Int. J. Aquat. Biol. (2016) 4(4): 224-232
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com

Original Article

Allometric growth pattern, sexual dimorphism and size at the onset of sexual maturity in *Opusia indica* (Brachyura: Ocypodoidea: Camptandriidae) from mangrove areas of Pakistan

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Abstract: Size at sexual maturity and patterns of somatic growth are important aspects of reproductive history of crab. The main purpose of this study is to provide an estimate for the onset of morphological sexual maturity in mangrove crab, *Opusia indica* from a population located in Korangi creek intertidal mud flat (Karachi, Pakistan) based on relative growth. The crabs were monthly collected through quadrat method from March 2001 to February 2002. A total of 1702 crabs was obtained, of which 764 were males, 939 were female. The morphometric measurement of carapace, abdomen, cheliped and male gonopod was related to carapace width. Based on carapace width males were significantly larger than female, indicating sexual dimorphism. The size at onset of sexual maturity in males was estimated as 5.51 mm carapace width and 5.3 mm carapace width in females. The positive allometric growth of female abdominal width were likely related to the incubation process.

Article history:
Received 7 July 2016
Accepted 8 August 2016
Available online 25 August 2016

Keywords:
Sexual maturity
Somatic growth
Intertidal
Morphometry
Allometry

Introduction

During the course of growth and development in brachyuran crabs, certain dimensions of animal's body increases at different rates in proportion to size, resulting in a phenomenon known as relative growth. A growth rate between male and female crabs as well as between juvenile and adult crabs shows great differences during ontogeny and can be used to determine morphological sexual maturity (Hartnoll, 1978). The difference in relative growth patterns among male and female crabs for size of chelipeds, abdomen and pleopods indicates sexual dimorphism, and can be used to predict maturity in crab (Hartnoll, 1978; Vannini and Gherardi, 1988; Saher and Qureshi, 2011b).

Estimation of size at sexual maturity is key to describe population biology and structure in brachyuran crabs (Pinehiro and Fransozo, 1998). It can be determined by different methodologies i.e. determining morphometric (allometric) changes at puberty molt (Hartnoll, 1969), gonadal development after attaining maturity (Viau et al., 2006) and functional maturity (Viau et al., 2006). Functional maturity in decapods can be estimated by the determination of ovigerous female in population and situation of actual participation of both in the reproductive process (Viau et al., 2006). Determining the size at sexual maturity in crabs is useful to understand population aspects concerned with abundance, structure and number of mature individuals in a given population as it is responsible by the future generation as well as for researches involves in conservation of biodiversity.

Opusia indica (Alcock, 1900) is a small ocypodoid crab of the family Camptandriidae (Ng et al., 2008). These small detritivorous crabs are inhabitant of intertidal mud flat associated with tropical and subtropical mangrove forest (Ng et al., 2009). Crab dig burrows in soft sediment to tolerate harsh environmental conditions as well as refuges

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from predators. These burrowing activities help in penetrating air into the deeper sediment layer. Deposit feeding crabs emerge from their burrows when tide descends, there by changing the quality and quantity of resources distributed along the coast in turn play a key role in ecological functioning and environmental management on the intertidal detrital food web (Saher and Qureshi, 2011a, b).

The review of literature reveals that there is no previous work on the morphometric studies on these small detritivorous crabs. The aim of the current study is to identify the allometric relationship in male and female crabs of *O. indica* and also to determine the size at the onset of sexual maturity based on morphological and functional maturity.

Materials and Methods

Study area: The Pakistan coastal belt is about 1050 km long, with 350 km along Sindh and 700 km along Balochistan coast. Karachi, Pakistan is located on the northern border of Arabian Sea having a coastal belt of about 100 km having Indus delta on its southeastern side and hub river in the west. The coast along the Indus delta consists of numerous dendritic tidal creeks network, including Korangi Creek (24°79'N, 67°20'E) (Fig. 1), located in the South East of Karachi, entouched with a system of creeks in its northeastern side, and open waters on its southern end (Qureshi and Saher, 2012). Mangrove forest mainly comprises of *Avicenna marina* along creeks coastal zone provides a critical habitat for variety of brachyuran crabs.

Field procedures and sampling methodology: Crabs were collected from tidal mud flats regularly from March 2001 to February 2002 through transect quadrat method. During low tide period sampling were done by digging square down to 30 cm. Excavated sediment were sieved (1 mm mesh size), the crab samples were collected in labelled bags and freeze till analyses.

Morphometric analyses: For morphometry crabs were initially sorted and sexed (juvenile male (JM), juvenile female (JF), adult male (AM) and adult female (AF), weighed and measured. The carapace

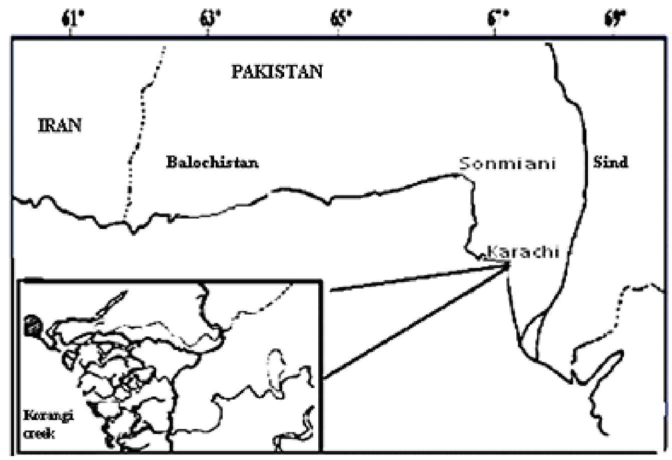

Figure 1. Coastal areas of Pakistan showing study site Korangi creek mangrove areas of Pakistan.

dimensions used in morphological analysis were carapace length (CL) (carapace length from anterior median part to posterior carapace margin) and carapace width (CW) (carapace width measured at its widest point). Cheliped dimensions included chela propodus length (Ch.L), Chela propodus width (Ch.W) and Chela propodus height (Ch.H). Abdominal dimensions included abdominal width (width of fifth abdominal somites in male and female crab) and length of first male pleopod (P1) (Fig. 2).

All measurements were taken using vernier caliper to the nearest 0.1 mm. Carapace width was used as independent variable which is denoted as X related to other body dimension which were considered as dependent variables Y. The mean values, minimum, maximum and standard deviation were calculated for each variable of female and male and compared by independent (students) T-test. Crab wet weight was estimated using analysis of variance (GLM) to estimate variation among juvenile and adult of *O. indica*.

The relative growth was described using the power function $Y=aX^b$ and linearized ($\log y = \log a + b \log x$) (Huxley, 1950) where "a" is the intercept and "*b*" is the slope or allometric growth constant. For size weight relationship, exponent '*b*' represent the weight gain which can be isometric, b=3; positively allometric, b>3; and negatively allometric b<3. The pattern of allometric growth for each developmental phase was established by the '*b*'

Figure 2. *Opusia indica* (Alcock, 1900). (A) dorsal view of male crab, (B) abdominal width of female, (C) chela of male, (D) abdominal length of male and (E) pleopod length of male.

values, considered as positive allometry when $b>1$, negative allometry $b<1$ and growth was considered isometric when $0.9<b<1.1$ (Hartnoll, 1982; Castiglioni and Negreiros-Fransozo, 2004; Saher and Qureshi, 2011b). To analyze growth patterns between male and female and between developmental phase slopes were statistically compared by analysis of covariance (ANCOVA).

Functional maturity analysis: Functional maturity in crabs was determined by identifying smallest ovigerous female (OF) carrying eggs found in the collected samples. Male and female smaller than this size were classified as juvenile (Saher and Qureshi, 2011b). For identifying adult females, additional criteria, i.e. convex abdomen which form an incubatory chamber in adult females was also considered, for adult male reflexed pleopod 1 (P1) which become more robust after attaining maturity were considered (Snowden and Jones, 1995).

In order to estimate the size at which 50% population got functional maturity (y), size classes of 2 mm carapace width were made. The relative frequency of adult in each size class was plotted and fitted in a sigmoid curve following the logarithmic equation.

$$y = \frac{1}{1 + e^{r(\mathrm{CW} - \mathrm{CW}_{50})}}$$

CW_{50} is the carapace width at which 50% population attains sexual maturity, r is the slope of the curve. The adjusted equation was fitted by the least square regression method (Vazzoler, 1996; Qureshi and Saher, 2011b).

Results

During study period, a total of 1703 crabs was collected, of which 764 were males (118 juvenile male, 646 adult male) and a total of 939 were females (204 were juvenile female, 735 adult females). Descriptive statistics of each variable were shown in Table 1 with carapace width (CW) size ranged 2.25-

Table 1. Summary statistics for the biometric analysis of *Opusia indica* collected from Korangi Creek, Karachi, Pakistan.

Variable	Sex	Juvenile crabs		Adult crabs	
		Mean±S.D	T-test, P-value	Mean±S.D	T-test, P-value
Carapace length (CL)	F	3.08±1.06	NS	5.1±0.74	-7.61, 0.000
	M	3.37±0.89		5.4±0.83	
Carapace width (CW)	F	4.3±1.3	NS	7.0±1.02	-7.41, 0.000
	M	4.7±1.1		7.5±1.1	
Abdominal length (Ab.L)	F	2.7±1.02	NS	4.9±0.75	-6.54, 0.000
	M	4.9±0.75		5.2±0.8	
Abdominal width (Ab.W)	F	2.2±0.83	-8.21, 0.000	6.0±1.80	82.16, 0.000
	M	1.5±0.50		2.2±0.47	
Cheliped length (Ch.L)	F	2.0±0.7	3.24, 0.001	3.2±0.46	-10.50, 0.000
	M	2.3±0.62		3.5±0.58	
Cheliped width (Ch.W)	F	0.8±0.4	3.02, 0.003	1.4±0.35	-9.32, 0.000
	M	0.96±0.39		1.90±0.38	
Cheliped height (Ch.H)	F	0.46±0.4	NS	0.7±0.28	-6.71, 0.000
	M	0.46±0.28		0.8±0.28	

(NS=not significant; S.D=Standerd deviation)

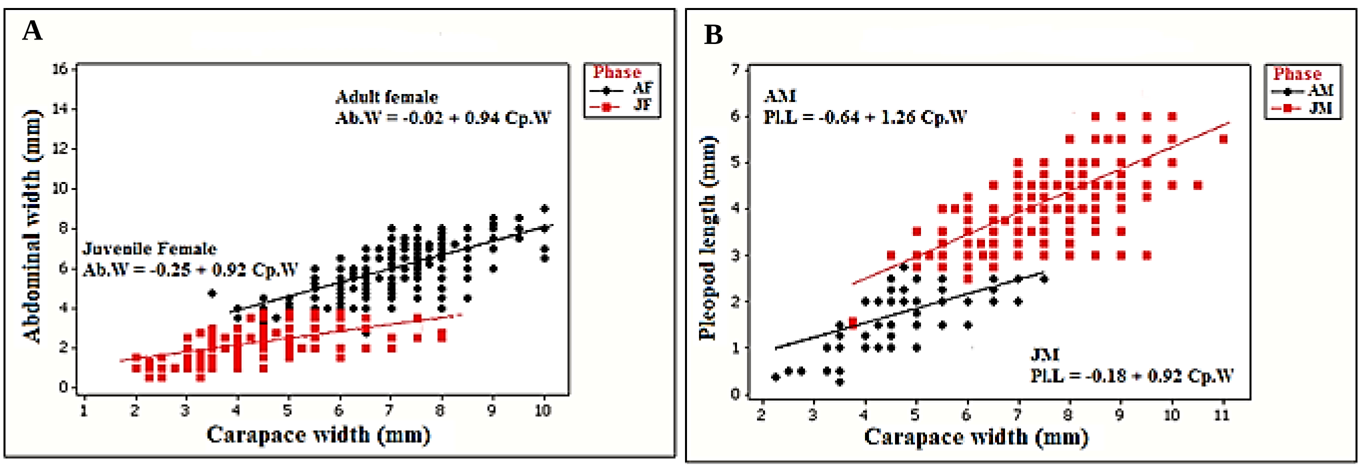

Figure 3. Relationships between (A) abdominal width and carapace width in female and (B) pleopod length and carapace width of male of *Opusia indica* (AM = adult male; AF = adult female; JM = juvenile male and JF = juvenile females).

11 mm and 2-10 mm for male and female crab, respectively. Intersexual difference in crab size (CW) was observed, as adult male crabs were significantly larger than females (F=7.41, P=0.000). Wet weight relationship also showed significant difference (F=190.48, P=0.000) among adult male and female crabs of *O. indica*, juvenile of both sex did not differs significantly (F=0.63, P=0.43).

Relative growth relationship:

Growth relationship of length (CL) and size (CW) with weight (Wt): The relationship between wet weight and length showed negative allometry and show higher value of the slope in male than in female crabs (Table 2). The growth relationship between CW and wet weight showed negative allometry in both sexes (Table 2).

Relative growth of carapace width (CW) with carapace length (CL): During ontogeny carapace width and length showed no significant difference, isometric relationship was observed in both male and female crabs (Fig. 3).

Relative growth of carapace width (CW) with abdominal width (Ab.W) and length (CL): The growth rate of abdomen width versus carapace width showed an isometric relationship in juvenile and adult female as well as in juvenile male while in adult male crabs it showed negative allometry. The student t-test for the slope values suggested that the growth

Table 2. Results of regression analysis for morphometric data of *Opusia indica* from the mangrove area of Korangi Creek, Pakistan.

Variables	Sex/ Phase	N	Linearized Equation Log y = loga + b log x	Allometry	Determinaion coefficient "R"
Wet weight (Wt.) vs. Carapace width (CW)	JF	184	logWt= - 3.04 + 2.26CW	Negative	0.733
	AF	753	logWt= - 2.95 + 2.27CW	Negative	0.680
	JM	117	logWt= - 2.64 + 1.72CW	Negative	0.578
	AM	644	logWt= - 3.16+ 2.59CW	Negative	0.760
Wet weight (Wt.) vs. Carapace length (CL)	JF	184	logWt= - 2.63 +2.14CL	Negative	0.761
	AF	753	logWt= - 2.58 + 2.19CL	Negative	0.674
	JM	117	logWt= - 2.27 + 1.50CL	Negative	0.560
	AM	644	logWt= - 2.81 + 2.60CL	Negative	0.764
Carapace length (CL) vs. Carapace width (CW)	JF	184	logCL= - 0.15 + 0.99CW	Isometry	0.928
	AF	753	logCL= - 0.05+ 0.90CW	Isometry	0.864
	JM	117	logCL= - 0.14 + 0.99CW	Isometry	0.905
	AM	644	logCL = - 0.04+ 0.89CW	Negative	0.887
Abdominal width (Ab.W) vs. Carapace width (CW)	JF	184	logAb.W= -0.25+ 0.92CW	Isometry	0.548
	AF	753	logAb.W =-0.02 + 0.94CW	Isometry	0.727
	JM	117	logAb.W =-0.45+ 0.94CW	Isometry	0.626
	AM	644	logAb.W =-0.32 + 0.77CW	Negative	0.577
Chela length (Ch.L) vs. Carapace width (CW)	JF	183	logCh.L= - 0.26 + 0.89CW	Negative	0.833
	AF	756	logCh.L = - 0.06 + 0.66CW	Negative	0.681
	JM	177	logCh.L = - 0.29 + 0.96CW	Isometry	0.773
	AM	644	logCh.L = - 0.11 + 0.75 CW	Negative	0.691
Chela width (Ch.W) vs. Carapace width (CW)	JF	184	logCh.W=-1.22 + 1.71 CW	Positive	0.835
	AF	753	logCh.W=-0.64 + 0.92CW	Isometry	0.506
	JM	116	logCh.W =-1.01 + 1.44 CW	Positive	0.666
	AM	664	logCh.W =-0.67 + 1.00 CW	Isometry	0.616
Chela height (Ch.H) vs. Carapace width (CW)	JF	184	logCh.H= - 1.42+ 1.52CW	Positive	0.367
	AF	753	logCh.H = - 1.31+ 1.37CW	Positive	0.477
	JM	117	logCh.H=-1.52 + 1.68CW	Positive	0.529
	AM	644	logCh.H=-1.15+1.23CW	Positive	0.49
First pleopod length (P1.L) vs. Carapace width (CW)	JM	96	logPl.L= - 0.64 + 1.26 CW	Positive	0.54
	AM	575	logPl.L= - 0.18 + 0.92 CW	Isometry	0.70

(Note: N, specimen number; JF, juvenile female; AF, adult female; JM , juvenile male; AM, adult male).

rate of abdominal width showed significant difference in juveniles as well as in adults (Table 2). Abdominal length against carapace width showed isometric growth in juvenile and adult female as well as in juvenile male, for adult male crabs it showed negative allometry (Table 2).

The relative growth of cheliped length, cheliped width and cheliped height: Allometric relationship of carapace width with the chela propodus length was negative in juvenile female which become more pronounced in adult (Table 2). In juvenile and adult male, growth is isometric showing higher growth rate in juvenile than adult. Chela width relationship with carapace width in juvenile male and female showed positive allometry while isometry for adult in both sexes. Positive allometric relationship exists between cheliped height and carapace width in male and female crabs. Value of slope is higher in male than in female.

Relative growth of pleopod with carapace width: The allometric growth of pleopod showed a positive relationship with carapace width in juvenile, but isometric in adult male crab and significantly different (Table 2).

Analyses of co-variance: By means of covariance analysis, results showed that relative growth pattern between juvenile and adult of both sex differs statistically in abdominal width versus carapace width, while, the growth pattern of chela length versus chela width relationship also showed

Table 3. Results of Analysis of covariance (ANCOVA) for test of significant differences between phases and sex (SS=sum of squares, F=F-statistics, *P*= the significance, * =significant at *P*<0.05).

Variable Relationship	N	Sex/ Phase	Parameter	SS	*F*	*P-value*
Carapace length (CL) vs.	302	JF Vs JM	Slope	0.01	0.04	0.838
Carapace width (CW)	1398	AF Vs AM	Slope	0.65	4.51	0.034*
Abdominal length (Ab.L) vs.	301	JF Vs JM	Slope	0.03	0.17	0.678
Carapace width (CW)	1398	AF Vs AM	Slope	0.07	0.35	0.554
Abdominal width (Ab.W) vs.	301	JF Vs JM	Slope	48.04	132.6	0.000*
Carapace width (CW)	1398	AF Vs AM	Slope	5315.3	1174	0.000*
Cheliped length (Ch.L) vs.	301	JF Vs JM	Slope	0.51	3.36	0.068
Carapace width (CW)	1398	AF Vs AM	Slope	8.08	55.48	0.000*
Cheliped width (Ch.W) vs.	302	JF Vs JM	Slope	0.187	2.53	0.113
Carapace width (CW)	1398	AF Vs AM	Slope	55.64	2.58	0.109
Cheliped height (Ch.H) vs.	292	JF Vs JM	Slope	0.148	1.17	0.280
Carapace width (CW)	1398	AF Vs AM	Slope	1.686	28.02	0.000*
First pleopod length (P1.L) vs.	671	JM Vs AM	Slope	0.02	0.075	0.112
Carapace width (CW)						

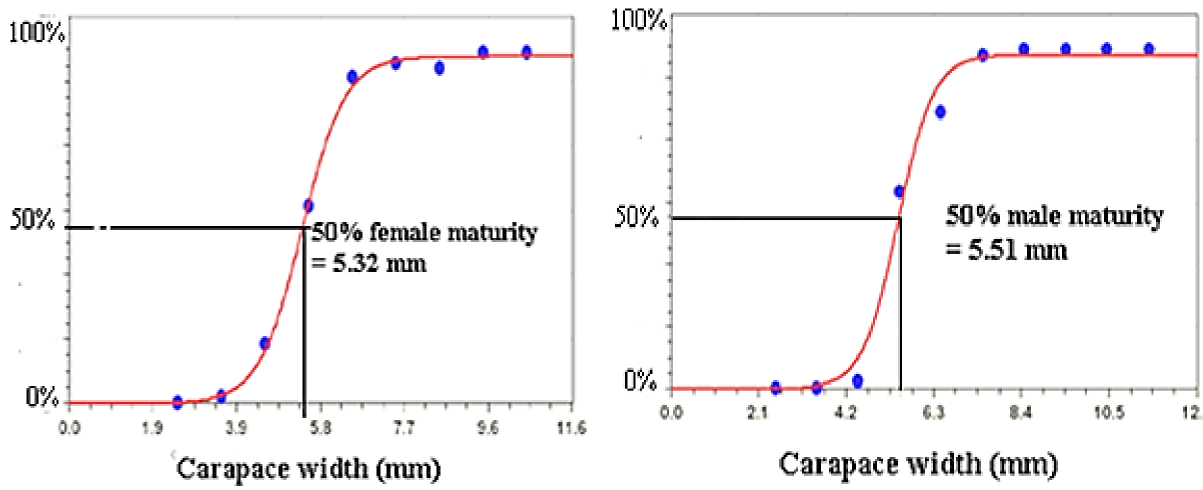

Figure 4. Sigmoid curve showing 50% maturity in adult female and male crab of *Opusia indica*.

different pattern of growth for adult male and females showed in Table 3.

Analysis for functional sexual maturity: The smallest ovigerous female (female having eggs on their pereopod) was 4 mm in size (CW). The size at which 50% population got sexual maturity was calculated as 5.32 mm in female crab and 5.51 mm in males (Fig. 4).

Discussion

The size at sexual maturity and patterns of somatic growth are important biological events occurs in reproductive cycle of crab which promotes morphological, physiological and behavioural changes (Hartnoll, 1982). Allometric analysis carried out in this study showed that male *O. indica* acquired greater averaged body sized than those of female. Size variation between sex can be explained by differential reproductive needs as size dominance in male crab increase the opportunities of winning during intra-specific competition, courtship and handling female during copulation (Castiglioni and Negreiros-Fransozo, 2004; Saher and Qureshi, 2011b). In brachyuran, female crabs showed slower growth after attaining sexual maturity, probably due to direct their large portion of the energy budget for reproductive strategies i.e. spawn and incubation of eggs production (Hartnoll, 1982; Diaz and Conde, 1989; Gregati and Negreiros-Fransozo, 2007) tend to mature with inferior sizes than males, who invest their energy resources in somatic growth, reaching larger sizes (Shine, 1988). The logistic function also showed that the size in which male *O. indica* attained morphological sexual maturity was higher than the values for females, similar to the pattern proposed by Shine (1988) for brachyurans. In brachyuran, male crabs can be considered morphologically mature when they are able to retain female during courtship and mating while female when they are able to copulate, carry and protect incubating eggs (Castiglioni and Negreiros-Franssozo, 2004). Sexual maturity study based on functionally maturity showed that female mature earlier than male crabs. The wet weight relationship with size showed that body weight was greater in males than females, this differences were associated with the males' faster growth and larger averaged body size which is the expected pattern to many brachyuran crabs which may result of the androgen gland secretion, improving the weight in the male crab after maturity (Bliss, 1968; Pinheiro and Fiscarelli, 2009; Marina et al., 2012).

Puberty moult in brachyuran is characterized by allometric changes in female abdomen and male cheliped and they are best representative secondary sexual characters. After puberty molt sexual dimorphism is well-pronounced in abdominal width which is related to the difference of function performed by pleopod in male and female crabs. The proficient size and shape of female abdomen facilitate developing eggs and act as an incubatory chamber (Hartnoll, 1978). In male, however, abdomen only protect two pairs of pleopod that are responsible of transferring sperm during mating. Relative growth relationship of abdominal width with body size showed positive allometry for both juvenile phase and adult female during entire life as predicted by Hartnoll (1982) indicated that growth of abdomen might be incomplete when female attain functional maturity thus growth remain continuous to enlarge incubatory chamber for protecting egg mass. These facts are also observed in studies conducted by Oh and Hartnoll (1999). In present study, the higher growth rate for cheliped was observed in juvenile and adult male than female crabs but was not significantly differs, these observation indicated that no sexual dimorphism and allometric growth at certain level in size of cheliped for male and female crabs. As size of male crab's increases, cheliped become stouter and larger in male *O. indica* presumably for a compensation of feeding and reproductive requirements. These results are similar to the observations made by Snowden and Clayton (1995) and Schuwerack et al. (2006). Another secondary sexual character used in brachyuran crabs is the length of first gonopod in male specimen. The level of allometric growth obtained for carapace width with pleopod width indicated positive growth during the juvenile phase that changes to isometric growth with the passage to the adult phase, differential growth has been related to the ability of male crabs to copulate successfully with wide range of females improving their reproductive output (Hartnoll, 1974; Bertini et al., 2007; Saher and Qureshi, 2011). Pleopod in male crabs do not increase in same rate as female positive growth of gonopod has no reproductive advantage comparative to female. It has been confirmed from many studies that analysis of male pleopod and abdominal width in female are among the best estimator of size at sexual maturity than cheliped, similar to the findings of Silva et al. (2007) and Ribeiro et al. (2013).

Acknowledgments

The research was supported by the Pakistan Science Foundation project PSF/Res/S-KU/Envr(51) and it is equally acknowledged.

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