santos & Negreiros-Fransozo, 1999).

The condition factor of the females of *P. segnis* was about seven times higher than males, due to the fact that gonads in females are heavier than those of males. The result is in accordance with other studies on some species of brachyurans, such as *Callinectes sapidus* (Atar & Seçer, 2003; Sumer et al., 2013), *Callinectes danae* (Araújo & Lira, 2012), *Charybdis bimaculata* (Doi et al., 2008), *Arenaeus cribrarius* (Pinheiro & Fransozo, 2002), *Portunus sanguinolentus* (Sukumaran & Neelakantan, 1997) and *Portunus pelagicus* (Sukumaran & Neelakantan, 1997; Josileen, 2011).

It is worth to be noted that a small difference in the regression coefficient (‘*b*’) between sexes could generate great differences in the condition factor (‘*a*’). In the present study the regression coefficient in males were about 14% higher than that of females, and the effect of this discrepancy can be presented in the values of the condition factor of females (seven times higher than that of males). Thus, sexual dimorphism in different physiological aspects (e.g., metabolic rates, nutritional aspects, stage of sexual maturity, time of recruitment or even a combination of them), besides the gonad weight and required energy for reproductive development may be influencing the values of the condition factor (Araújo et al., 2012).

As the other brachyuran crabs previously studied, the evaluation of the sexual variations of the *BW-CW* relationship and the condition factor proved to be good parameters for the study of the biology of *P. segnis*, especially regarding the sexual dimorphism of the growth. Indeed, more studies are needed on the growth and condition factor for this species and other marine brachyuran species with socio-economic importance. The data obtained in these studies are important for management plans, since they allow better comprehension of the reproductive behavior and provide evidence for environmental impacts, as observed herein.

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