Carapace width-weight relationships and condition factor of blue swimming crab, *Portunus pelagicus* Linnaeus, 1758 (Crustacea: Decapoda) in Lasongko Bay, Southeast Sulawesi, Indonesia

Abdul Hamid¹, Djamar TF Lumban Batu², Etty Riani² and Yusli Wardiatno^{2*}

¹Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Halu Oleo University, Kampus Hijau Bumi Tridharma Anduonohu Kendari 93232, Indonesia

²Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Jalan Raya Darmaga, Kampus IPB, Bogor 16680, West Java, Indonesia

Correspondence Author: Yusli Wardiatno, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Jalan Raya Darmaga, Kampus IPB, Bogor 16680, West Java, Indonesia

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Abstract

To date, studies of carapace width-weight relationships in blue swimming crab (*Portunus pelagicus* Linnaeus, 1758) have primarily focused on differences between males and females within a population, whereas studies of the condition factor of this species remain limited. The objective of this study is to assess the carapace width-weight relationships and the condition factor of juvenile and adult crabs throughout the season in Lasongko Bay, Southeast Sulawesi, Indonesia. Monthly samplings of crabs were conducted using gill nets from April 2013 until March 2014. Data were analyzed by sex (juvenile and adult) and season. Carapace width-weight relationships were expressed as power and linear equations. Parameter values of the equations and the growth coefficient were tested using ANCOVA and *t*-tests, respectively; the condition factor was analysed descriptively. Carapace width-weight relationships of male and female juveniles and adults as well as ovigerous females exhibited very strong and positive relationships and an isometric pattern of growth. The growth coefficient and condition factor in both sexes fluctuated throughout the study period. Monthly fluctuations in the condition factor of male and female crabs were within similar ranges. Temporal variation in the fluctuations and timing of peak values of *b* and the conditions factor of male and female crabs was likely related to the crab reproductive cycle, particularly peak spawning in Lasongko Bay.

Key words: Allometric relationships, BSC fishery, growth pattern, Portunidae

INTRODUCTION

Blue swimming crab (*Portunus pelagicus* Linnaeus, 1758) is one of the most economically important crab species due to high commercial demand. The distribution of this species is concentrated in Southeast Asian waters in a variety of habitats, i.e. from intertidal areas to depths of 65 m, in benthic areas covered by seagrass and algae, or even along a stretch of beach in substrates of mud, clay, or sand [5,6,14,19,22,25,44].

The growth of crustaceans, including crabs, often involves several changes in the dimensions of one part of the body, which is typically referred to as relative growth [2,18,21]. Relative growth in crustaceans can be expressed by two morphometric trait relationships, with carapace width or length generally fixed as the independent variable [2,18,26,34,43]. Carapace width or length is also widely used to illustrate relationships between crab size and egg number in reproductive studies of crustaceans [8,14-16,45]. In allometric studies, the relationships between these two variables are usually expressed as power and linear equations [2,21,26,40].

In ecological studies of crabs, carapace width-weight relationships can be converted to a weight growth regression equation, which is useful for estimating the stock population size, particularly for exploitation purposes [3,21]. Carapace width-weight relationships of crabs have been considered more suitable for evaluating crab population sizes compared to relationships between other crab morphometric characters [21]. Moreover, carapace width-weight relationships can be used in ecological studies to estimate the condition factor as a quantitative indicator of the 'well-being' of a species in its environment [2]. The condition factor of crabs may be influenced by environmental factors, gonadal development, growth, food availability, and parasitic conditions, and these factors often vary among seasons, populations [2,26], and rates of exploitation [10].

Numerous studies have assessed carapace width-weight relationships of blue swimming crabs [1, 6,20,21,23,24,31,37,38,40,41]. Nearly all of the published research has focused on male-female carapace width-weight relationships, whereas stage-based studies (i.e. juveniles versus adults) as well as seasonal studies are lacking, particularly in Indonesian waters. Several studies have examined the condition factor of crabs [4,31,32,41], but results have been variable.

Lasongko Bay is a centre of the blue swimming crab fishery in Province of Southeast Sulawesi, Indonesia. Biological information such as habitat-based distribution and reproductive aspects has been collected previously for *P. pelagicus* in the region [12,14-16], reproductive aspects [12,15,16], etc. The objective of the present study is to assess the carapace width-weight relationships and the condition factor of male and female *P. pelagicus* at the juvenile and adult stages throughout the season in Lasongko Bay. Our findings will be beneficial for the sustainable management of the blue swimming crab in the bay.

MATERIAL AND METHODS

Research Location

This study was conducted in Lasongko Bay, Southeast Sulawesi (05°15'–05°27'S, 122°27'–122°33'E; Fig. 1). Monthly samples were collected from April 2013 to March 2014 in an area of about 13.6 km². Sampling period was grouped into two seasons, i.e. East Season (April – September 2013) and West Season (October 2013 – March 2014).

Sampling and Measurement Procedures

Crabs were collected from seven sampling stations ranging from the inner to the outer area of the bay (see Fig. 1). Monthly samples were collected using bottom gill nets with mesh sizes of 1.5, 2.5, and 3.5 inches. Gill nets were set out in the late afternoon, and the entangled crabs were collected during the morning of the next day.

In the laboratory, individuals of *P. pelagicus* were first classified as male or female, and carapace widths (CW) were measured using callipers (Vernier Caliper 0–150 mm × 0.05) with an accuracy of 0.01 mm. Body weight was measured using a digital balance (Xon Med Digital Scale) with an accuracy of 0.01 g. Male and female crabs were also classified as juveniles (CW < 87.00 mm), adults (CW > 87 mm) and ovigerous females. Carapace width-weight relationships of the crabs were determined using an allometric growth equation in the form of the following power equation [6,21, 23, 38]:

$$BW = aCW^b \quad \dots\dots\dots(1)$$

where BW is body weight (g), CW is carapace width (mm), a is the intercept and b is the crab growth coefficient. To simplify calculations, equation (1) was transformed to log₁₀ to obtain a linear equation as follows:

$$\log(BW) = \log(a) + b\log(CW) \quad \dots\dots\dots(2)$$

Fig. 1: Location of the study site in Lasongko Bay, Central Buton, Indonesia. Black dots indicate sampling sites (adapted from Hamid et al. [15]). The condition factor (K) for each sex was determined using the following equation [3, 11]:

$$K = 100 \times BW_m / (CW_m)^3 \quad \dots\dots\dots(3)$$

where BW_m is the mean body weight (g), and CW_m is the mean carapace width (mm).

Data analysis

Analysis of covariance (ANCOVA) was used to test the significance of the regression coefficient “b” and intercept “a” of the carapace width-weight relationships [42]. The allometric growth pattern of the carapace width-weight relationships was determined based on the value of “b” using *t*-tests at *p* = 0.05 [42]. Allometric growth was categorised as follows: isometric if *b* = 3, negative allometric if *b* < 3, and positive allometric if *b* > 3 [18,21,40].

RESULTS

Carapace Width-Weight Relationships

In general, the growth coefficient (b) of the carapace width-weight relationships in males ranged from 3.065 to 3.151, while the value in females ranged from 2.168 to 2.961 (Table 1 and Fig. 2). The values of b for juveniles and adult males were relatively similar, whereas in females, the values for juveniles were lower than those of adults and ovigerous females.

The correlation coefficients (r) of the carapace width-weight relationships in male crabs (juveniles, adults, and both combined) ranged from 0.903 to 0.942, while those in females ranged from 0.705 to 0.942. Values of r for juveniles were higher than those of adult males but not in adult females.

Table 1: Carapace width-weight relationships, correlation coefficient (r), ANCOVA, t-test value b, and allometric growth pattern (AI) of male (juvenile and adult) and female (juvenile, adult and ovigerous) crabs *Portunus pelagicus* of Lasongko Bay, Southeast Sulawesi - Indonesia with linear equation.

Sex	Linear equation	r	ANCOVA		t-test b=3	AI
			a	b		
Male:						
Juvenile	$\text{Log BW} = -4.457 + 3.150 \log \text{CW}$	0.913	-12.751**	17.181**	-0.115 ^{ns}	0
Adult	$\text{Log BW} = -4.487 + 3.151 \log \text{CW}$	0.903	-34.140**	48.985**	-0.117 ^{ns}	0
Total	$\text{Log BW} = -4.309 + 3.065 \log \text{CW}$	0.942	-46.207**	66.702**	-0.050 ^{ns}	0
Female:						
Juvenile	$\text{Log BW} = -2.599 + 2.168 \log \text{CW}$	0.705	-4.525**	7.176**	0.690 ^{ns}	0
Adult	$\text{Log BW} = -4.112 + 2.961 \log \text{CW}$	0.942	-42.004**	61.912**	0.031 ^{ns}	0
Ovigerous	$\text{Log BW} = -0.957 + 2.837 \log \text{CW}$	0.895	-8.322**	26.433**	-0.291 ^{ns}	0
Total	$\text{Log BW} = -3.979 + 2.903 \log \text{CW}$	0.942	-47.689**	71.008**	-0.025 ^{ns}	0

** : Highly significant ($p < 0.001$), ns: not significant ($p > 0.05$), 0: isometric.

Fig. 2: Carapace width-weight relationships (as power equations) of male and female *Portunus pelagicus* in Lasongko Bay, Southeast Sulawesi, Indonesia. ANCOVA results for values of a and b in the carapace width-weight relationships of male and female juveniles and adults and ovigerous females were highly significant ($p < 0.001$), with strong, positive correlation coefficients (r). Values of b did not significantly differ (t-test, $p < 0.05$) from 3 (Table 2) for the juvenile and adult stages of both sexes as well as ovigerous females; therefore, the growth patterns for all categories were isometric.

Table 2: Carapace width-weight relationships, correlation coefficient (r) and type of allometric growth (AI) of male and female *Portunus pelagicus* of Lasongko Bay, Southeast Sulawesi - Indonesia at each season and month with power equation.

Season- Month	Male				Female			
	n	Power	r	AI ^(*)	N	Power	r	AI ^(*)
East season	311	BW=9E-05CW ^{2.947}	0.912		332	BW=0.000CW ^{2.824}	0.964	
April-13	62	BW=0.084CW ^{2.860}	0.815	0	56	BW=0.140CW ^{2.214}	0.824	-
May-13	99	BW=0.087CW ^{2.896}	0.964	0	89	BW=0.085CW ^{2.889}	0.973	0
June-13	54	BW=0.049CW ^{3.130}	0.961	0	58	BW=0.085CW ^{2.888}	0.914	0
July-13	44	BW=0.053CW ^{3.074}	0.920	0	52	BW=0.097CW ^{2.846}	0.902	0
August-13	33	BW=0.144CW ^{2.692}	0.874	-	42	BW=0.049CW ^{3.134}	0.978	0
September-13	20	BW=0.084CW ^{2.907}	0.942	0	36	BW=0.110CW ^{2.808}	0.897	0
West season	292	BW=3E-05CW ^{3.159}	0.964		328	BW=3E-05CW ^{3.134}	0.959	0
October-13	37	BW=0.077CW ^{2.960}	0.876	0	48	BW=0.077CW ^{2.946}	0.897	0
November-13	26	BW=0.042CW ^{3.187}	0.871	0	44	BW=0.104CW ^{2.816}	0.924	0
December-13	53	BW=0.041CW ^{3.198}	0.966	0	52	BW=0.039CW ^{3.198}	0.959	0
January-14	80	BW=0.050CW ^{3.109}	0.984	0	76	BW=0.027CW ^{3.350}	0.970	+
February-14	49	BW=0.049CW ^{3.131}	0.981	0	54	BW=0.056CW ^{3.054}	0.964	0
March-14	47	BW=0.041CW ^{3.202}	0.965	0	53	BW=3.054CW ^{3.065}	0.977	0

(*) Results t test of b=3 (p <0.05), 0 isometric - negative allometric, + allometric positif, n samples number

Results of ANCOVA analysis of a and b male and female were all highly significant (p <0.001)

Values of b of for the carapace width-weight relationships in males during the East and West Seasons were 2.947 and 3.159, respectively, and monthly values ranged from 2.692 to 3.198, with a maximum in December and minimum in August. Monthly values of r for the carapace width-weight relationships of male crabs ranged from 0.815 to 0.961 (Table 2). Values of b for the carapace width-weight relationships of female crabs during the East and West Seasons seasons ranged from 2.824 to 3.134, and monthly values ranged from 2.214 to 3.350, with values of r from 0.824 to 0.978. Values of b for the carapace width-weight relationships of female crabs were highest in January and lowest in April. In general, the values of b for male and female crabs during the East Season tended to fluctuate more than during the West Season (Fig. 3).

Fig. 3: Monthly values of b for the carapace width-weight relationships of male and female *Portunus pelagicus* in Lasongko Bay, Southeast Sulawesi, Indonesia. The carapace width-weight relationships of male crabs during the East and West Seasons and during each month exhibited highly significant positive relationships (p < 0.001). Most values of b for male and female crabs during each month and season did not significantly differ (t-test, p > 0.05) from b = 3, except for male crabs in August and for female crabs in April and January. Therefore, the type of allometric growth for male and female crabs during each season and month was primarily isometric, except for male crabs in August and female crabs in April (negative allometric) and female crabs in January (positive allometric).

Condition Factor

The values of the condition factor of juvenile and adult male crabs were 71.18×10^{-4} and 69.99×10^{-4} , respectively, and those for juvenile, adult, and ovigerous females were 68.68×10^{-4} , 67.72×10^{-4} , and 76.66×10^{-4} , respectively (Table 3). The condition factor of male crabs during the East Season was lower than during the West Season, while the opposite was true of female crabs (Table 4).

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Table 3: Carapace width, weight, condition factor of juvenile and adult male and female as well as ovigerous female of *Portunus pelagicus* of Lasongko Bay, Southeast Sulawesi – Indonesia.

Sex	n	Carapace width (mm)	Body weight (g)	Condition factor
Male:				
Juvenile	61	81.02 ± 8.97	37.85 ± 12.84	71.18 x 10 ⁻⁴
Adult	542	110.87 ± 11.99	95.40 ± 35.40	69.99 x 10 ⁻⁴
Total	603	107.85 ± 14.78	89.57 ± 38.00	71.40 x 10 ⁻⁴
Female:				
Juvenile	54	79.60 ± 7.20	34.64 ± 9.39	68.68 x 10 ⁻⁴
Adult	484	112.60 ± 15.13	96.69 ± 42.54	67.72 x 10 ⁻⁴
Ovigerous	174	118.25 ± 12.12	126.75 ± 42.28	76.66 x 10 ⁻⁴
Total	639	110.91 ± 17.28	98.34 ± 46.33	72.09 x 10 ⁻⁴

Table 4: Carapace width (CW) and condition factor of male and female *Portunus pelagicus* of Lasongko Bay, Southeast Sulawesi - Indonesia according to season.

Sex	East season			West season		
	n	CW (mm)	Condition factor	n	CW (mm)	Condition factor
Male	311	106.35±13.67	70.49 x 10 ⁻⁴	292	109.50±15.73	72.34 x 10 ⁻⁴
Female	292	107.37±16.16	71.55 x 10 ⁻⁴	328	114.82±17.22	70.58 x 10 ⁻⁴

Monthly values of the condition factor of male crabs ranged from 65.08×10^{-4} to 74.64×10^{-4} , with a (mean± SE) of $(71.30 \times 10^{-4} \pm 2.40 \times 10^{-4})$ and a maximum in February and minimum in April. Monthly values of the condition factor of female crabs ranged from 68.66×10^{-4} to 73.51×10^{-4} , with a (mean± SE) of $(70.91 \times 10^{-4} \pm 1.58 \times 10^{-4})$ and a maximum in August and minimum in April (Fig. 4).

Fig. 4: Monthly values of the condition factors of male and female *Portunus pelagicus* in Lasongko Bay, Southeast Sulawesi, Indonesia.

DISCUSSION

Carapace Width-Weight Relationships

In general, the values of *b* in the carapace width-weight relationships of male crabs were larger than values for female crabs, indicating that the growth of male crabs in terms of weight was faster than that of female crabs. All values of *b* for juvenile, adult, and composite male crabs were greater than 3, whereas all values for female crabs and ovigerous females were less than 3. However, the values of *b* for both sexes and all categories of crabs did not differ significantly (*t*-test, *p*>0.05) from 3. Therefore, the growth of both sexes of *P. pelagicus* was isometric, i.e. growth by weight was balanced by the (cubic) growth of carapace width. The values of *b* and *r* for the carapace width-weight relationships of male and female crabs in Lasongko Bay are limited to specific ranges in both Indonesia and other areas around the world (Table 5). The values of *b* and *r* for male crabs from other areas ranged from 2.7542 to 3.6167 and from 0.860 to 0.9936, respectively, while those for females ranged from 2.6508 to 3.299 and from 0.817 to 0.9961, respectively. Relationships for both sexes varied geographically. The observed isometric growth pattern for both sexes of crabs in Lasongko Bay was similar to those observed along the Karachi coast of Pakistan [35] and the Oman coast for females [27], whereas both positive and negative allometric growth have been observed in other areas (Table 5). The type of allometric growth of male and female crabs in Lasongko Bay did not differ between the juvenile and adult stages, whereas the rate of growth by the weight and by the carapace width changed. The growth rate by weight of male crabs did not differ between juveniles and adults. In contrast, the growth rate by weight of juvenile female crabs was slower than for adult females. The growth rate by weight of ovigerous female crabs was also slower than that for non-ovigerous adult females.

The type of growth by the weight and by the carapace width in juvenile and adult male and female crabs in Lasongko Bay differs from those observed along the northwest coast of Karnataka, India. Juvenile male and female crabs in Karnataka exhibited negative allometric growth by weight, whereas that of adults was

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positive [40]. Differences in the value of b between juvenile and adult crabs (both male and female) may be caused by differences in diet due to stage-based variation in factors such as size, claw strength, foraging behaviour, and metabolic rates [40], as well as by differences in food availability, sex, gonad maturation stage, and season [10, 39].

Table 5: Growth coefficient (b), correlation coefficient (r) and type of allometric growth (AI) carapace width-weight of male and female blue swimming crab from some locations.

Location	Sex	b	r	AI	Source
Bardawil Lagoon, North Sinai, Egypt	Male	3.2062	0.966	+	36
	Female	2.9517	0.987	-	
Oman Coast, Oman	Male	3.2401	0,974 6	+	27
	Female	3.0061	0,9591	O	
Persia Gulf & Oman Bay, Iran	Male	3.214	0.9758	+	37
	Female	3.299	0.9055	+	
Karnataka Coast, South-west India	Male	3.6167	0.985	+	40
	Female	3.2327	0.988	+	
Mandapam Coast, Southeast India	Male	3.607	0.9691	+	21
	Female	3.293	0.9365	+	
Karachi Coast, Pakistan	Male	3.0278	0.9936	O	34
	Female	2. 9864	0.9961	O	
Sindh & Balochistan, Pakistan	Male	2.56	0.8994	-	1
	Female	2.95	0.9386	-	
Kung Krabaen Bay, Thailand	Male	2.9211	0.981	-	24
	Female	2.8944	0.967	-	
Batu Itam- East Belitung, Indonesia	Male	3.2509	0.9424	+	32
	Female	3.1481	0.9325	+	
Pati Waters, Indonesia	Male	3.342	0.957	+	9
	Female	3.259	0.948	+	
Pangkep Waters, Indonesia	Male	2.7542	0.860	-	20
	Female	2.6508	0.817	-	
Betahwalang Coast - Demak, Indonesia	Male	3.2120	0.9473	+	30
	Female	3.1518	0.9417	+	
Lasongko Bay, Indonesia	Male	3.065	0.942	O	This study
	Female	2.903	0.942	O	

Note: O = isometric, - = negative allometric, + = positive allometric

The values of b for the carapace width-weight relationships of male and female crabs during the East Season were lower than those during the West season. The values of b for males and females fluctuated throughout the year (see Fig. 3), with coefficients of variation of monthly values for male and female crabs of 5.37 and 9.61%, respectively. Based on the values of b , three periods of peak growth in body weight can be differentiated for both male and female crabs in Lasongko Bay: peaks for males occurred in June, November–December, and March, while those for females occurred in May, August, and December (see Fig. 4). These results differ from those reported for the carapace width-weight relationships of mud crab (*Scylla serrata*), for which the values of b tended to vary annually or periodically [29, 39]. Changes in the value of b can be triggered by metamorphosis, moulting, the initial maturation of gonads, and changing environmental conditions [1,39], as well as sizes and length range of samples used, sexual dimorphism, and availability of food (1,28).

Condition Factor

The condition factor of composite male crabs was lower than that of composite female crabs; crab females contained more fat than did males, and male crabs were smaller than females (Table 3). Higher condition factors in female versus male crabs have also been observed in other crab species, such as *Callinectes sapidus* [3], *C. danae* [2], and *P. segnis* [31]. In contrast, the condition factor was larger in males relative to females in *S. serrata* [29,39]. In the present study, the condition factor of ovigerous female crabs was higher than values for non-ovigerous females and juveniles, likely due to the larger body size of ovigerous females and the fact that incubating eggs increase body weight. The condition factors of male and female juvenile crabs were higher than values for adults.

The condition factors of composite male and female crabs were smaller than those reported in the waters of Brebes, Indonesia [41], the eastern waters of Batu Itam-Belitung, Indonesia [32], several locations in the Persian Gulf [4], as well as those reported for *C. danae* [2]. In contrast, the conditions factors observed in Lasongko Bay were higher than those for blue swimming crab (*P. segnis*) in the Bandar Abbas along the Persian Gulf [31] and for *P. validus* along the coast of Lagos, Nigeria [33]. The condition factors of aquatic organisms such as crabs are strongly influenced by food availability, habitat quality, disease, population density, gonad development, growth rate, and over-exploitation [7,10]. The latter factor is particularly important in the over-harvested population of crabs in Lasongko Bay [13,17].

During our study, the condition factors of male and female crabs fluctuated throughout the year, and each sex tended to exhibit four peaks (see Fig. 3). The first two peaks of the condition factor of female crabs were more prominent (in May and July–August), while the peaks in November and January were less pronounced (see Fig. 4). The peaks in the condition factor of male crabs in Lasongko Bay occurred in May, August, December, and February, all of which occurred at relatively the same level. The condition factor of male crabs was more variable than that of females, resulting in a higher coefficient of variation in the condition factor for males (3.37%) relative to females (2.22%).

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In Lasongko Bay, the peak period of fluctuation in the condition factor of male and female crabs tended to occur during the same period as peak spawning. These waters experience three peaks in crab spawning: in May–June, August, and October–November [12]. This correspondence between peak fluctuation and peak spawning is consistent with previous reports documenting that variation in the condition factors of crabs occurs throughout the year and is related to the reproductive cycle, particularly during peak periods of spawning [2,31–39].

CONCLUSION

The carapace width-weight relationships of male and female crabs were strong and significantly positive, both by stage (juveniles and adults) and by season; overall, the type of allometric growth was isometric. The condition factors of juvenile male and female crabs were higher than those of adults but lower than those of ovigerous females. The condition factor of male crabs during the East Season was lower than during the West Season, whereas the opposite pattern occurred in females. Temporal variation in the fluctuations and timing of peak values of b and the condition factor of male and female crabs was likely related to the crab reproductive cycle, particularly peak spawning in Lasongko Bay. The information obtained in this study is beneficial for crab fishery biologists to estimate the carapace width-weight based on the body crab and for the sustainable management of the blue swimming crab.

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