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Statistical Relations Between Lengths and Weights of Green Tiger Prawns, *Penaeus semisulcatus*, in Kuwait Waters

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Abstract

A quadratic model was found appropriate in describing the relations among the total, body and carapace lengths of green tiger prawns (*Penaeus semisulcatus* De Haan), irrespective of maturity, in Kuwait waters; whereas a linear model fitted well the length-length relations when the data for mature and immature female shrimp were analyzed separately. Residual analysis suggested that the logarithm of the allometric form fitted well the weight-length data of large green tiger prawns with total length larger than or equal to 55 mm, whereas a linear model fitted well the weight-length data of small shrimp with total length less than 55 mm. Significant negative and positive deviations from isometric growth were found, respectively, for weight-carapace length and weight-total length relations for large shrimp; whereas tail weight-body length relations followed nicely the isometric growth. We suggest that the length-length relations of other shrimp species be reexamined using regression analysis with a model adequacy test. A variance estimator for predicted weight from length using regression equation was proposed.

Introduction

Weight and length relationships play a basic role in fisheries studies (Beverton and Holt 1993). Although such relationships are among the few in fisheries relationships that look nice statistically (Hilborn and Walters 1992), and the estimation of the parameters in a length-weight relation is usually straightforward (Pauly 1993), some problems in data analysis and applications of these relationships in stock assessment are of concern.

There are several ways to measure the length of shrimp, such as body length, total length or carapace length. Due to limitations of time and manpower, usually only one or two variables are measured in a study. Moreover, in most industrial fisheries such as those in Kuwait, shrimp are often headed at sea for packing purposes. This makes it impossible to obtain data such as total

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length, carapace length and individual total weight data directly from the sample. Therefore, it is necessary to find the relationships between the variables so that the uncollected information can be obtained from the known by using derived relations.

Farmer (1986) studied the morphometric relationships of green tiger prawns (*Penaeus semisulcatus* De Haan, Penaeidae) in Kuwait waters; however, he did not estimate the variances of the parameters, which are very important for estimating the variance of the prediction. Also, because of the lack of small and large specimens in the data collected by Farmer (1986), his regression equations are based only on the central range of length distributions. Moreover, the length-length relations might not be the simple linear form that Farmer (1986) assumed. In the present study, great efforts were made in sampling to get more representative data covering as much as possible the entire size range of green tiger prawns in Kuwait waters. The statistical relationships between lengths and weights of green tiger prawns were investigated using regression analysis.

Materials and Methods

Samples of green tiger prawns were collected from research vessel surveys, and speed boat and dhow boat catches during 1985 and 1986 covering the whole fishing area. Fresh specimens were used in all the measurements. The carapace, total and body lengths were measured to the nearest 0.1, 1.0 and 1.0 mm, respectively. Weights were measured to the nearest 0.1 g. Shrimp were headed by hand as is practiced at sea so that the measured tail weight would be comparable with the fishery data. A total of 341 male and 452 female green tiger prawns were sampled and measured during this study. In addition, maturity stages of female shrimp were recorded so that the differences in relations between lengths and weights for mature and immature shrimp could be tested.

Let x_i and y_i denote, respectively, independent and dependent variables, i.e., the measurements of the ith shrimp. The linear and quadratic models

$$y_i = \beta_0 + \beta_1 x_i + e_i$$

$$y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + e_i$$

were fitted by the method of least squares to length-length data of green tiger prawns and weight-length data of small shrimp. The logarithm of the allometric form

$$\log(y_i) = \log(\beta_0) + \beta_1 \log(x_i) + e_i$$

was fitted by the method of least squares to the weight-length data. β 's denote regression parameters; e_i is assumed to be an independent normal random variable with mean zero and constant variance. *Log* denotes natural logarithm. Since there might be differences in length-length or weight-length relations between female and male or between mature and immature or between large and small shrimp, an indicator variable, x_{i2}, was introduced into the regression models

$$y_i = \beta_0+\beta_1 x_{i1}+\beta_2 x_{i2}+\beta_{12} x_{i1} x_{i2}+e_i$$

$$y_i = \beta_0+\beta_1 x_{i1}+ \beta_{11} x^2_{i1}+\beta_2 x_{i2}+\beta_{12} x_{i1} x_{i2}+ \beta_{112} x^2_{i1} x_{i2}+e_i$$

where y_i and x_{i1} are measurements (in case of linear and quadratic models) or logarithm of measurements (in case of logarithmic form) of the *i*th shrimp; $x_{i2} = 1$ and 0, respectively, for female and male or for mature and immature or for large and small shrimp. The hypotheses of no differences in length-length and weight-length relationships between female and male or between mature and immature or between large and small shrimp, i.e., $H_0{:}\beta_2=\beta_{12}=0$ or $H_0{:}\beta_2=\beta_{12}=\beta_{112}=0$, were tested using the partial *F*-test to determine if the regression functions for female and male or for mature and immature or for large and small shrimp are identical. The residual analysis and lack-of-fit test were applied to check the model adequacy.

The deviations of the estimated weight-length relations from isometric growth, i.e., $H_0{:}\beta_1=3$, were tested using *t* statistics, $t=(\hat\beta_1-3)/SD(\hat\beta_1)$, where $\hat\beta_1$ indicates the regression coefficient in the logarithmic form, and $SD(\hat\beta_1)$ is the estimated standard deviation for $\hat\beta_1$.

Results

Length-Length Relations

The linear model was fitted to each pair of total length, body length and carapace length, respectively, for immature and mature female green tiger prawns (Table 1). No evidence of lack of fit was detected for all the regression functions. Residual analysis showed no patterns in residual distribution against predicted lengths. Significant differences were found in all the length-length regression functions between immature and mature female shrimp, i.e., $H_0{:}\beta_2=\beta_{12}=0$ was rejected. Since no information on the maturity of male shrimp was collected, the linear and quadratic regression models for each pair of length measurements were fitted to the male shrimp data irrespective of maturity. For comparison, the linear and quadratic models were also fitted to the female shrimp data irrespective of maturity. The lack of fit was significant under the linear model (Table 1); whereas there was no indication of lack of fit under the quadratic model (Table 2) except the model of total length versus carapace length for male ($P=0.032$). The residual analysis showed apparent curve patterns for the linear model (Fig. 1), but no pattern for the quadratic model. Accordingly, the quadratic model was considered to be the appropriate form to

Table 1. Fitted linear regression model for length-length relations of green tiger prawns in Kuwait waters.

Y (mm)		TL	BL	BL	CL	TL	CL
X (mm)		BL	TL	CL	BL	CL	TL
	$\hat{\beta}_0$	2.0918	-1.4854	2.2038	-0.4127	4.3765	-0.8685
	SD	0.4081	0.3558	0.4969	0.1334	0.4622	0.1082
Immature	$\hat{\beta}_1$	1.1724	0.8489	3.8138	0.2595	4.4907	0.2212
♀	SD	0.0064	0.0046	0.0308	0.0021	0.0286	0.0014
n=162	$\hat{\sigma}$	1.4642	1.2450	1.8337	0.4783	1.7066	0.3783
	$\bar{X}$	61.19	73.83	15.47	61.19	15.47	73.83
	LOF	$P>0.9$	$P>0.3$	$P>0.7$	$P>0.1$	$P>0.2$	$P>0.2$
	R^2	0.995	0.995	0.990	0.990	0.994	0.994
	$\hat{\beta}_0$	12.1487	-10.3846	20.8230	-6.0229	34.4088	-9.2717
	SD	0.7121	0.7108	0.7753	0.2802	0.9935	0.3584
Mature	$\hat{\beta}_1$	1.0732	0.9261	3.1915	0.3098	3.4276	0.2871
	SD	0.0050	0.0043	0.0201	0.0020	0.0258	0.0022
♀	$\hat{\sigma}$	2.0958	1.9472	2.6477	0.8250	3.3927	0.9825
n=290	$\bar{X}$	141.21	163.70	37.72	141.21	37.72	163.70
	LOF	$P>0.1$	$P>0.3$	$P>0.1$	$P>0.1$	$P>0.2$	$P>0.2$
	R^2	0.994	0.994	0.989	0.989	0.984	0.984
	$\hat{\beta}_0$	5.9028	-5.0642	8.1297	-2.1367	15.0529	-3.5494
♀	$\hat{\beta}_1$	1.1160	0.8943	3.5099	0.2833	3.9146	0.2532
n=452	LOF	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$
	R^2	0.998	0.998	0.994	0.994	0.991	0.991
	$\hat{\beta}_0$	4.4542	-3.7494	2.7683	-0.5954	7.6504	-1.5557
♂	$\hat{\beta}_1$	1.1362	0.8786	3.8344	0.2594	4.3543	0.2278
n=341	LOF	$P=0.0019$	$P=0.002$	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P>0.0001$
	R^2	0.998	0.998	0.995	0.995	0.992	0.992

TL = total length, BL = body length, CL = carapace length, SD = estimated standard deviation of estimated parameters, $\hat{\sigma}$ = estimated standard deviation of regression models; n = sample size; $\bar{X}$ = mean of independent variable; LOF = lack of fit, R^2 = coefficient of determination.

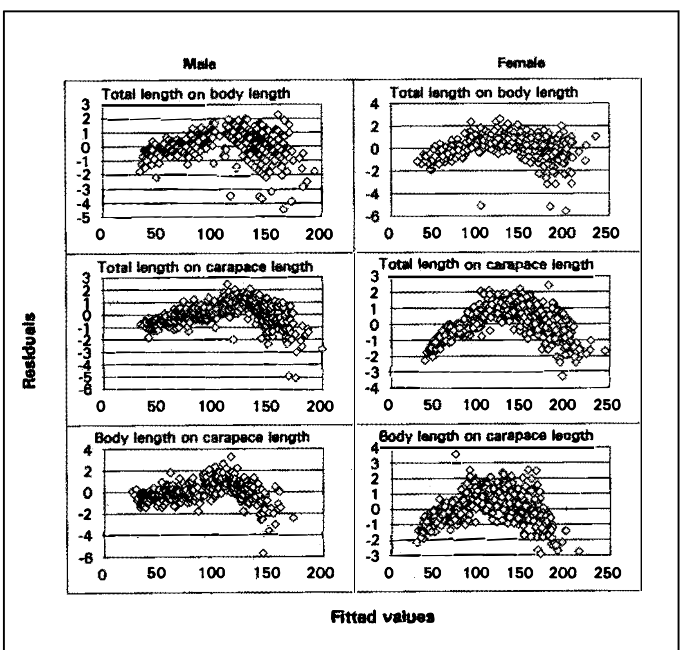

Fig. 1. Residual plots of linear regression of length on length of green tiger prawns.

Table 2. Fitted quadratic regression model for length-length relations of green tiger prawns in Kuwait waters.

	Y (mm) X (mm)	TL BL	BL TL	BL CL	CL BL	TL CL	CL TL
	$\hat{\beta}_0$	0.4893	-0.4001	-3.1491	1.2442	-2.1082	1.3666
	SD	0.5568	0.5427	0.6057	0.2063	0.7695	0.2599
	$\hat{\beta}_1$	1.2372	0.8055	4.4559	0.2076	5.3540	0.1596
♀	SD	0.0113	0.0095	0.0457	0.0042	0.0581	0.0045
n=452	$\hat{\beta}_2$	-0.0006	0.0004	-0.0161	0.00035	-0.0246	0.00037
	SD	0.00005	0.00004	0.0008	0.00002	0.00097	0.00002
	$\hat{\sigma}$	1.9400	1.7821	2.3686	0.7187	3.0093	0.8464
	$\bar{X}$	112.53	131.49	29.74	11.253	29.74	131.49
	LOF	$P>0.09$	$P>0.1$	$P>0.4$	$P>0.1$	$P>0.1$	$P>0.1$
	R^2	0.998	0.998	0.997	0.997	0.996	0.996
	$\hat{\beta}_0$	-0.1514	0.0481	-4.9885	1.2101	-5.4931	1.312
	SD	0.5616	0.5468	0.7545	0.2211	0.9625	0.2790
	$\hat{\beta}_1$	1.2580	0.7941	4.6331	0.2117	5.7077	0.164
♂	SD	0.0137	0.0113	0.0712	0.0054	0.0909	0.0058
n=341	$\hat{\beta}_2$	-0.0007	0.0004	-0.0172	0.0003	-0.0292	0.0003
	SD	0.00008	0.00005	0.0015	0.00003	0.0019	0.00003
	$\hat{\sigma}$	1.5452	1.3995	2.2121	0.6081	2.8216	0.7134
	$\bar{X}$	93.65	110.85	23.70	93.65	23.70	110.85
	LOF	$P>0.7$	$P>0.2$	$P>0.05$	$P>0.07$	$P=0.032$	$P>0.2$
	R^2	0.999	0.999	0.996	0.996	0.995	0.995
	$\hat{\beta}_0$	0.3234	-0.1401				
♂&♀	$\hat{\beta}_1$	1.2431	0.7989				
n=793	$\hat{\beta}_2$	-0.0006	0.0004				
	LOF	$P=0.003$	$P=0.0069$				
	R^2	0.999	0.999				

TL = total length, BL = body length, CL = carapace length, SD = estimated standard deviation of estimated parameters, $\hat{\sigma}$ = estimated standard deviation of regression models; n = sample size; $\bar{X}$ = mean of independent variable; LOF = lack of fit, R^2 = coefficient of determination.

represent the length-length relations for green tiger prawns irrespective of maturity. No significant differences were detected, or $H_0{:}\beta_2=\beta_{12}=\beta_{112}=0$ was not rejected in quadratic functions relating total length on body length or body length on total length between female and male shrimp, whereas $H_0{:}\beta_2=\beta_{12}=\beta_{112}=0$ was rejected, i.e, there were significant differences between female and male shrimp in the quadratic functions which included carapace length. Quadratic relations of total and body lengths irrespective of sex were further developed with the sexes combined data (Table 2). No pattern in residual distribution against fitted lengths was detected; the lack of fit, however, was significant (Table 2). Therefore, in the application of these relations, it is suggested to use the separate, instead of combined, equations when the gender data are available.

Weight-Length Relations

The residual analysis indicated that the variances were inconsistent between large and small shrimp (Fig. 2) when the logarithmic form was fitted,

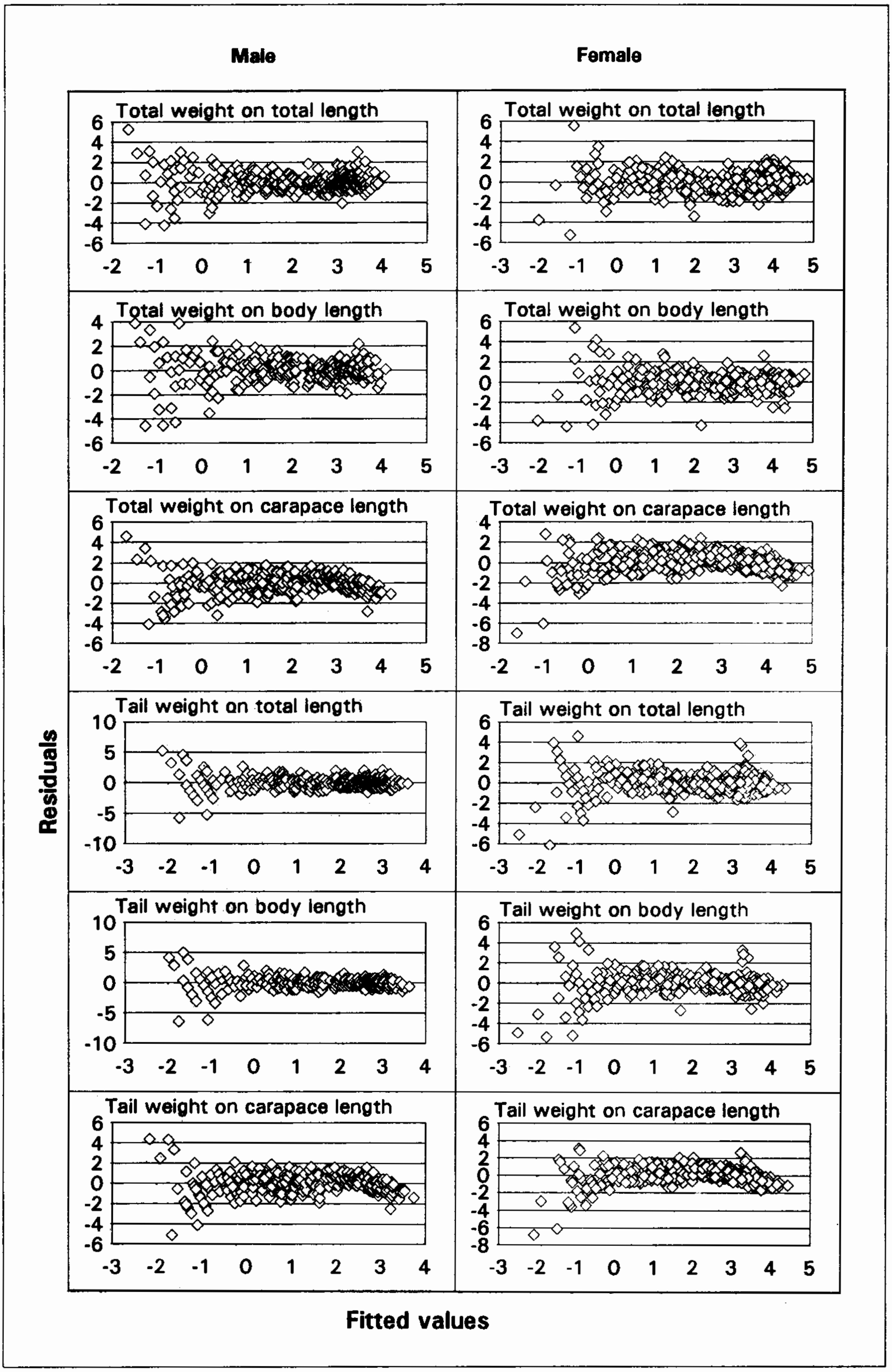

Fig. 2. Residual plots of logarithmic regression of weight on length of green tiger prawns.

Table 3. Fitted logarithmic regression models for weight-length relations of large female and male green tiger prawns in Kuwait waters.

	Y (g) X (mm)	TW TL	TW BL	TW CL	BW TL	BW BL	BW CL
	$\log(\hat{\beta}_0)$	-12.6748	-11.3802	-6.5120	-12.9982	-11.7169	-6.8914
	SD	0.0433	0.0346	0.0304	0.0491	0.0409	0.0389
	$\hat{\beta}_1$	3.2008	3.0356	2.7990	3.1672	3.0036	2.7670
♀	SD	0.0089	0.0073	0.0089	0.0100	0.0385	0.0114
n=415	$\hat{\sigma}$	0.0654	0.0570	0.0754	0.0741	0.0674	0.0966
	$\bar{X}$	4.8761	4.7151	3.3743	4.8761	4.7151	3.3743
	LOF	P=0.0005	P=0.01	P>0.1	P>0.1	P>0.1	P=0.008
	R^2	0.997	0.998	0.996	0.996	0.997	0.993
	$\log(\hat{\beta}_0)$	-12.4739	-11.2634	-6.8727	-12.9464	-11.7373	-7.3330
	SD	0.0542	0.0429	0.0433	0.0577	0.0445	0.0507
	$\hat{\beta}_1$	3.1481	3.0013	2.9201	3.1501	3.0037	2.9192
♂	SD	0.0114	0.0094	0.0135	0.0122	0.0097	0.0158
n=303	$\hat{\sigma}$	0.0657	0.0566	0.0836	0.0699	0.0587	0.0980
	$\bar{X}$	4.7313	4.5594	3.1826	4.7313	4.5594	3.1826
	LOF	P>0.6	P>0.6	P=0.016	P>0.05	P>0.1	P=0.0008
	R^2	0.996	0.997	0.994	0.996	0.997	0.991
	$\log(\hat{\beta}_0)$				-13.0195	-11.7504	
	SD				0.0373	0.0299	
	$\hat{\beta}_1$				3.1691	3.009	
♀&♂	SD				0.0077	0.0064	
n=718	$\hat{\sigma}$				0.0738	0.0645	
	$\bar{X}$				4.8150	4.6494	
	LOF				P=0.005	P=0.039	
	R^2				0.996	0.997	

TL = total length, BL = body length, CL = carapace length, SD = estimated standard deviation of estimated parameters, $\hat{\sigma}$ = estimated standard deviation of regression models; n = sample size; $\bar{X}$ = mean of independent variable; LOF = lack of fit, R^2 = coefficient of determination; TW = total weight, BW = tail weight.

respectively, to the data of female and male green tiger prawns. The data were divided into two groups, large and small shrimp, respectively, for male and female shrimp based on a breaking point at which the residual patterns changed. This point was located around zero on the axis of the fitted logarithmic total weight (Fig. 2), which was corresponding approximately to 55 mm in total length or 45 mm in body length. The logarithm of the allometric form was fitted, respectively, to the data of large female and male shrimp (Table 3) with no patterns in residual distributions versus the fitted values. The lack of fit, however, was significant in three of six models for female and two of six models for male. Significant differences were detected, i.e., H_0:β_2=β_{12}=0 was rejected for all the regression functions of weights on lengths between large female and male shrimp except the relations of tail weight on total and body lengths. The logarithmic regression equations of tail weight on total and body lengths were further estimated with the sexes combined data (Table 3).

The deviations of the estimated weight-length relations from isometric growth for large shrimp, i.e., H_0:β_1=3, were tested using t statistic with the estimated parameters and standard deviations in Table 3. There were always significant negative deviations from isometric growth for relations of weight on carapace length and significant positive deviations for relations of weight on

Table 4. Fitted linear regression model for weight-length relations of small female and male green tiger prawns in Kuwait waters.

	Y (g) X (mm)	TW TL	TW BL	TW CL	BW TL	BW BL	BW CL
	$\hat{\beta}_0$	-1.1113	-1.0208	-1.0961	-0.7277	-0.6628	-0.7095
	SD	0.1156	0.1236	0.1310	0.1113	0.1147	0.1211
♀	$\hat{\beta}_1$	0.0392	0.0456	0.1910	0.0251	0.0290	0.1215
n=37	SD	0.0026	0.0034	0.0142	0.0025	0.0031	0.0132
	$\hat{\sigma}$	0.0944	0.1046	0.1059	0.0910	0.0970	0.0979
	$\bar{X}$	44.84	36.54	9.12	44.84	36.54	9.12
	LOF	P=0.024	P>0.5	P>0.05	P>0.6	P>0.8	P>0.1
	R^2	0.871	0.841	0.837	0.749	0.714	0.709
	$\hat{\beta}_0$	-1.1270	-1.1302	-1.0655	-0.6658	-0.6681	-0.6144
	SD	0.1117	0.0998	0.1269	0.0815	0.0753	0.0933
	$\hat{\beta}_1$	0.0397	0.0450	0.1888	0.0238	0.0293	0.1114
♂	SD	0.0025	0.0028	0.0142	0.0019	0.0021	0.0105
n=38	$\hat{\sigma}$	0.0931	0.0841	0.1069	0.0679	0.0635	0.0787
	$\bar{X}$	43.50	35.32	8.82	43.50	35.32	8.82
	LOF	P>0.1	P>0.2	P>0.5	P>0.1	P>0.2	P>0.1
	R^2	0.871	0.895	0.830	0.820	0.843	0.758
	$\hat{\beta}_0$	-1.1164	-1.0689	-1.0758	-0.6956	-0.6629	-0.6588
	SD	0.0788	0.0781	0.0894	0.0674	0.0670	0.0746
	$\hat{\beta}_1$	0.0394	0.0471	0.1893	0.0244	0.0291	0.1162
♀&♂	SD	0.0018	0.0022	0.0099	0.0015	0.0018	0.0082
n=75	$\hat{\sigma}$	0.0925	0.0940	0.1051	0.0791	0.0807	0.0877
	$\bar{X}$	44.16	35.92	8.97	44.16	35.92	8.97
	LOF	P>0.06	P>0.1	P>0.4	P>0.4	P>0.3	P>0.2
	R^2	0.872	0.867	0.834	0.781	0.773	0.732

TL = total length, BL = body length, CL = carapace length, SD = estimated standard deviation of estimated parameters, $\hat{\sigma}$ = estimated standard deviation of regression models; n = sample size; $\bar{X}$ = mean of independent variable; LOF = lack of fit, R^2 = coefficient of determination; TW = total weight, BW = tail weight.

total length. No significant deviations were found for relations of tail weight on body length for green tiger prawns and for relation of total weight on body length for male shrimp.

The logarithmic form, linear and quadratic models were fitted to the data of small shrimp. The residual analysis and lack-of-fit test indicated that both linear and quadratic models fitted the data of small shrimp better than the logarithmic form; the linear model was preferred to the quadratic model, however, for its simplicity (Table 4). There were no significant differences in linear regression functions between small male and female shrimp, i.e., $H_0{:}\beta_2=\beta_{12}=0$ was not rejected. Therefore, the data were combined to derive combined regression functions (Table 4).

Discussion

Statistical methods are powerful tools in fisheries research. However, misapplication of statistical methods in fisheries studies are not uncommon (Chapman 1990; Trippel and Hubert 1990). One of the statistical problems involves tests of the assumptions that underlie the statistical model (Chapman

1990). Regression analysis has been intensively applied in fisheries studies; however, the model adequacy is usually not examined in the studies. The present study showed that the quadratic model was appropriate in describing the length-length relationships of green tiger prawns irrespective of maturity. This finding is different from the former study (Farmer 1986), in which the length-length relations were fitted by a linear model without testing the validity. Usually, one cannot be certain in advance that a regression model is appropriate for an application until the aptness of the model for the data has been examined (Neter et al. 1990), and underlying assumptions for the model can rarely be accepted without tests of their validity (Chapman 1990). As far as we know, the reported relationships among lengths of shrimp irrespective of maturity were mostly fitted by linear models (e.g., Fontaine and Neal 1968; Enomoto 1971; Brusher 1972; Kashiwagi 1974; Lares and Khandker 1976; Ito 1978a, 1978b; Ramamurthy and Manickaraja 1978; Ivanov and Krylov 1980; Pérez Farfante and Ivanov 1982; Farmer 1986; Chu et al. 1993), except that Mallo and Boschi (1982) and Nataranjan et al. (1988) fitted the total length and carapace length relationship by logarithmic form. Formoso et al. (1980) found that the carapace length and total length relationship for female *Plesiopenaeus edwardsianus* is not isometric and developed linear regression models separately for small and large shrimp. It is difficult to judge if these models are appropriate for their cases because no raw data were supplied in these papers. Because of possible discontinuity in growth between immature and mature shrimp, differences in length-length relations between mature and immature shrimp would be expected. Therefore, a reexamination of the length-length relations of these species using regression analysis with the model adequacy test would likely improve their results.

Both the non-linearity of length-length relations and clear inconsistency in weight-length relations between small and large shrimp provide evidence for the divergence in growth rates of small and large shrimp. The linearity of weight-length relations for small shrimp suggests that the individual weight increases in a consistent rate with length; whereas the logarithmic form for large shrimp suggests that weight increases faster than length, and the difference in growth rate between weight and length increases as shrimp grow bigger.

Since the regression function is based on the data collected, the value of the independent variable should be in the range of the data distribution when using the function for predictions. The weight-length regression function has often been used to estimate W_∞ from L_∞ (Beverton and Holt 1993), however, it must be borne in mind that predicted W_∞ from the regression function might not be reliable when L_∞ is far from the length distribution range of the data, on which the regression analysis is based. Sprugel (1983) proposed a simple approach to correcting the bias in log-transformed allometric equations to predict weight from length, although the errors usually are fairly small. If weight-length equation is used to predict weight (W) from length (L), the variance of predicted $Log\ (W)$, $\hat{V}[L\hat{o}g(W)]$, can be estimated using (see Neter et al. 1990, p. 82)

$$\hat{V}[L\hat{o}g(W)] = \hat{\sigma}^2[1+\frac{1}{n}+\frac{(Log(L)-\bar{X})^2}{\Sigma\ (X_i-\bar{X})^2}$$

where $\hat{\sigma}^2$ represents estimated variance of the regression model or mean squares of error; n is the sample size used for regression analysis; $\bar{X}$ is the mean of the logarithm of length. Note that $\Sigma(X_i-\bar{X})^2$ is equal to the ratio of estimated variance of reggression coefficient $\hat{\beta}_1$, over the estimated variance of the regression model. The estimated variance for predicted weight ($\hat{W}$) can then be estimated by

$$\hat{V}[\hat{W}] = \hat{W}^2\hat{V}[L\hat{o}g\ (\hat{W})].$$

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