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Observations on the Carapace Length-Width and Carapace Width-Weight Relationships of the Blue Swimming Crab, *Portunus Pelagicus* (Linnaeus, 1758) in Bahraini Waters.

القياسات الحيوية للسرطان السابح *Portunus pelagicus* (القبقب) في مياه البحرين: نمط النمو، علاقات أبعاد وعرض، ووزن الجسم

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Abstract: Studies on the biometric relationships of the blue swimming crab *Portunus pelagicus* from Bahraini waters, have been undertaken in the present investigation in order to understand the growth pattern of this species in terms of carapace length-width (CL-CW) and carapace width-weight (CW-Wt.) relationships, in this part of the world. From the (759) male and (1,233) female crabs that were collected from the offshore study region from October to November 1999, data have indicated that slopes of (CL-CW) relationships are found to be similar in both genders. The average slopes for crabs in areas (A) and (B) had exhibited an isometric growth with (CW) being (1.7) times (CL). The slope recorded for area (C) proved to be significantly less than (1), indicating an allometric growth with (CW) getting relatively longer in bigger crabs. As for the (CW-Wt.) relationship, the total of (2,070) male and (3,005) female crabs, which were collected over a period of (14) months (i.e. March 1999-April 2000), showed that males are heavier than females at (2) cms (CW), becoming more so above (6) cms (CW). Male exponents varied significantly between study areas and from one month to another, unlike those for females which are found to be similar across the study areas and months, except for area (B), June 1999, where the exponent was at its lowest at (2.71). The higher exponents of males throughout most of the study period indicate their better condition over females. Both genders were found to be heavier during the Summer months, i.e. May-September. However, male and female slopes for (CW-CL) and many exponents for (CW-Wt.) exhibited small differences which prove statistically significant. This is attributed to the large number of observations that make small differences significant, yet the biological significance may be less obvious.

Keywords: Crustacea, Decapoda, Brachyura, Portunidae, Biometric, Bahrain waters.

المستخلص: يتناول البحث التقصي عن القياسات الحيوية للسرطان السابح، *Portunus Pelagicus*، المعروف محلياً بالقبقب، من أجل فهم جانب من نمط النمو عند هذا النوع من القشريات، من حيث علاقة "طول، عرض الدرع"، وعلاقة ""عرض الدرع، وزن الجسم"، في هذه المنطقة من العالم. وجِد من بيانات (759) ذكر و (1233) أنثى جمعت من منطقة الدراسة في الفترة من أكتوبر إلى نوفمبر 1999م، أن الميل *(Slopes)* لعلاقات طول الدرع وعرض الدرع، متشابهة في كِلا الجنسين. كما بينت معدلات الميل أن نمو أبعاد الدرع (الطول والعرض) عند القباقب في المناطق *(A)* و *(B)*، تسلك مساراً متماثلاً *(Isometric)*، إذ يبلغ عرض الدرع (1.7) مرة طول الدرع. أما في المنطقة *(C)*، فقد أكدت بيانات القياسات الحيوية وجود دالة إحصائية أن الميل أقل من (0.1) وهو ما يشير إلى أن نمو أحد البعدين مستقل عن الآخر *(Allometric)*، إذ تكون الزيادة في عرض الدرع أطول نسبيا، كلما كبر حجم القباقب. تقترح الدراسة أن لهذا النمط من النمو أهمية من حيث الوظائف الحيوية ذات الصلة بالتكاثر، وإتاحة أكبر مساحة ممكنة لحمل البيض في الجانب البطني خارج الجسم. أما فيما يخص علاقة عرض الدرع و وزن الحيوان، فقد بينت بيانات (2070 ذكر) و (3005 أنثى)، جمعت على مدى (14) شهر (مارس 1999– ابريل 2000م)، أن القباقب الذكور أثقل وزناً من الإناث، بدءً من الأفراد الذين يزيد عرض الدرع عندهم على (2 سم)، ويزداد فرق الوزن لصالح الذكور الأكبر من (6 سم). اختلاف القيم الأسية (Exponents) لهذه العلاقة عند الذكور بين مناطق الدراسة ومن شهرٍ إلى أخر، فقد كان كبيراً وذو دلالة إحصائية، بخلاف القيم الأسية للإناث التي وجِدت متماثلة في مناطق الدراسة وسلسلة الفترة الزمنية، بإستثناء القباقب بالمنطقة *(B)* في شهر يونيه، حيث كانت القيمة الأسية في أدنى مستوياتها عند (0.2,71) كما أن ارتفاع القيم الأسية للأفراد الذكور على مدى فترة الدراسة تشير إلى تمتعهم بحالة أفضل من الأفراد الإناث. عموماً، وجد أن أفراد كِلا الجنسين أكبر وزناً خلال شهور الصيف (مايو–سبتمبر).

كلمات مدخلية: البحرين، مياه، قشريات، سرطان سابح، القبقب، قياس أبعاد

Introduction

The study of biometric relationships identifies changes in shape (length-length) or condition (length-weight), which often accompany the growth of an organism and also to illuminate relative growth differences that are often driven environmentally. The length-weight relationship (l-wt.) assumes an added importance in fisheries biology in converting easily measured length to stock biomass. Several studies on (l-wt.) relationships have been carried out on portunid crabs across their geographical range, e.g. *Portunus pelagicus* from: Australia (Weng, 1992), Philippines (Batoy *et al.*, 1988), India (Dhawan, *et al.* 1976; Prasad, *et al.* 1989; (Sukumaran and Neelakantan, 1997b) and Egypt (Abdel Razek, 1987). The (l-wt.) relationships for related species, i.e. P. Sanguinolentus from India (Sukumaran and Neelakantan, 1997b) and *Callinectes sapidus* from America (Pullen and Trent, 1970) have also been described. The scale of scientific effort indicates the importance of this type of fisheries data, which are useful to determine the relative condition and estimate size at sexual maturity (Pullen and Trent, 1970). Furthermore, the derived relationships are as predictive as they are descriptive and readily permit comparisons of populations from different localities. Length-weight relationships are also used as indicators of physical condition, breeding state and possibly even food availability (Prasad, *et al.* 1989).

Morphometric information for *Portunus Pelagicus* in the Arabian Gulf region is lacking. Thus, the objective of the present study was to establish a precise mathematical model to use as a reliable tool for monitoring *P. Pelagicus* populations in Bahraini waters.

Materials and methods

(1) Study area

Specimens of *P. Pelagicus* were collected within the territorial waters of the Kingdom of Bahrain Sampling was restricted within areas ranging from 25°: 42´ to 26°: 33´ North and 50°, 21´ to 50° : 57´ East, where the major fishing grounds for crustacean resources are situated. The study area fell naturally into three distinct sub-areas, representing the Northern (A), North-Eastern (B) and Southern (C), fishing grounds. Being a vast area with different habitats, wherein the abundance and distribution of benthic marine life varies, the sub-areas were divided into grids, each (31 km²) (See, Fig. 1).

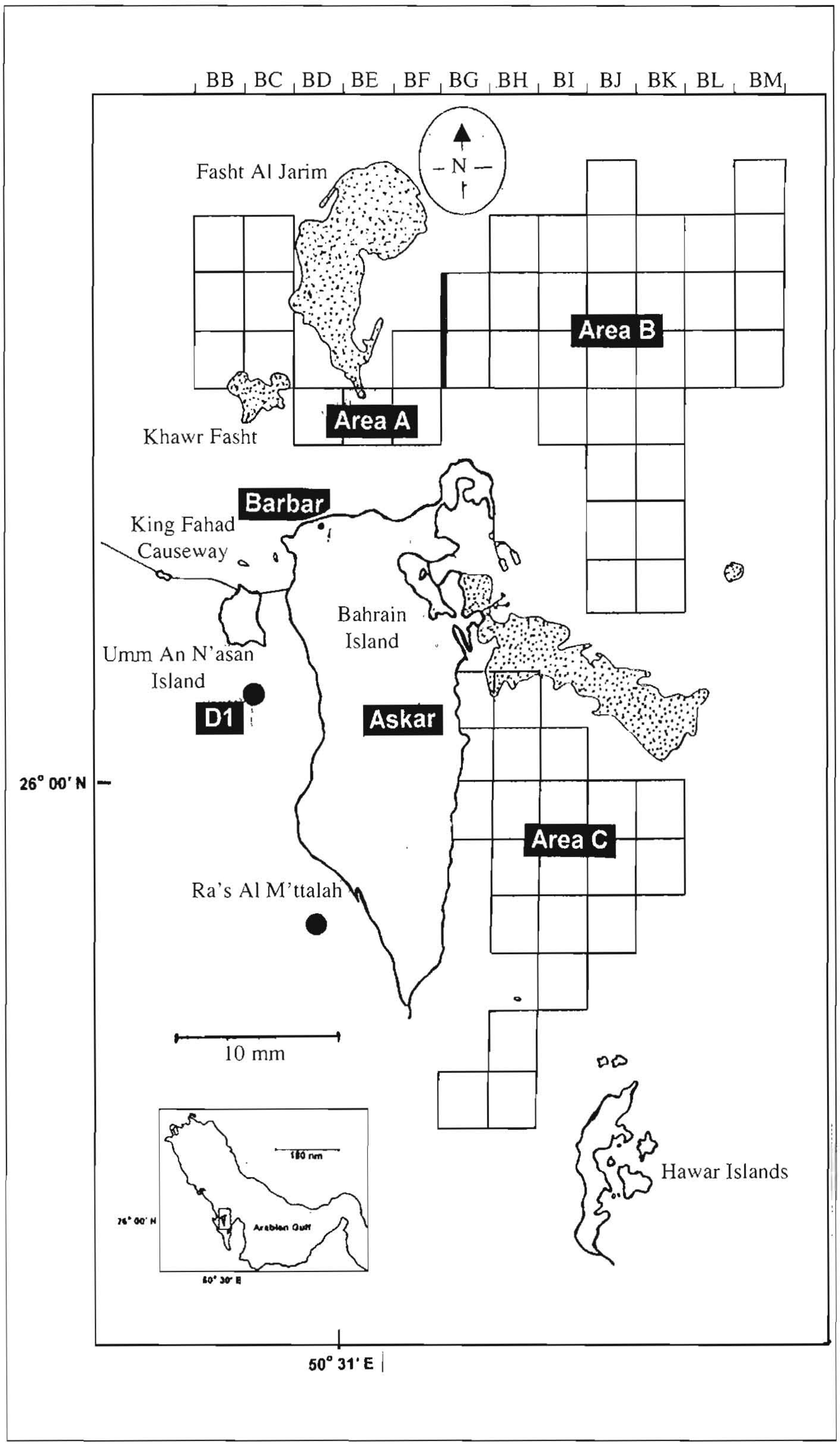


Fig. (1): Map of the study area in Bahraini waters indicating fishing grounds where the swimming crab, *Portunus pelagicus,* was surveyed.

(**2**) Field sampling

Portunus pelagicus used in this study are taken from catches collected during a major survey of shrimp resources {*Portunus pelagicus* is a by-catch of the shrimp landings (Abdulqader, 2001)}. Catches of *Portunus pelagicus* were taken at monthly intervals between March 1999 and April 2000, using a Gulf of Mexico flat otter-board trawl with a (29) metre foot-rope and a (3.8) cms mesh size in the belly and codend. A stratified random sampling approach was applied during this work for the three areas; hence, out of the total grids, only (60%) from each area were chosen randomly and surveyed. Each trawl, lasting for (30) minutes at a speed of (3.5) knots into the prevailing currents, was considered a replicate within an area. Catches were separated gender-wise based on abdomen shape. (The difference in their shape between males and females is very easy to distinguish, even in juvenile crabs). The male abdomen is a narrow and inverted (T) shape, while in females, it is triangular in juveniles and semicircular in adults (Abd El-Hamid, 1988); (Sukumaran and Neelakantan, 1997a). Samples for morphometric analysis are processed as follows:

(**2.1**) Carapace length-width relationship

Portunus pelagicus carapace length-width relationship (CL-CW) for male and female crabs was established using selected trawls from each sub-area. The criteria used for selecting samples were:

(**a**) Large catches containing all possible class sizes.

(**b**) Crabs from grids from all shallow water and offshore sites, so as to represent the population of crabs at a given time and sub-area.

Crabs that were collected from grids within the sub-area were grouped to represent their overall population.

The crabs designated for (CL-CW) relationship were measured for (CW) (the distance across the carapace from the notches between the 8th and 9th anterolateral spines) and (CL) (the distance from the centre of the frontal margin to the centre of the posterior margin). Carapace dimensions were measured to the nearest 0.01 cm using a Vernier calliper.

(**2.2**) Carapace width-weight relationship

For the length-weight relationship investigations (CW-Wt.), (4-8) healthy hard-shelled male and female crabs with all appendages intact were taken from each trawl. The sampling strategy ensured that every sample should include specimens across the full size range from each trawl. Ovigerous females and crabs with autotomised or regenerating appendages, broken carapaces, or with epizoic organisms were not considered, as such features would result in a marked variation in weight (Sukumaran and Neelakantan, 1997b).

For (CW-Wt.) measurements, the crabs were brought to the laboratory in fresh condition and were examined soon after their arrival from the field. The adhering water on the overall surface, including the appendages, was completely wiped off using a towel and the total wet weight of each crab free of debris and epizoic forms, and with all appendages intact, was weighed to the nearest (0.1g) using a digital balance (Sartorius, Model L310). The CW of the crabs was also measured (see above).

(**3**) Data analysis

(**3.1**) Carapace length-width relationship

All (CL) and (CW) measurements for male and female crabs from areas (A), (B) and (C) were considered for analysis. The relationship was analysed by the method of least squares using simple linear regression of $\log_{10}$ transformed observations. Transformation was used with the implicit assumption that a single power function (Pauly, 1983); (Sparre and Venema, 1992) would adequately represent the relationship, even if no data was gathered for organisms of (< 2.5 cms) (CW).

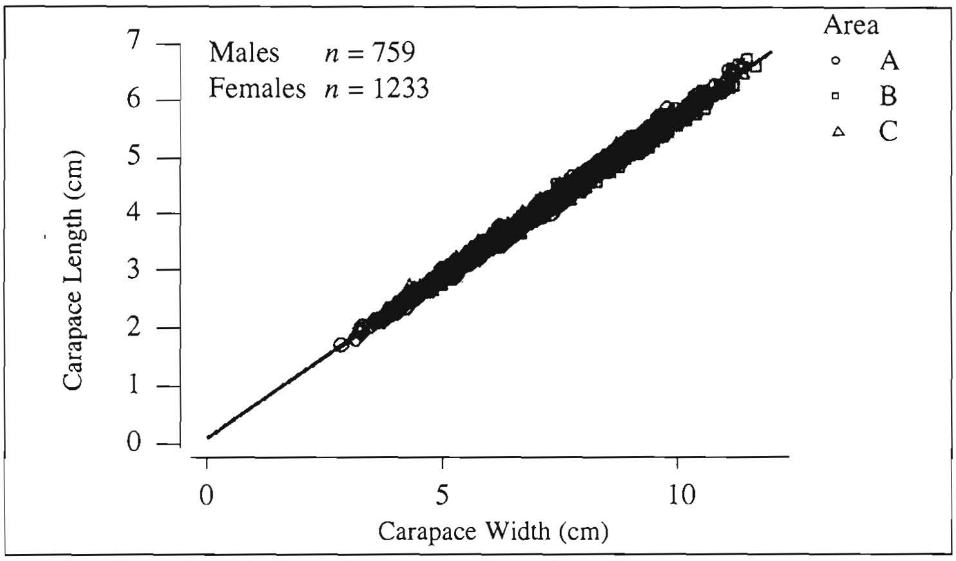
(**3.2**) Carapace width-weight relationship

(CW-Wt.) carapace relationships for *Portunus pelagicus* were determined separately for males and females from each area. Again the method of least squares, using simple linear regression on $\log_{10}$ transformed observations of (CW) (cm) and wet weight (g), was used to compare crab condition over time (month to month) and between the three sampling areas. The (CW-Wt.) relationships were compared between the three areas over the whole (13) month sampling period. March 2000 data were excluded from the analysis, due to a lack of crabs in area (B). The major aim was to determine whether the exponents differed between gender, month and locality to indicate potential differences in condition.

Results

(I) Carapace length-width relationship

In October and November 1999, a total of (1233) female and (759) male *Portunus pelagicus* were measured for (CL) and (CW). The crabs spanned an almost identical range of (CW) (3.2-11.4 cm) for females and (2.9 -11.7 cm) for males. The relationships for all (3) areas in both months and gender are plotted in (Fig. 2). There is so much overlap between dimensions of the male and female crabs that they appear as an indistinguishable linear function.



**Line fitted by least squares regression.*

Fig. (2): Carapace width to length relationship for *Portunus pelagicus* males and females collected from the 3 (A, B and C) areas around the coast of Bahrain in October and November 1999.

The relationships were analysed by 4-Factor analysis of variance (area, month, gender and (CW) as a covariate) and all (12) possible regression fits (2 genders in 2 months for each of the 3 areas) between (CL) and (CW) were highly significant (ranging from

($F_{1,39} = 87.33$) to ($F_{1,576} = 267.41$) all with ($p < 0.001$).

The slopes of all (12) regressions were very similar ranging from (0.546) (area B, October) to (0.567) (area A, November) for females and from (0.563) (area B Nov.) to (0.571) (area B Oct.) for males. None of the (4 - or 3)-way interactions terms were significant

(range from ($F_{2,1968} = 0.24$), ($p = 0,784$) to ($F_{1,1968} = 3.46, p = 0.063$).

(Table 1) shows the average slopes represented by 2-way interactions in the analysis.

The averages range from (0.552) to (0.57), a difference equivalent to (1.8%) in the ratio of (CL) to (CW). In all cases the standard errors are very small, which is due as much to the large number of observations as it is to small variances. The standard deviation of (CL) estimated from the anova was (± 0.071 cm), seven times greater than the measurement resolution (0.01 cm).

The difference between the slopes for female and male *Portunus pelagicus* was indicated as significant ($F_{1,1968} = 4.39, p = 0.036$). So too were differences between slope averages for the 3 areas ($F_{2,1968} = 3.72, p = 0.025$) with crabs in area (B) suggested as having a significantly lower slope than those in Areas (A) and (C). Regression intercepts varied from,

(0.03) to (+ 0.08) cm,

again with small standard errors (± 0.01 cm).

The significant differences indicated by the analysis are very small and likely to result from the very large numbers of crabs measured during the

Table (1): Slopes (± SE) for the relationships between (CL) and (CW) for *Portunus pelagicus* collected from 3 areas (A, B and C) around Bahrain in October and November 1999.

Area	Slop average	Gender		Time	
		Female	Male	October 1999	November 1999
A	**0.569**	0.566 – 0.003	0.570 – 0.003	0.570 – 0.003	0.596 – 0.003
B	**0.559**	0.552 – 0.004	0.568 – 0.005	0.561 – 0.005	0.588 – 0.004
C	**0.563**	0.562 – 0.002	0.564 – 0.003	0.562 – 0.003	0.564 – 0.002
Slop average		**0.560**	**0.566**	**0.565**	**0.561**

Table (2): ANOVA table for the carapace length and carapace width (covariate) relationship in relation to gender, area and month, for *Portunus pelagicus* collected from Bahraini waters, October and November 1999.

Source	*df*	Seq. SS	Adj SS	Adj MS	*F*	*p*
CW	1	21.59101	7.233	7.23285	1.2^{+05}	< 0.001
Month	1	0.00134	0.00011	0.00011	1.79	0.181
Area	2	0.00265	0.00159	0.00030	4.84	0.008
Gender	1	0.00055	0.00004	0.00004	0.70	0.403
CW*month	1	0.00069	0.00010	0.00010	1.63	0.202
CW*area	2	0.00033	0.00039	0.00019	3.16	0.043
CW*gender	1	0.00013	0.00008	0.00008	1.26	0.262
Month*area	2	0.00009	0.00003	0.00001	0.22	0.803
Month*gender	1	0.00010	0.00005	0.00005	0.78	0.379
Area*gender	2	0.00045	0.00012	0.00006	0.98	0.376
CW*month*area	2	0.00003	0.00003	0.00001	0.23	0.794
CW*month*gender	1	0.00013	0.00006	0.00006	0.99	0.319
CW*Area*gender	2	0.00013	0.00014	0.00007	1.11	0.329
Month*area*gender	2	0.00004	0.00012	0.00006	0.95	0.386
CW*month*area*gender	2	0.00011	0.00011	0.00605	0.86	0.424
Error	1979	0.12127	0.12127	0.00006		
Total	**2002**	**21.71904**				
Average intercept	-0.234 – 0.003					
Average slope	0.988 – 0.003					

**Data linearised as log_{10} transformed.*

study, making standard errors tiny. It is questionable whether such small differences have any biological significance. A (13 cm) wide female crab is predicted to have a carapace length of (7.28 cm) and the same width male crab a (CL) of (7.36) (in each case with a SD of ± 0.07 cm).

Such a difference, (800) urn or (~1%), on average is virtually the same as the (SD), and it would be difficult to ascribe a functionality to such a tiny difference. Any differences indicated between crabs caught in different months or areas might well be highly dependent on the ratio of female to male crabs in the catch. Over the whole study the ratio was (1.62) females to males. In October and November the ratio was (1.58) and (1.66) respectively. In area (A) and (C), the ratio varied from (1) to (1.7) but in area (B) the ratio was (3.33) and (2.56) in October and November, respectively *(Table 3)*.

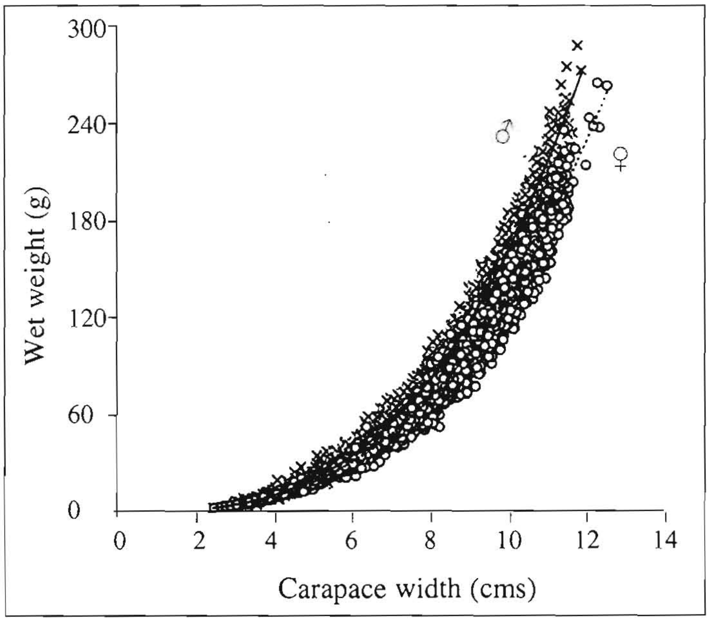
Considerably, more female crabs are represented in the samples for area (B) than in any of the other combinations. Since females are shorter, albeit by a tiny amount, they will bias the regression slope for areas in which they greatly predominate hence crabs in area (B) appear to show significantly shorter (CL) for their (CW) on average. The statistical significance of these results owes more to bias in the sampling (from different months in different areas) and to the large numbers of crabs measured than it does to any real biological differences in carapace shape between 'populations' of crabs.

Table (3): Average slopes and intercepts (log_{10} [CL cms]) for carapace length-carapace width relationships of Portunus pelagicus in areas A, B and C.

Area	Slope – SE	Intercept – SE
A	0.994 – 0.007	-0.229 – 0.006
B	0.989 – 0.008	-0.232 – 0.008
C	0.981 – 0.006	-0.241 – 0.006

(II) Carapace width-weight relationship

Total of (2,070) male (CW ranging from 2.4 to 11.9 cms, wet Wt. ranging from 2.2 to 286.9 g) and (3,005) female (CW ranging from 2.41 to 12.56 cms, wet Wt. ranging from 2 to 263.7 g) *Portunus pelagicus* from (82) samples collected from areas (A), (B) and (C) over a period of (14) months were used to investigate the (CW-Wt.) relationship of this species in Bahraini waters. The $\log_{10}$ (CW-Wt.) linear regression models for all (82) samples were found to be highly significant, with correlation coefficient (r) values ranging from (0.936) to (0.983) (p < 0.001). The overall regression models for males and females are shown in (Fig. 3).



*Males n - 2,070 *Females n - 3,005
Wt. (g) = 0.167 CW$^{2.98}$ (cms) *Wt. (g) = 0.177 CW$^{2.88}$ (cms)*
$F_{1,2068}$ = 160908.7; p<0.001 $F_{1,3003}$ = 283054.3; p<.001
**Curves are fitted by least squares regression of $\log_{10}$ transformed data. Males (x) and females (*)*

Fig. (3): Carapace width-weight relationship for male and female *Portunus pelagicus* collected from the three areas around Bahrain from March 1999 to April 2000.

(Fig. 3) clearly illustrates that male crabs were relatively heavier than females throughout the size range (CW). The difference in relative weight is obviously accentuated as the crabs grow. Indeed the models predict a (1 cm) (CW) female to be (6%) heavier than a (1) cm (CW) male, but this prediction lies beyond the bounds of the current data set. Since there such an obvious difference between male and female crabs (Fig. 3), the differences between areas and seasonal differences were analysed for males separately from females. The results of (ANOVA) with (CW) as a covariate for male and female *Portunus pelagicus* are presented in (Tables 4 and 5) respectively. For males (Table 4) there was a significant three-way interaction indicating that significant differences in exponents between areas were not generally consistent over time.

(Fig. 4) shows the exponents for male crabs in each area and month. The major contribution to the significant 3-way interaction appears to come from area B, where in April 1999 and February 2000 unusually low exponents (2.74) and (2.84) respectively, were found. The general trend

Table (4): ANOVA table for the carapace width (covariate)-weight relationship for male *Portunus pelagicus* collected from Bahraini waters, March 1999-April 2000, in relation to month and areas.

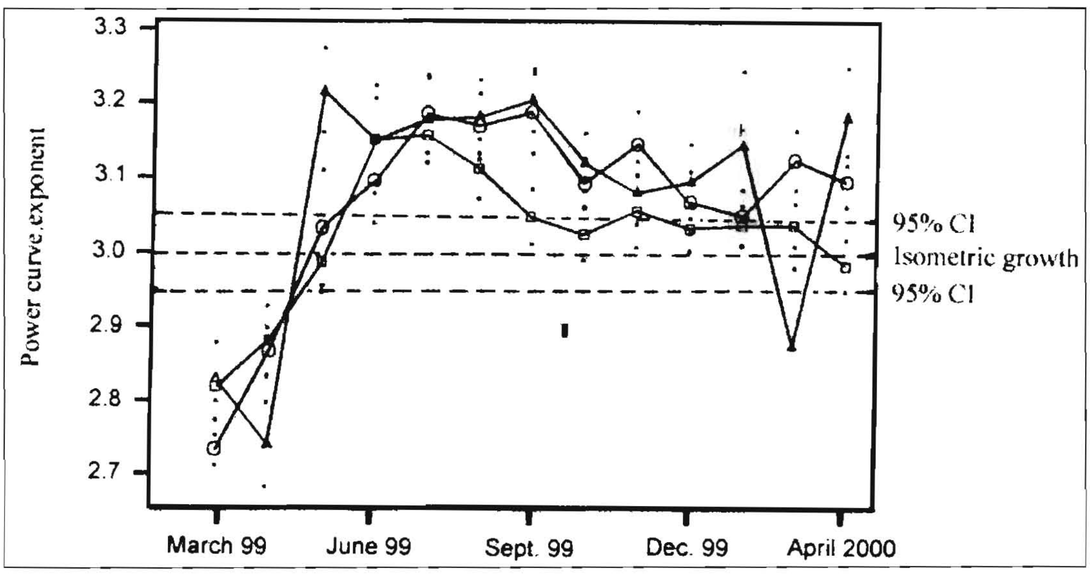
Source	df	Seq. SS	Adj SS	Adj MS	F	p
CW	1	371.5394	184.8968	184.8968	1.5+05	< 0.001
Month	12	1.4747	0.5176	0.0431	35.07	< 0.001
Areas	2	0.0415	0.0148	0.0074	6.01	0.002
CW*month	12	0.5623	0.3805	0.0317	25.78	< 0.001
CW*areas	2	0.0725	0.0148	0.0074	6.02	0.002
Month*areas	24	0.1047	0.0666	0.0028	2.26	< 0.001
CW*month*areas	24	0.0690	0.060	0.0029	2.34	< 0.001
Error	1992	2.4503	2.4503	0.0012		
Total	**2069**	**376.3144**				
Average intercept	-0.855 – 0.007					
Average Slope	3.053 – 0.008					

**Data linearised as $\log_{10}$ transformed.*

Table (5): ANOVA table for the carapace width (covariate)-weight relationship for female *Portunus pelagicus* collected from Bahraini waters (March 1999-April 2000) in relation to month and areas.

Source	df	Seq. SS	Adj SS	Adj MS	F	p
CW	1	428.7778	176.4376	176.4376	1.3+05	< 0.001
Month	12	0.1322	0.1102	0.0092	6.74	< 0.001
Areas	2	0.0642	0.0037	0.0018	1.34	0.262
CW*month	12	0.2218	0.1275	0.0106	7.80	< 0.001
CW*areas	2	0.0108	0.0029	0.0014	1.06	0.348
Month*areas	24	0.0986	0.0269	0.0011	0.82	0.711
CW*month*areas	24	0.0341	0.0341	0.0014	1.04	0.406
Error	2927	3.9874	3.9874	0.0014		
Total	**3004**	**433.3268**				
Constant	-0.772 – 0.007					
CW	2.910 – 0.008					

**Data linearised as log10 transformed.*



**Exponents for March 2000 are not available. Area A (—o—), area B (—△—) and area C (—□—). Dots indicate the spread of SE. Isometric growth (± 95% confidence intervals) is represented as the horizontal dotted line.*

Fig. (4): Plot of power curve exponents for the carapace width-weight relationship of male *Portunus pelagicus* collected from the study areas from March 1999 to April 2000.

in all three areas shows a steady increase in exponents from around (2.8) in March 1999 to (3.1-3.2) in the Summer followed by a small but consistent decline in exponents towards Winter (See Fig. 4). Differences between areas are indicated as significant ($F_{2,1992} = 6.02$); ($p < 0.001$), (Table 4) and seem largely to reflect lower exponents in area (C) than in either areas (A) or (B) throughout the summer to winter decline. Apart from the negative allometric exponents found in all areas in spring 1999, most months and areas show slightly positive allometry throughout the year (See Fig. 4).

For female crabs (See table 5), the three-way interaction was not significant

($F_{24,2927} = 1.04$); ($p = 0.406$)

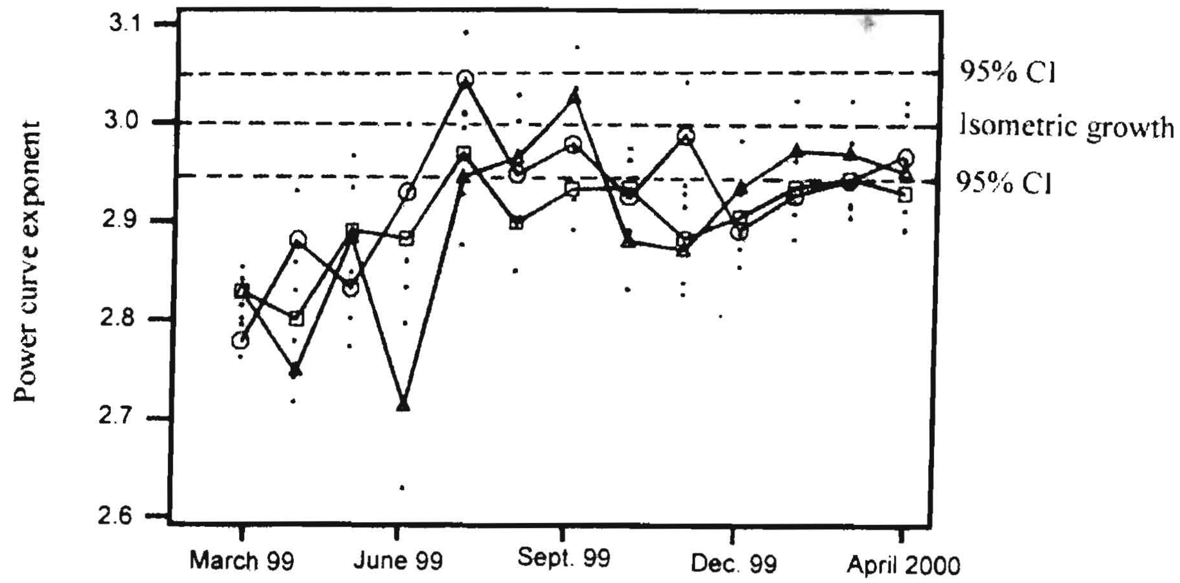
and no significant difference between areas was evident

($F_{2,2927} = 1.06$); ($p = 0.348$).

However, exponents varied significantly over time

($F_{12,2927} = 7.8$); ($p < 0.001$).

(Fig. 5) shows the variability between exponents



**Exponents for March 2000 are not available.*
**Area A (—o—), area B (—△—) and area C (—□—).*
**Dots indicate the spread of SE. Isometric growth (± 95% confidence intervals) is represented as the horizontal dotted line.*

Fig. (5): Plot of power curve exponents for the carapace width-weight relationship of female Portunus pelagicus collected from the study areas from March 1999 to April 2000.

for female crabs for each area in each month. As with males, area (B) shows the greatest variability with a particularly low exponent in June, 1999. The differences between areas are not significant (See Table 5) and all exponents show a general negative allometric relationship between weight and (CW). Lowest exponents (around 2.8) are seen in early 1999, rising steadily till early summer (as with the male relationship, (See, fig. 4). The exponents stay fairly constant, just below (3), for the remainder of the study period.

Thus both for male and female *Portunus pelagicus,* a lack of condition at the beginning of the study period in 1999 was overcome by the summer of the same year. Conditions remained fairly constant through to April 2000, with males being relatively heavier than females throughout.

Discussion

(1) Carapace length-width relationship

The results of this study shows that the relationship between (CL) and (CW) (over the (CW) size range (2.9 -11.7 cm) in *Portunus pelagicus* is linear, indicating isometric growth of the two

Table (6): Carapace length-width relationships reported for *Portunus pelagicus,* across its geographic range.

Location	TCW range (cms)	Gender				Reference
		Male		Female		
		Intercept	Slope	Intercept	Slope	
India	5-15	- 0.74	0.65	- 0.3	0.61	Devi (1985)
Bahrain	5-15	+ 0.04	0.46	+ 0.04	0.45	Al-Rumaidh (1995)
Australia (Gulf of Carpentaria)	N/A	- 0.16	0.47	+ 0.005	0.45	Wneg (1992)
Australia (Moreton Bay)	N/A-15	- 0.21	0.48	- 0.18	0.48	Wneg (1992)
Bahrain	3-14	- 0.19	0.48	- 0.05	0.46	Present Study

**All functions follow the format CL = a + b x TCW (dimensions in cm).*

dimensions. On average, female *Portunus pelagicus* are slightly shorter for their width than are the male crabs. (Table 6) details previous measurements of length width relationships for *Portunus pelagicus* over a wide geographic range. All the relationships have been adjusted to fit the same format

(CL = a + b x TCW)

for adequate comparison.

(Table 6) shows a remarkable convergence of data gathered over a considerable period of time and geographic distance, indicating a fairly rigid relationship between carapace length and width in *Portunus pelagicus*. (CL) is generally around (45%-48%) of the total carapace width and intercepts are all close to (zero). The Indian study of (Devi, 1985) differs from the rest by suggesting (CL) to be between (61%) and (65%) of (TCW). The intercepts for (Devi's, 1985) relationships are negative and the largest recorded deviations from (zero). The Indian crabs were, thus, generally longer than equivalent sized crabs in Australia or the Arabian Gulf. The negative intercepts for relationships, however,

(**Table (7)**: Average slopes (b) and intercepts (a) for carapace length-weight relationships of *Portunus pelagicus* recorded at different locations across its geographical range.

Region	Gender				References
	Male		Female		
	a	b	a	b	
Zuari Estuary, Size range: N/A	0.000000275	3.636	0.000000000423	4.969	Dhawan et al. (1976)
Abu-Kir, Egypt Size range: 3.5-1.9 cms	0.0085	2.913	0.0057	3.032	Adel Razeq (1987)
Leyte and Vicinity, Philippines, Size range: N/A	.0008	2.406	0.00046	2.515	Batoy et al. (1988)
Goa, India Size range: N/A	Juveniles 0.000046	2.506			Prasad et al. (1989)
	Adults 0.0000345	3.104	Adults 0.0000048	3.018	
Gulf of Carpentaria, Australia. Size range: N/A	0.00000568	3.023	0.0000806	2.943	Weng (1992)
Moreton Bay, Australia. Size range: N/A	Crabs < 15 cms TCW 0.0000021	3.284	Crabs < 15 cms TCW 0.0000023	3.25	
Moreton Bay, Australia. Size range: N/A	Crabs > 15 cms TCW 0.00000855	3.466	Crabs > 15 cms TCW 0.00000931	2.984	
Bahrain	Crabs 5-15 cms TCW 0.00050199	3.293	Crabs 5-16 cms TCW 0.00000691	3.001	Al-Rumaidh (1995)
Karnataka coast, India Size range: N/A	Juveniles 0.000009	2.873	—	—	Sukumaran and Neelakantan (1997c)
	Adults 0.00000032	3.617	Adults 0.00000163	3.23	

**Relationships are expressed as wt. (g) = a TCWb (cms). TCW = total carapace width.*

might indicate a curved rather than linear relationship (Davi's, 1985).

(Weng 1992) provides evidence that the relationship might well be curved over a very large size range of crabs. In Moreton Bay in Australia, found a different relationship for crabs larger than (15 cm) (TCW, maximum size is not given) whereby (CL) was (69%-73%) of (TCW) with intercepts at (-3.7 cm), clearly indicative of a curvilinear relationship, with allometric growth not easily discernible until crabs reach a monstrous size. In all cases, including (Weng 1992) from Moreton Bay when expressed to (3) decimal places, the male (CL) is longer relative to (TCW) than the female (CL). The difference between males and females was significant for the measurements in the present study and that significance does not appear to be a simple function of a large number of observations.

The fact that males have relatively longer carapaces than females and that, potentially, that difference is exaggerated with age would indicate that the difference might relate to egg mass brooding by females. *Portunus pelagicus* is a renowned swimmer and, in common with most swimming crabs, has a relatively flattened carapace which presumably helps decrease drag during swimming. The swimming power derives from the last pair of periopods which provide thrust from the rear. The shape (specifically CL/CW ratio) of the carapace and the posture (and probably length) of the chelae must balance any tilting movement (pitch) developed during swimming strokes. The tilting problem presumably increases with size and can be compensated by a relative increase in the carapace length. In potentially egg brooding females, the weight of the egg mass (carried at the rear) would tend to compensate for a downward body tilt produced by the swimming stroke and hence require less compensation in carapace elongation.

(**B**) Carapace width-weight relationship

This has shown *Portunus pelagicus* males to be relatively heavier than females, especially above (6) cms (CW). Work on *Portunus pelagicus* across its geographical range, i.e. Egypt (Abdel Razek, 1987), Australia (Weng, 1992), Bahrain (Al-Rumaidh, 1995) and India (Prasad *et al.*, 1989) and (Sukumaran and Neelakantan, 1997b) show similar results (Table 7).

The finding appears general in swimming crabs e.g. *Callinectes sapidus* (Pullen and Trent, 1970) and *Scylla serrata* and *Portunus sanguinolentus* (Prasad, *et al.* 1989); (Sumpton, *et al.* 1989); (Sukumaran and Neelakantan, 1997a). In contrast, (Dhawan *et al.* 1976) and (Batoy *et al.* 1988) working on *Portunus pelagicus* using (TCW) and (CL) respectively showed that females were relatively heavier than males (See table 7). The exponent given by (Dhawan *et al.* 1976) for female crabs as high as (4.969) may well be a typographical error as it is far higher than the cubic relationship expected. (Batoy *et al.* 1988) related the relatively heavier weight of females to environmental conditions, which differ between temperate and tropical regions. However, findings from Bahrain (~26°N) and Egypt (~22°-32° N) representing temperate environments, and from the tropical waters of Australia (~11°-45° S), where in both regions male *Portunus pelagicus* were found to be heavier, indicate that environmental conditions are not responsible directly for the difference in gender weight. As to the present study, the heavier weight exhibited by male crabs over time indicates the continued good conditions across the study area, particularly during the summer months (i.e. May-September) when moulting and breeding occur. The higher exponents for males in areas (A) and (B) almost throughout, suggest a ready food supply available in both these areas compared with area (C). The present study has shown that further investigations are now needed on size and weight of chelae, as well as the weight of the whole exoskeleton of both genders of similar sizes (CW). Such information should allow a better understanding as to why the male *Portunus pelagicus* is the heavier sex.

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