J. Fish. Soc. Taiwan, 27(3): 175-185 (2000)

Sex-Variant Morphometrics of the Swimming Crab, *Portunus sanguinolentus* (Herbst), from the Waters off Northern Taiwan

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(Received, June 23, 2000; Accepted, July 20, 2000)

ABSTRACT

The swimming crab, *Portunus sanguinolentus*, is one of the most commercially important and productive crustaceans fished in Taiwan. However, evaluation of the stock status is difficult due to the lack of knowledge of some fundamental biological parameters. Thus, to investigate the size structure, size (carapace width, CW in mm) -weight (body weight, BW in g) relationship and their differences between sexes of this species, a total of 1880 individuals were collected off northern Taiwan between April 1997 and July 1998. The relationships of body weight, weight of appendages, carapace length, chela length and width of the 5th abdominal segment against CW were derived either in *ln-ln* relations (power function) or linear relations. Those relationships between sexes were compared by likelihood ratio tests. The results of all those comparisons showed significant differences between sexes. Hence, size-weight equations were derived as $BW=1.4880 \times 10^{-5} CW^{3.2903}$ for males and $BW=3.3056 \times 10^{-5} CW^{3.1227}$ for females, respectively.

Key words: *Likelihood ratio test, Morphometric relationship, Portunus sanguinolentus, Size-weight relationship.*

INTRODUCTION

The swimming crab, *Portunus sanguinolentus* (Herbst), is an edible crab that inhabits on sand or mud-sand substrate (Sumpton *et al.*, 1989) throughout the Indo-Pacific region, from the East African continent to the Hawaiian waters (Stephenson and Campbell, 1959). Their size and sex composition varies with depths as the juveniles are often found in estuary and inshore waters, while females are abundant in deep waters (Wenner, 1972; Campbell and Fielder, 1986; Sumpton *et al.*, 1989). In Taiwan, *P. sanguinolentus* is one of the most common and economically important crab caught in the southwestern and northern waters between 20 and 60 m depth throughout the year (Huang, 1993).

The swimming crab has been exploited for several decades in Taiwan, the prawn trawl and the artisanal trap are the two major fisheries for this species in the waters off northern and southwestern Taiwan. The trap fishery is generally conducted in the coastal region of northern Taiwan on rocky substrate that is inconvenient for prawn trawl operation. The trawl fishery is mostly conducted in the offshore waters of southwestern and northern Taiwan.

However, the stock assessment of *P. sanguinolentus* is still too difficult to make a plausible management strategy because few studies were made only on taxonomy and morphology (Huang, 1993; Wang and Liu, 1996) and the fundamental biological parameters mentioned above are unknown in Taiwan waters. Fundamental biology

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parameters are required in studying the population dynamics, and further the management strategies. For instance, the production model analysis is based on biomass, but catch of the study species is always counted individually by fishermen, hence, a size-weight relationship is necessitated on catch conversion from number into weight. Furthermore, relationships among external characters by means of morphometric studies are important for the stock structure and identification. Growth parameters are important to understand the productivity evaluation as analyzed by yield per recruit model that is always adopted by the crustacean assessments, and mortality estimation by catch curves (King, 1995). Those mentioned topics of importance for the species in Taiwan waters are investigated further following the present study.

Therefore, the objectives of this study are to derive and compare the relationships among external characters in relation to the carapace width for *P. sanguinolentus* from the waters off northern Taiwan. To accomplish those curves comparisons, a new developed likelihood ratio test (Cerrato, 1990; Quinn and Deriso, 1999; Hsu *et al.*, 2000) was used instead of the traditional analysis of covariance (Sokal and Rohlf, 1995; Zar, 1999). This study will be essential to draw the first sound step on how to treat data of the same stock with different allometry for population dynamics and helpful to make fishery strategies for *P. sanguinolentus* sustainable management.

MATERIAL AND METHODS

Samples collection

Portunus sanguinolentus were sampled periodically from trap and trawl catches between April 1997 and July 1998. Crab samples from Keelung Island (northern Taiwan) were caught by trap in the coastal waters and by commercial trawls operating offshore (Fig. 1). A total of 1880 individuals were collected for morphometric measurements.

The samples were firstly classified as juveniles or adults by visual inspection. The adult samples were then separated for both sexes by external sexual characters. Sex can be determined by examining the ventral side of the body. The juvenile female abdomen is triangular with abdominal segments firmly attached to the cephalothorax (van Engel, 1958), while the abdomen of adult female is almost semicircular with the abdomen segments becoming flappy. The male abdomen is narrow and acute, and does not change after sexual maturation. The most accurate external determinant of sexual maturity in males is the distinct chela color principally on the inner surface of the dactylus (Ryan, 1967), which is recognized as a secondary sex character. In contrast, the color of the inner surface of the fixed finger is white with an amber spot at the base of teeth for the juvenile males. When they undergo puberty molt, a patch or spot of oxblood red appears on the inner surface of fixed finger of the propodus. At the next molt, the color extends completely over the inner surface of both the dactylus and propodus.

Those samples with rhizocephalan parasitized were excluded, because rhizocephalan may change the morphological configurations (Hochberg *et al.*, 1992; Jespersen and Lutzen, 1992; Sumpton *et al.*, 1994).

Morphometric characters, carapace width (CW), carapace length (CL), chela length (CH), and width of the 5th abdominal segment (FAB), were measured (Fig. 2) for each crab. The characters were measured (Fig. 2) using precision vernier calipers to the nearest 0.01 millimeters (mm). Individual body weights, and weight of each appendage were measured individually to the nearest 0.1 grams (g) by electronic balance (Mettler, AE-2000). Crab and its appendages were measured in wet condition but wiped water on surface by towel paper before measured. The weight of each appendage was used to derive their relationships with CW, and may be useful in adjustment of body weight, as some of appendages were broken or missing when the species was caught.

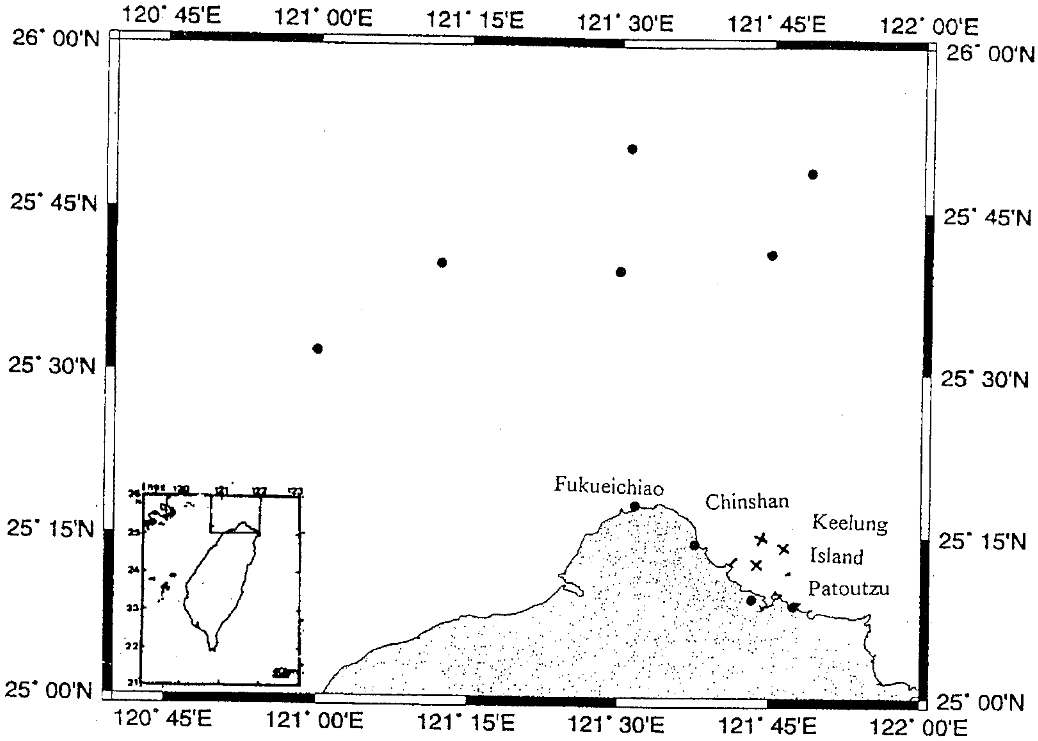


Fig. 1. Map showing the studied regions at the waters off northern Taiwan, the cross marks denote the regions (25°15'N, 121°45'E) where samples were caught by traps, and the solid circles denote the regions where *P. sanguinolentus* caught by trawls were sampled.

Statistical Analysis

1. Size-weight and morphometric relationships *vs.* CW

Since appendages of crab are undersized when regenerates after autotomy, which may result in bias-estimate of the relationship between body weight (BW) and CW, the crab with broken or regenerated appendages were recovered for the body weight measurement. Hence, the relationships between weight of each appendage and CW were derived for this purpose. To formulate the relationship between weight of appendages and CW, the crab that both corresponding right and left appendages were selected, cut and weighed, then, the Student's t-test (Zar, 1999) was used to compare the difference between right and left corresponding appendages to assess whether or not the appendages were in significant differences. If there were no difference, only weight of the right-hand side appendage was selected to formulate the relationship.

The scatter-plot between BW and CW indicates that the relationship of $BW = \alpha CW^{\beta}$ was appropriate. Further, the logarithmic transformation, $lnBW = ln\alpha + \beta lnCW$, and the maximum likelihood method (MLE) were used to estimate the parameters α and β (Bickel and Doksum, 1977; Quinn and Deriso, 1999). Moreover, all morphometric measurements were also ploted *in priori* and regressed on CW by sexes.

Similarly, simple linearity is usually applied to the relationship between external morphological characters (CL, CH, and FAB in the present study) and CW. Also the MLE was used to estimate the parameters of those linear relationships.

2. Comparison among morphometric

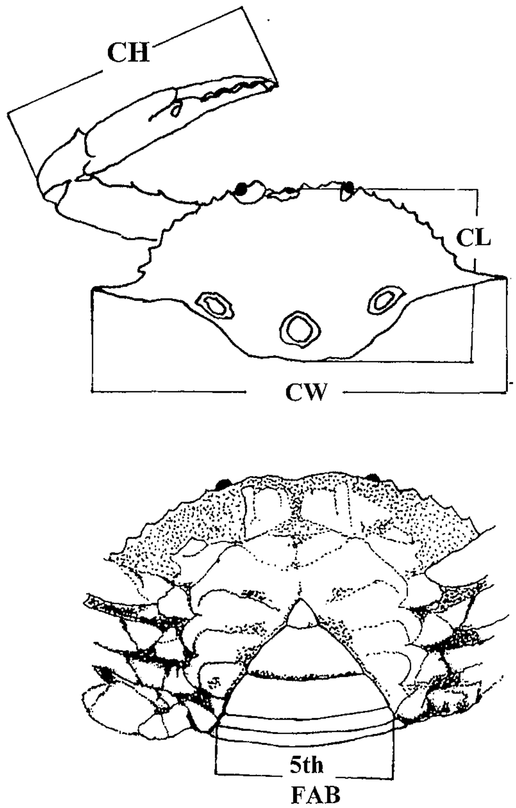


Fig. 2. The dimensional measurements of external morphometric characters for *P. sanginolentus* from the waters off northern Taiwan. Where CW is the distance between the tips of the lateral spines at the widest part of the body (carapace width); CL is the distance from the groove between the rostral teeth to the posterior edge of the carapace (carapace length); CH is the length of dactylopodite of chela (chela length); and FAB is the horizontal distance of the fifth abdominal segment.

characters and CW

The slopes and the intercepts of those relationships between sexes were compared by the likelihood ratio test that is able to compare models with all parameters together (Kimura, 1980; Cerrato, 1990; Sokal and Rohlf, 1995; Quinn and Deriso, 1999).

Kimura (1980) and Cerrato (1990) firstly introduced the likelihood ratio test in testing equality of parameters between data sets. The likelihood ratio tests can be used to compare full models with a reduced model for two or more data sets. By assuming a normal distribution with additive errors for all morphometric data sets, the maximum likelihood estimation (MLE_i) of parameters, $\hat{\Theta}_i$ and standard deviation, $\hat{\sigma}_i$ for data set $\mathcal{L}_i$ i, Y_i with sample sizes, n_i, the likelihood, $\mathcal{L}_i$, maximized by minimizing the sum of squares results in

$$\max ln\mathcal{L}_i(\hat{\Theta}_i, \hat{\sigma}_i \{Y_i\}) = \frac{n_i}{2}[ln(2\pi\hat{\sigma}_i^2)+1], \quad (1)$$

and

$$\hat{\sigma}_i^2 = \sum_{j=1}^{n_i}(Y_{ij} - \hat{Y}_i)^2/n_i . \quad (2)$$

The joint maximum log likelihood $ln\mathcal{L}_F$ for the full model is obtained by

$$ln\mathcal{L}_F = \sum_{i=1}^{R} \max ln\mathcal{L}_i . \quad (3)$$

Meanwhile the maximum log likelihood for reduced model, $ln\mathcal{L}_R$, is then from (3) with n_i and $\hat{\sigma}_i^2$ replaced by n and $\hat{\sigma}^2$. Therefore, the likelihood ratio test statistics is

$$\chi^2 = -2ln\left(\frac{\mathcal{L}_R}{\mathcal{L}_F}\right) \quad (4)$$

The asymptotic distribution is a chi-square distribution with degrees of freedom equal to the difference in the degrees of freedom between the full model and reduced model.

The hypothesis test is $H_0 : \Theta_i = \Theta_j$ for all pairs (i,j) vs. $H_a : \Theta_i \neq \Theta_j$ for at least one pair (i,j). There are $f = R_p\text{-}p = (R-1)p$ degrees of freedom, where R is the number of data sets and p is the number of parameters. A significant ratio indicates a reduced model is not statistically similar to the full model.

RESULTS AND DISCUSSION

The comparison between weights of the corresponding appendage on both sides shows that there were no significant differences between the corresponding appendages by the paired sample test ($P > 0.01$). Then, as pre-assumed, weights of the right-hand side appendages were used to formulate the relationships between weight of each right appendage and CW.

The *ln-ln* relationship (a power function) between weights of each appendage *vs.* CW was derived as in Table 1 for both sexes, respectively. Of all those relationships are statistically significant (P<0.001). The test hypothesis of equality of parameters was not done among appendages within sex, but between sexes, because those relationships were used to adjust the body weight as any appendage was broken or missing when crab was caught. The results obtained from comparisons by likelihood ratio tests indicate that significantly different relations were found between sexes for each appendage vs. CW (P <0.001). Hence, using individual relationship derived from each sex is sound necessary to adjust the body weight when the corresponding appendage was found broken or missing.

The CW vs. BW (Fig. 3) equations are estimated as: $BW=1.4580 \times 10^{-5}\ CW^{3.2903}$ for males and $BW=3.3056 \times 10^{-5}\ CW^{3.1227}$ for females from northern Taiwan. The relationships of both sexes were compared by likelihood ratio test (χ^2=12.1844, 0.001<P <0.005), indicating that the two equations are significantly different.

Linear relationships were investigated from the scatter-plots between each of the measured morphometric characters, CL, CH, and FAB vs. CW (Figs. 4-6). The comparison of models with the slope and the intercept together between sexes by likelihood ratio test indicate that there were significant differences between sexes in each paired relationship of CL vs. CW (χ^2= 29.884, P<0.001), CH vs. CW (χ^2= 999.391, $P \ll 0.001$) and FAB vs. CW (χ^2= 1455638.739, $P \ll 0.001$).

As usual, the present study has evidenced that there are sex-variant morphometrics for *P. sanguinolentus* using selected external morphological characters. This finding is very common for most of the morphological studies of *P. sanguinolentus* from waters around the world (Campbell and Fielder, 1986; Jacob *et al.*, 1990), but it is the first analysis for the species from the waters off Taiwan. Similar morphometric studies of this species result

Table 1. Regression parameters and statistics for the CW (in mm) vs. each of the five appendages. A traditional power function ($W_i = \alpha CW^{\beta}$, where W_i is the weight measured in g for the ith appendage, α and β are parameters needed to be estimated) was applied for *P. sanginolentus* from the waters off northern Taiwan. Where r is the correlation coefficient, and *** denotes significance at level 0.001.

Appendages	*ln - ln* regression			
	n	β	α	r
Male				
1st	87	3.5150	3.7076×10^{-7}	0.956***
2nd	90	3.2810	2.2821×10^{-7}	0.978***
3rd	94	3.2983	1.6910×10^{-7}	0.976***
4th	91	3.6165	2.9661×10^{-8}	0.971***
5th	100	3.0895	5.4008×10^{-7}	0.967***
Female				
1st	131	3.1380	3.1128×10^{-6}	0.907***
2nd	137	2.9424	9.9488×10^{-7}	0.928***
3rd	137	2.8370	1.4793×10^{-6}	0.908***
4th	141	2.7581	1.5068×10^{-6}	0.916***
5th	142	2.8055	2.6606×10^{-6}	0.924***

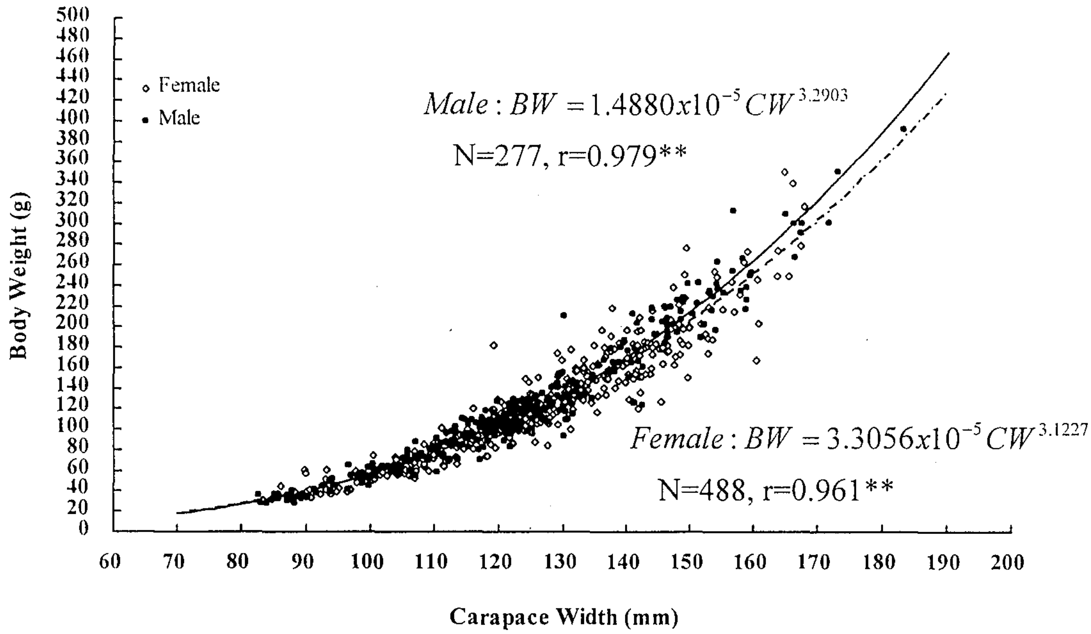


Fig. 3. The scatter-plot of body weight (BW) *vs.* carapace width (CW) by sexes of *P. sanguinolentus*, from the waters off northern Taiwan.

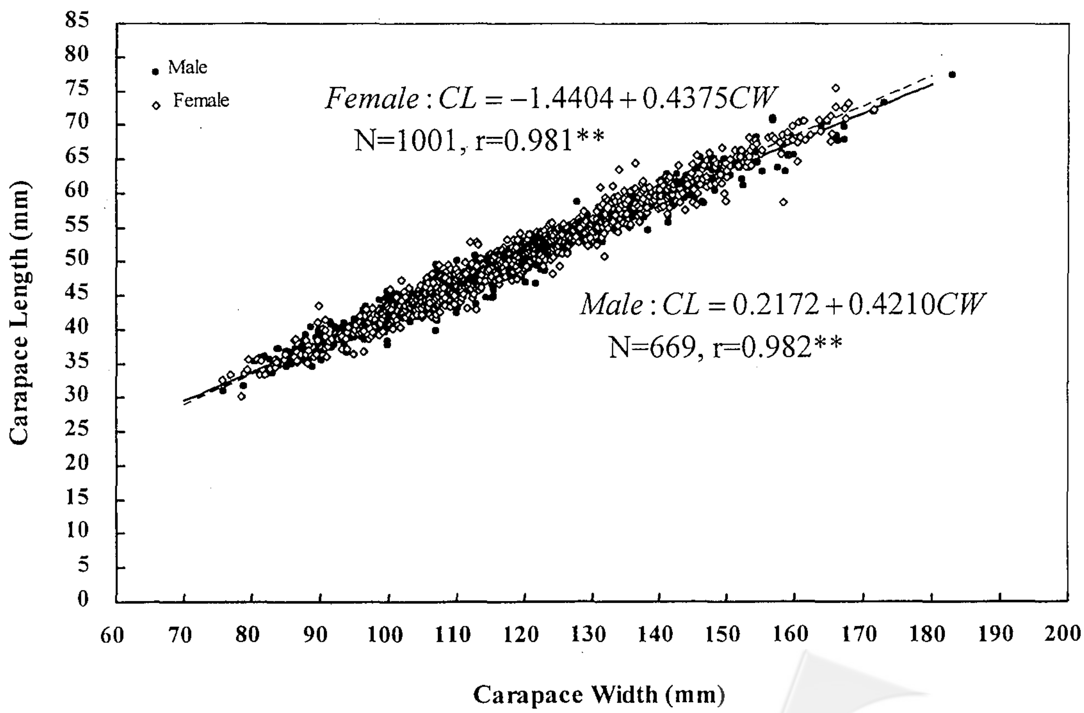


Fig. 4. The scatter-plot of chela length (CH) *vs.* carapace width (CW) by sexes of *P. sanguinolentus*, from the waters off northern Taiwan.

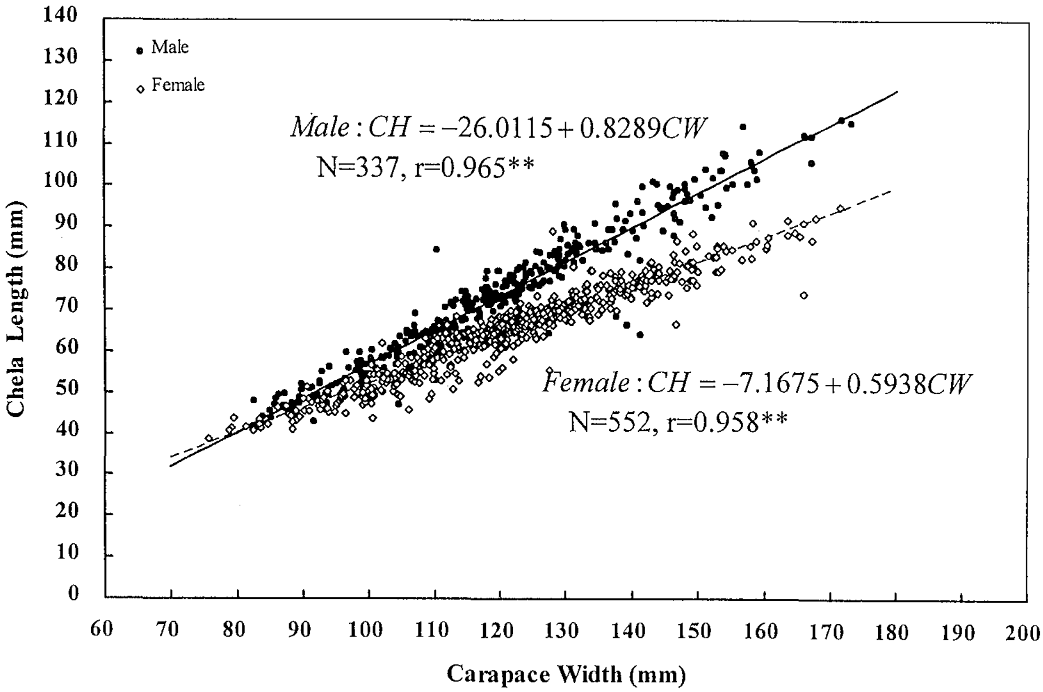
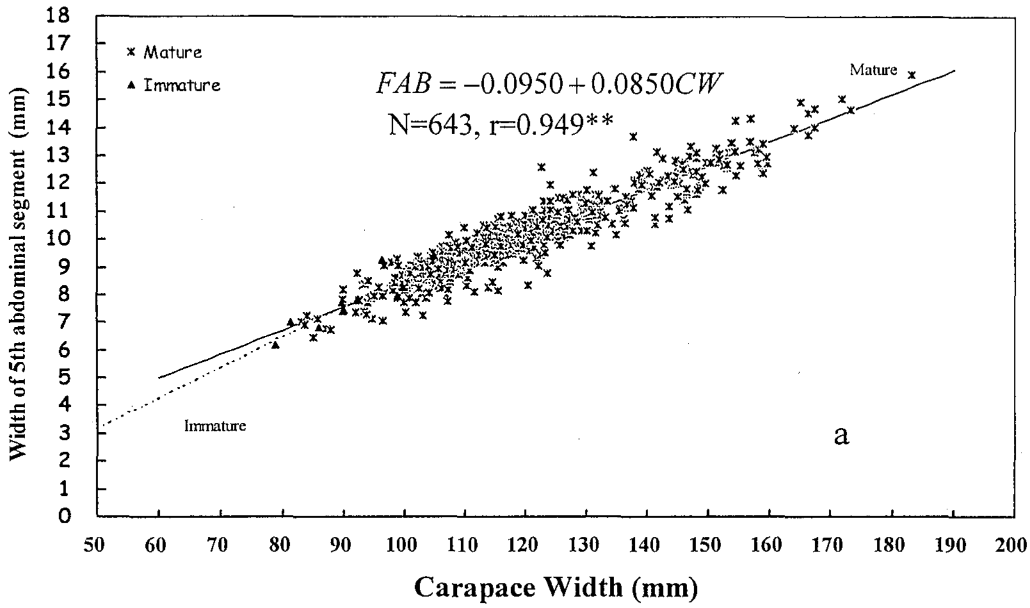


Fig. 5. The scatter-plot of chela length (CH) *vs.* carapace width (CW) by sexes of *P. sanguinolentus*, from the waters off northern Taiwan.

in the same variation from the waters off Queensland (Sukumaran *et al.*, 1986; Sumpton *et al.*, 1989), Kanara (Jacob *et al.*, 1990; Reeby *et al.*, 1990) and the present study from the northern Taiwan waters (Table 2). Of those, for the same CW, the weight of males from the northern Taiwan waters is different from the Queensland, and is larger than the one from the south Kanara waters. Moreover, the weight of females is also larger than both of the two waters mentioned above. As the consequence, to take life parameters separately by sexes is wisdom for population dynamics and stock assessment of the species in the future study.

Upon samples using in the present analysis, a few juvenile crab were collected. As the result, the juvenile samples were discarded, and the relationships of FAB *vs.* CW for adult samples only were compared between sexes. The result indicates that the width of the 5th abdominal segment of females, usually used as a maturity index for female crab, is significantly different with that of males. However, a further similar study should be made for the juvenile samples.

Traditionally live and primiparous females are valuable at most of Taiwan markets and are always sold in number rather than in weight. Consequently, to do a more accurate catch statistics for assessment purpose, a size-weight relationship is useful for the conversion of catch in number into weight; only the average CW of all crab or sub-sampled crab was known as in trap fishery. On the other hand, the conversion can be estimated from weight into number using this equation; if only average weight made from sub-sampling was known as in trawl fishery. Moreover, the size-weight relationship can be used for stock assessments incorporating into the analyses of yield per recruit and biomass models (King, 1995). Additionally, the relationships between weight of each appendage and CW were conducted to adjust body weight accurately in deriving size-weight relationship when the



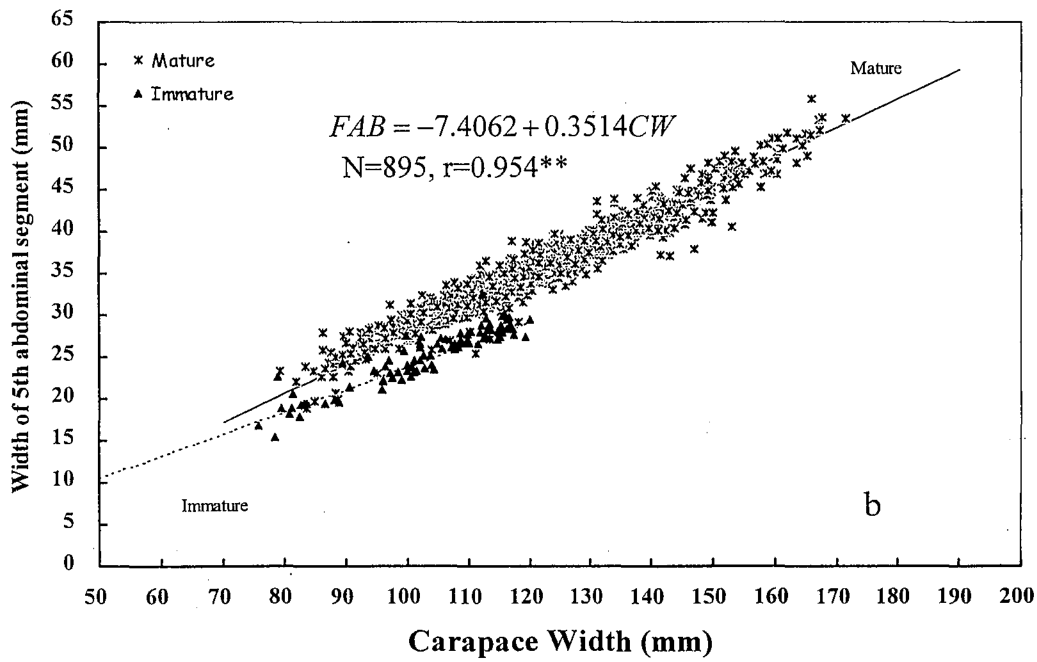


Fig. 6. The scatter-plot of the 5th abdominal segment (FAB) *vs.* carapace width (CW) for (a) immature and mature males and (b) females of *P. sanguinolentus*, from the waters off northern Taiwan. Where the immature crab data were also shwon, but not used in comparison analysis because of very small sample sizes.

appendages are broken or missing in sampling.

Morphological dimorphism of *P. sanguinolentus* reminds that to separate

Table 2. The comparison of the relationships between body weight (BW, in g) and carapace width (CW, in mm) from different waters for *P. sanguinolentus*

Authors and waters studied	Females	Males
Compbell and Fielder (1986)		
Queensland water (Australia)	$BW=1.1967 \times 10^{-4} CW^{2.865}$	$BW=6.5917 \times 10^{-5} CW^{3.009}$
Jacob *et al.* (1990)		
South Kanara waters (India)	$BW=6.58 \times 10^{-5} CW^{2.9604}$	$BW=3.62 \times 10^{-5} CW^{3.0997}$
The present study		
Keelung waters (Taiwan)	$BW=3.3056 \times 10^{-5} CW^{3.1227}$	$BW=1.4880 \times 10^{-5} CW^{3.2903}$

sexes is important in the accuracy of assessing stock. In addition, the abdominal segment of females will be allometry growth after puberty molt. Hence, to inspect the female maturity not only uses the shape and size of abdominal segment as the apparent maturity index, also examine their abdominal segment in whether or not is firmly attached to the thorax. For males, the width of abdominal segment is not significant between immature and mature individuals, however, to investigate the color of the inner surface of both the dactylus and propodus may be helpful for checking accurately the sexual maturity of males (Ryan, 1967; Huang, 1993). A very limited juvenile sample sizes were collected in the present study, the information (Fig. 6) seemed not sufficiently to evidence the sexual maturity discrepancies within the sex.

As usual, two approaches were used to estimate the parameters of nonlinear curves. For example, to estimate the parameters of size-weight relationship, the unbiased least squares (LS) and nonlinear least squares (NLS) can be used (Hsu, 1999). However, both LS and NLS are all sensitive to outliers that may exist in measurements (Chen *et al.*, 1994). Thus, a regression diagnostic technique may be used to identify possible outliers because outliers always pull the regression curve towards themselves (Sen and Srivastava, 1990). Therefore, robust regression analyses (Rousseeuw, 1984; Rousseeuw and Leory, 1987) may be used to estimate the parameters. In the present study, the subjective visual inspection on the relationship among morphometric characters and CW has been *a priori* made from scatterplots. It seems that there are no outliers in the data set using in the present study. Simply, only the MLE was used in the estimation of parameters of regression, because the sum of squares obtained from MLE were used in likelihood ratio test to compare the curves.

The likelihood ratio tests are usually used to compare the growth curves that derived either from different seasons and places or from different readings (Quinn and Deriso, 1999), and used to compare the length and weight relationships (Hsu *et al.*, 2000). One of the advantages of likelihood ratio tests is to compare curves with all parameters together once in a time without separating parameters. However, the analysis of covariance needs to compare the regression by separating slope and elevation each time (Sokal and Rohlf, 1995; Zar, 1999). Therefore, in the present study, relationships between external morphological characters and CW are compared with considering slope and elevation parameters together, other than the traditional morphological comparisons with parameters being considered separately, such as covariance analysis.

ACKNOWLEDGEMENTS

We thank the National Science Council for supporting the research project in contract no. NSC86-2611-B-002-A-001. Appreciations is extended to Ms. Stacy Kao, Research Assistant of Tuna Research Center, Institute of Oceanography, National Taiwan University, who helps in collecting and measuring crab samples. Specially we would like to thank referees for reviewing and provision of constructive comments on the original manuscript.

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臺灣北部海域產紅星梭子蟹之性別差異形態形質測定

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（2000年6月23日收件；2000年7月20日接受）

紅星梭子蟹是臺灣最重要具商業性價值之多產蟹類之一。但由於一些基礎生物學資料的闕如，系群資源狀態評估有所困難。因此，為探討體型結構，體型（甲殼寬，CW: 公釐）和體重 (BW: 公克）間關係式，以及性別間的形態差異，自1997年4月至1998年7月在北臺灣海域蒐集了1880隻紅星梭子蟹為標本，進行形態測量研究。分別以雙對數或線性式來分析推導體重、附肢重、甲殼長、螯長及第五腹節寬對甲殼寬的關係式。並以概似比測驗法比較這些關係式在性別間的異同。結果顯示這些關係式在性別間有顯著的統計差異。對於臺灣北部海域產紅星梭子蟹，可用於系群評估所必須的體型-體重關係式可以表示為-雄蟹：$BW=1.4880\times10^{-5}\ CW^{3.2903}$；雌蟹：$BW=3.3056\times10^{-5}\ CW^{3.1227}$。

關鍵詞：紅星梭子蟹，概似比測驗，形態形質，體型與體重關係式。

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