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Analysis of Length and Weight Characteristics of Green Mussel, *Perna viridis*, from Thailand*

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Abstract

The following parameters were measured (females and males separately) in 1,760 individuals of the green mussel, *Perna viridis* (Mytilidae): size (length, height), weight (total, flesh + shell, shell, flesh wet, flesh dry). Size/weight relationships were determined as well as the relationships within various weight units. The analysis suggests that the weight unit "flesh + shell" should be used as a standard unit for total weight. With this unit taken as weight, the exponent "b" of the size/weight relationship varies between 2.55 and 2.87, depending whether "length" or "height" is used as dimension unit. The sex ratio in the sample was 44% male to 56% female. Sexual growth dimorphism was not observed.

Introduction

In fisheries research, measuring length and weight are standard tasks and the data obtained are the backbone of many models used in

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fish population dynamics. The applications reach from growth estimates to the prediction of potential catch or harvest.

The properties of weight data obtained from fish are generally such that the data on total weight can be used directly in most of the models applied. To define a biologically meaningful weight for marine invertebrates is, however, in some cases difficult and needs careful evaluation of the purpose of data collection. Quite clearly, when assessing the availability of food for human consumption, the total weight of an animal with large parts of its body consisting of hard structures (e.g., carapace or shell) is relatively meaningless. On the other hand, to measure a more appropriate weight might often be impracticable.

Molluscs are a typical example of this problem. The present study analyses the length and weight characteristics of the green mussel *(Perna viridis)* which plays an important role in the shellfish industry of Thailand and other countries in Southeast Asia.

The objectives of this work were to establish the quantitative relationships of a standard set of weight units both among themselves and in comparison to morphometric characteristics such as length and height.

Materials and Methods

The data analyzed in this paper were generated in the context of research on the green mussel culture industry in Thailand, jointly organized by the International Center for Living Aquatic Resources Management (ICLARM) and the Department of Fisheries (DOF) of Thailand. It was part of a four-year project: "Applied Research on Coastal Aquaculture in Thailand".

The research reported here was carried out over a period of 15 months from April 1984 through June 1985. Two important green mussel farming areas were selected for sampling: Ban Laem, Phetchaburi Province, in the northwestern part of the Gulf of Thailand and Samae Kao, Chachoengsao Province, in the northeastern part of the Gulf. These sites were visited monthly and data collected on biological and economic aspects of the green mussel and its related processing industry.

In addition, live green mussel samples were collected every month directly from boats at the landing sites and brought back to Bangkok, where they were kept overnight in water tanks.

On the following day, any green mussel found dead was removed from the tanks. Out of the remaining mussels, subsamples totaling 120 specimens were selected for further investigation (80 mussels from Ban Laem and 40 mussels from Samae Kao). The investigation aimed at obtaining quantitative data on size, weight and sex of every individual.

A total of 1,760 records was available, each comprising eight variables defined as follows:

- Length: maximum shell length along the anterior/posterior axis; measured with callipers to the nearest 0.1 mm.
- Height: maximum shell length along the dorsal/ventral axis; measured with callipers to the nearest 0.1 mm.
- Total weight: weight of mussel immediately after removal from the tank with completely closed shell. (Any animal found to have lost some of its cavity water prior to weighing was replaced by another mussel.) Weight's were recorded on an analytical scale, in grams.
- Flesh weight: weight of the soft parts of the mussel including adductor muscles. Flesh was removed from the shell and adherent water was blotted off prior to weighing.
- Shell weight: weight of the shell after removal of the soft parts.
- Flesh & shell weight (FL & SH): computed by summing the individual weights recorded for Flesh and Shell.
- Flesh dry weight (Dry wt): the soft part of the mussel (Flesh) was dried in an oven for 48 hours at 70°C. Weighing was done directly after removal of the samples from the oven to avoid an artificial weight increase from humidity.
- Sex: the color of the gonads was used for sexing; orange for females, cream for males. In case of doubt, animals were listed as unidentifiable.

Throughout this paper, all relationships were analyzed by least-square regression of the form

$$y = a + b \cdot x \qquad \ldots 1)$$

The predictive power of the computed functions were assessed from the following parameters: S_b: standard error of the regression coefficient b; S_y: standard error of estimate; r^2: coefficient of determination; n: number of observations included in the regression; % outliers: number of observations excluded from analysis (in per cent of total N = 1,760).

Size-weight relationships are generally expressed by a non-linear function of the form

$$W = a \cdot L^b \qquad \text{... 2)}$$

These size and weight data were analyzed with the logarithmic transformation:

$$\log W = \log a + b \cdot \log L \qquad \text{... 3)}$$

with W being the weight and L the size (length or height).

The use of a logarithmic transformation introduces a systematic bias into the calculations which has to be counteracted by means of a correction factor (Sprugel 1983). This is done by multiplying "a" in equation (2) with a correction factor (CF) of the form:

$$CF = \exp (SEE^2 \cdot 2^{-1}) \qquad \text{... 4)}$$

where SEE is the standard error of estimate (S_y) multiplied by $\log_e$ 10 (= 2.303) to convert the base-10 S_y to a base-e standard error of estimate.

The computation of the regression constants a and b was always done in two runs to detect and eliminate outliers by means of residual analysis. The first run used all 1,760 data pairs available. The resulting (preliminary) values of "a" and "b" allowed the calculation of an estimate of y (= $\hat{y}$) for every given value of x. From this, "standard residuals" (STR) were computed for every observation using the formula

$$STR = R \cdot S_R^{-1} \qquad \text{... 5)}$$

where R are the residuals (y - $\hat{y}$) and S_R is the standard deviation of the computed residuals.

STR expresses the deviation of a single data point from the regression line in units of its own standard deviation. If the measurements of size and weight are unbiased, STR is a random variable following (ideally) a normal distribution with mean zero. Any strong deviation from this rule would suggest the inapplicability of the least-square regression technique in the analysis of a given data set.

The distribution of the STR-values was inspected graphically by plotting their frequencies along an x-axis reaching from -10 to +10. Any observation resulting in a standard residual exceeding ±3 was considered an outlier (Chatterjee and Price 1977). Regression analysis was then performed a second time with outliers excluded. The number of outliers are given with every analysis (in % of the total available N = 1,760) to provide an estimate of possible additional source of variation.

Results

The various relationships presented below pertain to mussels ranging in length from 38 to 109 mm and in height from 19 to 42 mm. Any extrapolation to a size beyond these ranges has to be viewed with some precaution.

The results of the regression of length on height and vice versa are summarized in Table 1.

Table 1. Morphometric relationships of *Perna viridis* ("% outlier" denotes number of records in per cent excluded from analysis.)

Function	$Y = a + b \cdot X$	
X-Variable Y-Variable	Length Height	Height Length
a	5.38	- 0.1404
b	0.3467	2.37
S_b	0.0037	0.0258
S_y	1.6768	4.4767
r^2	0.836	0.834
n	1,742	1,748
% outlier	1.02	0.68

Table 2 shows the results of the relationship between the length of green mussel and various forms of weight. To check whether the computed values of "b" were significantly different from b = 3, a value of t* was calculated using the formula:

$$t^* = |b - 3| \cdot S_b^{-1} \qquad \text{... 6)}$$

The tabulated value of the t-statistics (student distribution) for df > 1,000 and a 1% error level was $t_{\infty,0.01} = 2.576$.

Table 2. Length/weight relationships of *Perna viridis* ("% outlier" denotes number of records in per cent excluded from analysis; reference value of t-distribution: $t_{\infty,0.01}$ = 2.576).

Function	$Y = a \cdot X^b$				
X-Variable Y-Variable	Length Total	Length FL & SH	Length Flesh	Length Shell	Length Dry Wt
a	2.22 E-4	2.41 E-4	2.17 E-4	0.69 E-4	0.89 E-4
b	2.70	2.55	2.37	2.72	2.18
S_b	0.0196	0.0250	0.0349	0.0274	0.0466
S_y	0.0552	0.0701	0.0986	0.0764	0.1315
r^2	0.916	0.856	0.725	0.850	0.555
n	1,744	1,747	1,7541,743	1,754	
% Outlier	0.91	0.74	0.34	0.97	0.34
t*	15.33	17.87	18.01	10.23	17.65

The t*-values listed in Table 2 are all larger than the tabulated value of 2.576; thus, at the 1% error level, "b" is significantly different from 3. This shows that green mussel growth, when using the anterior/posterior axis as unit of length, is not isometric.

Table 3 summarizes the results of the height/weight relationships. It is interesting to note that the regression of height on total weight (i.e., shell + flesh + cavity water) results in a value of b = 2.98 which is not significantly different from 3 at the 1% level. The value of b in the height/shell relationship was also quite close to but significantly different from 3.

Table 3. Height/weight relationships of *Perna viridis* ("% outlier" denotes number of records in per cent excluded from analysis; reference value of t-distribution: $t_{\infty,0.01}$ = 2.576).

Function	$Y = a \cdot X^b$				
X-Variable Y-Variable	Height Total	Height FL & SH	Height Flesh	Height Shell	Height Dry wt
a	8.69 E-4	7.48 E-4	8.66 E-4	2.04 E-4	3.28 E-4
b	2.98	2.87	2.56	3.09	2.35
S_b	0.0232	0.0262	0.0400	0.0260	0.0523
S_y	0.0591	0.0663	0.1026	0.0655	0.1345
r^2	0.905	0.873	0.702	0.891	0.535
n	1,744	1,742	1,748	1,738	1,754
% outlier	0.91	1.02	0.68	1.25	0.34
t*	0.77	5.14	10.87	3.41	12.49

Tables 4 and 5 give an overview of how the various weight units are related to each other when fitted by a linear function of the form given in equation (1).

Even though the regression parameters "a" and "b" can be used to convert one unit of weight into another one, the relatively low

Table 4. *Perna viridis:* Summary of regression coefficients for the conversion of total weight to lower weight units. ("% outlier" denotes number of records in per cent excluded from analysis.)

Function	$Y = a + b \cdot X$			
X-Variable Y-Variable	Total FL & SH	Total Flesh	Total Shell	Total Dry wt
a	1.028	0.969	- 0.008	0.292
b	0.53	0.19	0.34	0.03
S_b	0.0038	0.0030	0.0021	0.0007
S_y	1.5981	1.2363	0.8660	0.2986
r^2	0.917	0.711	0.938	0.479
n	1,736	1,748	1,727	1,728
% outlier	1.36	0.68	1.88	1.82

Table 5. *Perna viridis:* Summary of regression coefficients for the conversion of Flesh & Shell, Shell, and Flesh to lower weight units. ("% outlier" denotes number of records in per cent excluded from analysis.)

Function	$Y = a + b \cdot X$					
X-Variable Y-Variable	FL & SH Shell	FL & SH Flesh	FL & SH Dry wt	Shell Flesh	Shell Dry wt	Flesh Dry wt
a	- 0.292	0.292	0.137	1.199	0.297	0.069
b	0.61	0.39	0.06	0.54	0.09	0.16
S_b	0.0034	0.0034	0.0011	0.0086	0.0021	0.0020
S_y	0.7914	0.7914	0.2419	1.2614	0.2950	0.1817
r^2	0.949	0.882	0.663	0.697	0.498	0.793
n	1,745	1,745	1,724	1,746	1,725	1,727
% outlier	0.85	0.85	2.05	0.80	1.9	1.88

coefficient of determination (r^2) in some of the cases is proof of the large variations in these relationships.

Another way to perform weight conversion is to express a given weight as a fraction (in %) of the next larger units. This is demonstrated in Table 6. The values listed are the fractions (means, in %) of the weight in the corresponding row in comparison to the weight unit indicated in the column headings. Also given are the standard deviations to estimate confidence intervals in the conversion.

Of the 1,760 samples, 735 were males and 945 were females. In 80 cases, the sex could not be identified beyond doubt. The sex ratio was 44% male to 56% female.

To test whether sexual dimorphism occurred, the mean length and height of both females and males was computed separately and the results compared. They showed no significant difference at the 1% error level.

Table 6. *Perna viridis:* Summary of various weights expressed in mean per cent of higher weight units (second value denotes standard deviation.)

	Total	FL & SH	Flesh
FL & SH	58.00		
	± 7.65		
Shell	33.75	58.55	
	± 4.32	± 5.97	
Flesh	24.25	41.45	
	± 5.73	± 5.97	
Dry wt	4.40	7.51	18.02
	± 1.47	± 2.04	± 3.62

As the dry weight of the green mussel meat is strongly affected by the condition of the gonads, the mean dry weights per month were plotted along a time axis for both females and males. Even though the course of both curves was synchronized, males had a consistently higher dry weight than females.

Discussion

When recording the weight of mussels, much attention has to be paid to the time between the moment the animal is removed from the water and thé actual weighing. Mussels keep water within their shell for some time. As Table 6 shows, the average weight of this water makes up 42 per cent of the total initial weight, with extreme cases as high as 50 per cent.

Table 7 summarizes previously published values of the coefficients "a" and "b" for *Perna*. The values of "b" show considerable variation, ranging from 2.37 (Lee 1985) to 2.86 (Narasimham 1981).

Table 7. Compilation of the coefficients "a" and "b" of the allometric length/weight relationship in *Perna* from various locations. (Adapted from published data.)

Species	Location	a	b	Length units	Source
Perna viridis	Hong Kong	1.12E-03	2.37	mm	Lee (1985)
	India, Goa	5.13E-04	2.50	mm	Parulekar et al. (1982)
	India, Kakinada Bay	1.63E-04	2.86	mm	Narasimham, K.A. (1981)
	Malaysia, Penang	2.22E-04	2.76	mm	Choo and Speiser (1979)
	Singapore	9.81E-02	2.79	cm	Cheong and Chen (1980)
	Thailand, upper Gulf	7.07E-02	2.78	cm	Chonchuenchob et al. (1980)
Perna canaliculus	New Zealand, Ahipara	2.14E-04	2.80	mm	Hickman (1979)

This might partly be explained through the influence of ecological factors such as density, shore level, etc. Such ecological differences were demonstrated by Hickman (1979) who compared wild stocks and raft-grown populations of *Perna canaliculus*.

Another source of variation, however, might be the effect that the cavity water has on the final result. As the figures in Table 2 show, the value of "b" may range from 2.55 to 2.70 for the same animal, depending on the amount of water included in the measurement of weight.

The factor "cavity water", therefore, introduces a considerable error into the data analysis. This also becomes obvious when expressing the weight of the mussel meat (Flesh) in per cent of "total weight": this can be anything between 24% and 41%, depending on how much water the mussel lost prior to weighing. To avoid this problem, "total weight" should be defined (and measured) as the weight of the green mussel with its shell forced open (by severing the adductor muscle) and drained of water.

The exponent "b" of the size/weight relationship in *Perna viridis* is generally different from 3 as shown in Tables 2 and 3. Growth analysis of green mussel based on a model that involves the parameter "b" should, therefore, be checked on its assumption concerning the value of the exponent "b". If a model applied assumes b = 3 and does not provide for any adjustment for a different exponent, it would be more appropriate to use "Height" as the reference length with b = 2.87 as the coefficient of the size/weight relationship. This value comes at least close to the (assumed) value of b = 3.

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