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ARTICLE

Biometric Relationship of *Tegillarca granosa* (Bivalvia: Arcidae) from the Northern Region of the Strait of Malacca

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Abstract

This study on the growth pattern of the blood cockle *Tegillarca granosa* focused on the aspects of biometric prints on the shell, which aimed to predict the growth of the *T. granosa* population in the northern region of Malacca Strait. The local sample populations of the cockle were collected in three different intertidal areas called Lhokseumawe and Banda Aceh in Indonesia and Pulau Pinang in Malaysia. The biometric analysis showed that the length–weight relationship model of *T. granosa* populations in this region indicated that the cockle population generally had a negative allometric growth pattern ($b < 3$) or that shell length is more dominant compared to shell weight. Therefore, the result showed that the growth performance of *T. granosa* was not ideal, and the highest b value (the coefficient of biometric relationship) was recorded in Lhokseumawe, followed by Banda Aceh and Pulau Pinang. The value of the coefficient b could be affected by various factors such as environmental conditions, adaptation, and dietary patterns. Cluster analysis revealed that the population of *T. granosa* from the northern region of the Strait of Malacca was divided into two clusters, which were *T. granosa* from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and *T. granosa* from the Western Strait of Malacca (Pulau Pinang in Malaysia). The factors that might cause the differences in the biometric component of both clusters were at the geographical level on the source of population and local environmental parameters.

Keywords Blood cockle · Bivalvia · Morphometric · Growth model · Malacca Strait

1 Introduction

Tegillarca granosa is one of the important fishery commodities in several areas of Southeast Asia. This species has been cultivated in countries such as Malaysia and Thailand due to limited natural stocks. However, this species in Indonesia is still harvested directly from nature (Broom 1983; Khalil et al. 2017). Nevertheless, annual harvested-cockle data reveal a reduction in natural stocks in the last decade. One of the main factors for the significant reduction in natural stocks is overharvesting due to the high demand as a protein source. This condition may also be a result of the lack in management in controlling the wild cockle population stock. Therefore, the management of this species is required for the sustainability of this important species. Comprehensive information on biometrics (morphometric relationship pattern of the species) is necessary to predict the annual recruitment, as well as to interpret growth, mortality, reproductive biology, and survival data in the marine culture of species (Kim et al. 2006; Peharda et al. 2007; Pinn et al. 2005; Zelditch et al. 2004).

Length–weight is an essential variable for comparing growth, physiological processes, and environmental factors that affect aquatic organisms (Hemachandra and Thippeswamy 2008). Growth of bivalves can be defined as the increase of the length size of the shell and body weight (body mass) and these indicators have also been used extensively

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as corresponding parameters to assess their growth (Bailey and Green 1988; Bayne and Worrall 1980; Garton and Haag 1991; Smit et al. 1992). Measuring the length and weight of aquatic species is used to evaluate the growth patterns of species quantitatively. Such relationships are expressed via the data distribution of shell length and cockle weight. These data also represent the ratio of the addition of an animal's body size by period. Length and weight relationships have several purposes, namely (1) for measuring the weight and length ratio of a species to the weight–length in Taxa class (Anderson and Neumann 1996; Shine 1990), and (2) for age (Pauly 1983).

The length and weight relationship allows life history and morphological differences to be identified between species and populations from different habitats (Beukema and Meehan 1985; Gaspar et al. 2002; Holopainen and Hanski 1986). This study sought to analyze the biometric relationship of *T. granosa* using a morphometric relationship and dendrogram analysis of specimens collected from the northern region of the Strait of Malacca.

2 Materials and Methods

2.1 Samples Collection

The specimens of *T. granosa* (120 specimens/month) were collected monthly from Jun 2009 till Sep 2010 from the muddy natural habitat in Banda Aceh (5°32′34.67″N–95°17′2.54″E), Lhokseumawe (5°09′35.3″N–97°08′29.4″E) in Aceh Province, Indonesia and Pulau Pinang (5°16′9.66″N–100°23′27.37″E) in Malaysia (Fig. 1). The selection of these three sampling areas was based on the geographical distribution characteristics of *T. granosa* in the northern region of the Malacca Strait. Banda Aceh and Lhokseumawe sampling areas share similar features such as larger coastal mudflat areas exposed during all low tides, minimum wave action, high salinity waters surrounded by mangroves patches and such locations are a natural habitat for *T. granosa*. Meanwhile, Pulau Pinang sampling area is differentiated by larger cockle culture plots which were continuously submerged underwater and composited by muddy substrate with no wave action, located near industrial zones and are thought to be disturbed by human activities.

The total number of specimens sampled was 1920, with cockle sizes ranging from 38–71 mm in length. The specimens were collected at a depth of 5–30 cm, and salinity ranged from 10–33 ppt. The live samples were collected manually with the aid of a harrow during the low tide period. After collection, the specimens were stored in isotherm containers and directly transferred to the laboratory. The samples were cleaned from mud and organisms attached to the shell were removed in the laboratory, then reared in the aquarium where biometric values were continuously recorded (Fig. 2), including shell length, shell thickness, cockle height, fresh tissue weight, wet cockle weight, and sex category. The measurement of length and width of the cockle was taken with a digital Vernier caliper with an accuracy of 0.1 mm, and the cockle weight tissue was weighed using a digital weighing scale (in grams). The length was defined as the maximum shell length (measured from the posterior margin to the anterior margin of the cockle); the thickness was measured on the inflating position, from the most protruding part on the top of the cockle to the most protruding portion on the bottom of the cockle. The height was measured from the highest ventral margin of the cockle towards the dorsal margin of the cockle.

2.2 Morphometric Relationship

The morphometric ratio of *T. granosa* between length: height, length: thickness and height: thickness was analyzed using the following formula:

$a = L/H$, $a = L/C$ and $a = H/C$where: L = shell length, H = shell height, C = shell thickness, a = index (coefficient).

The growth pattern of the cockle was able to be designated through the relationship of shell length and cockle body weight (wet weight), which was analyzed through the equation of power regression (Ricker 1975). From the results, it could be determined if the growth rate of cockle length balanced with the cockle weight or the ratio (between length and weight) could be formulated in the mathematical expression $b = 3$, and if so then it was assumed that the cockle growth was isometric. Whereas if $b \neq 3$, it was allometric, which means the growth of cockle length was not proportionate to the weight. To test whether the constants were $b = 3$ or $b \neq 3$ (isometric or allometric), a statistical test was performed through a statistical *t*-test. The equation above applied both to the whole cockle and by sex. Based on the statistical *t*-test, the hypotheses used were:

H_0: $b = 3$, shell length and cockle weight relationship was isometric

H_1: $b \neq 3$ mean shell length and cockle weight relationship was allometric (namely: positive allometry), if $b > 3$ meant that the growth of cockle weight was faster than the growth of shell length (namely: negative allometry) and if $b < 3$ meant the growth of shell length was faster than the cockle weight.

2.3 Environmental Parameter Measurement

Maximum and minimum seawater temperatures were measured daily using a portable max–min thermometer fixed in the sampling areas. Seawater salinity, pH, and dissolved oxygen were assessed regularly using a handheld

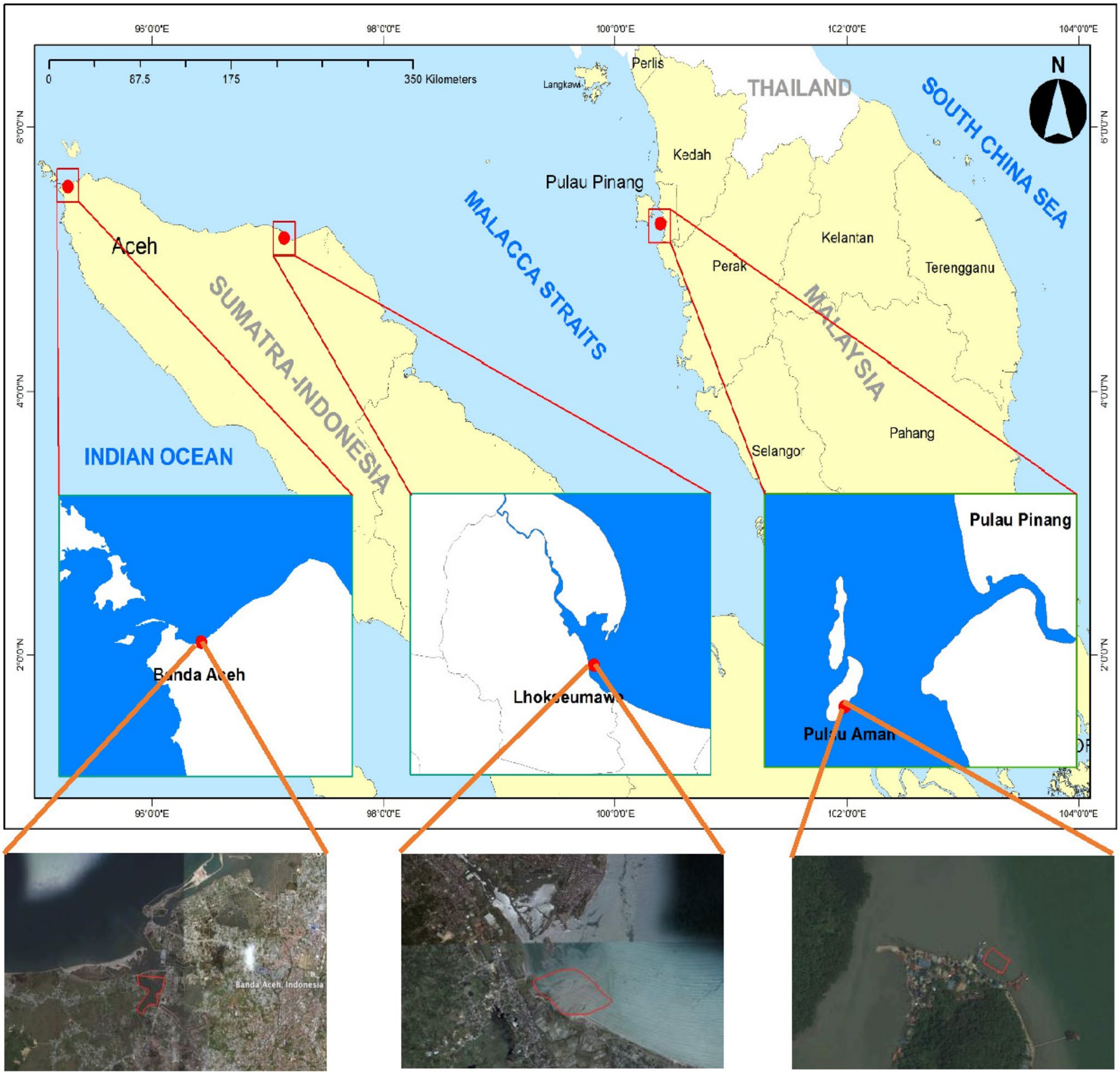

Fig. 1 *Tegillarca grannosa* sampling location in the northern region of the Strait of Malacca

Multiparameter Portable Meter (Hanna HI-9828) at the study sites, where turbidity was measured with a turbidity meter (Turbidity meter 800-ESD). Monthly analyzes of dissolved nutrients for ammonium, nitrate, nitrite, and phosphate concentrations were performed using standard methods (Brewer and Riley 1965; Grasshoff 1976; Mantoura and Woodward 1983; Kirkwood 1989; Zhang and Chi 2002). Phytoplankton samples were obtained monthly from mid-surface water by towing a plankton net (mouth diameter 0.35 m) made of bolting silk (No. 30, mesh size: 48 μM) for 30 min and preserved using Lugol's solution. Phytoplankton cell density was measured monthly using a hemocytometer and a compound microscope following the Martinez et al. (1975) protocol.

2.4 Statistical Analysis

The raw data obtained were collected and put into a package of Microsoft Excel 2011 software Macintosh version to be processed and analyzed. Statistical analysis of Co-Variant was used to determine significant differences in the values obtained in each collected group data. The determining factor used in this study was the population differences in the three different regions. Therefore, the coefficients *a* and *b*

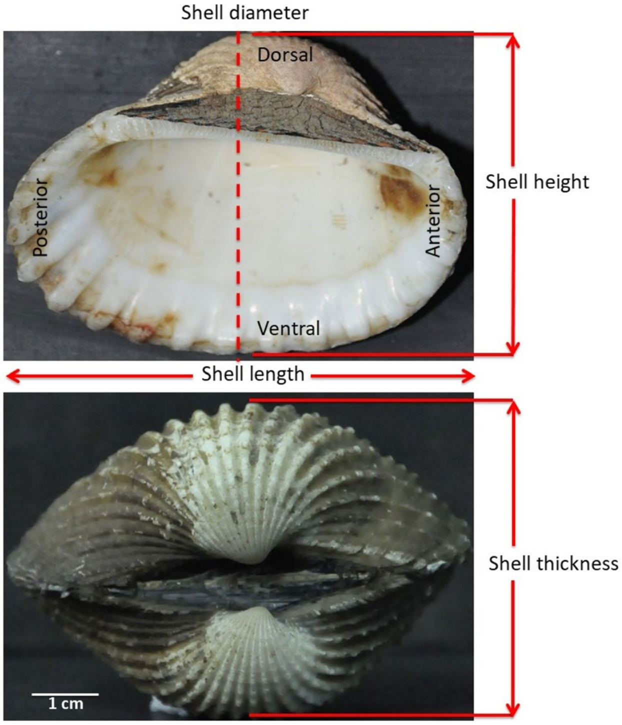

Fig. 2 Biometric of *Tegillarca grannosa*

were analyzed by observing the growth differences in population and sex differences in the sample (male, female, or neutral). The statistical test was continued by the post hoc test to determine which factor significantly differed in one particular parameter.

The parametric statistical test of Co-Variant analysis was analyzed using the package of SPSS (Statistical Package for the Social Science) software version 23.0 Macintosh version. Relationships existed between two variables: the relationship between the *b* coefficient (relationship of shell length and cockle weight) and environmental factors in the sampling area. Hypothesis testing was then performed on the sample parameters to test the significance of correlation at the level of 95% ($P = 0.05$). The statistical *t* test was used to find significant differences in the pattern of change in the *b* coefficient that was the growth nexus of shell length and cockle weight of each sampling area.

Cluster analysis through the dendrogram diagram was designed to clarify the relationship between each biometric component (Ramesha and Thippeswamy 2009) regarding *T. granosa* from the northern region of the Strait of Malacca. Cluster analysis was processed using SPSS software.

3 Results

3.1 Equality *a* and *b* Coefficients from Different Populations

The biometric studies of *T. granosa* (from Jun 2009–Sep 2010) from the northern region of the Strait of Malacca involving 1920 individuals consisted of 756 males, 974 females, and 190 neuters. The statistical analysis showed that *T. granosa* shell height: shell length relationship from three sampling areas revealed a dissimilar coefficient *a*, but the coefficient *b* was similar. Furthermore, the relationship of shell thickness: shell length of *T. granosa* populations showed that the coefficients *a* and *b* were identical between populations. In contrast, the relationship of shell thickness: shell height coefficient (*a* and *b*) values in terms of their allometric equations showed differences between populations (Table 1).

3.2 Morphometric Coefficients Model from Different Populations

T. granosa weight and shell length relationship analysis showed no differences in coefficient *a* and *b* values between populations (Table 2). A statistical test was performed on the coefficient *b* through a *t* test indicating the coefficient $b < 3$ or negative allometry in all *T. granosa* populations. This condition showed that the growth of cockle shell length was faster or more dominant compared to the growth of cockle weight. A further test of the hypothesis also showed that H_0 was rejected ($P < 0.05$) and indicates that the growth rate of shell length and cockle weight was in an overall imbalance.

Table 1 Equality *a* and *b* coefficients in the biometric model from different populations

Model	Banda aceh		Lhokseumawe		Pulau pinang		ANCOVA's *F*, df, *p*	
	$a \pm Sea$	$b \pm \mathrm{Se}b$	$a \pm \mathrm{Se}a$	$b \pm \mathrm{SE}b$	$a \pm \mathrm{SE}a$	$b \pm \mathrm{SE}b$	*a*	*b*
$\mathrm{SH} = a \times \mathrm{SL}^{\mathrm{b}}$	1.662 ± 4.031	0.765 ± 0.088	7.487 ± 8,107	0.650 ± 0.125	10.832 ± 5.863	0.502 ± 0.146	7.155, 1, 0.011	3.220, 1, 0.080
$\mathrm{ST} = a \times \mathrm{SL}^{\mathrm{b}}$	1.820 ± 4.640	0.646 ± 0.103	5.902 ± 8.240	0.574 ± 0.139	13.458 ± 5.418	0.362 ± 0.142	0.827, 1, 0.368	1.099, 1, 0.301
$\mathrm{ST} = a \times \mathrm{SH}^{\mathrm{b}}$	0.924 ± 3.313	0.831 ± 0.089	3.101 ± 7.191	0.797 ± 0.165	3.283 ± 3.661	0.796 ± 0,127	11.850, 1, 0.001	16.408, 1, 0.00

Table 2 Equality a and b coefficients in the biometric model from different populations

Model $W = a \times L^b$	Banda aceh		Lhokseumawe		Pulau pinang		ANCOVA's *F*, df, *P*	
	$a \pm Sea$	$b \pm$ Seb	$a \pm$ Sea	$b \pm$ SEb	$a \pm$ SEa	$b \pm$ SEb	a	b
Whole sample	0.0016 ± 0.0025	2.6178 ± 0.2095	0.0015 ± 0.0328	2.7629 ± 0.3894	0.0061 ± 1.4319	2.2018 ± 0.5866	0.510, 1, 0.479	2.752, 1, 0.105
Males	0.0015 ± 0.0079	2.6306 ± 0.2831	0.0008 ± 0.1961	2.7713 ± 0.567	0.0127 ± 2.9646	2.0043 ± 0.889	0.002, 1, 0.961	0.332, 1, 0.568
Females	0.0019 ± 0.0069	2.5695 ± 0.3368	0.0009 ± 0,0447	2.7559 ± 0.3838	0.0033 ± 2.5539	2.3697 ± 0.7607	0.135, 1, 0.715	0.023, 1, 0.881
ANCOVA's *F*, df, *P*	1.570, 1, 0.217	4.386, 1, 0.042	2.966, 1, 0.092	2.878, 1, 0.097	2.985, 1, 0.091	0.324, 1, 0.572	–	–

3.3 Environmental Parameter

Seasonal variations of environmental parameters in the sampling areas are presented in Table 3. Water temperature, salinity, and phytoplankton density fluctuated significantly compared to other environmental parameters during the study period.

4 Discussion

4.1 Biometric Relationship Model of *Tegillarca granosa*

Biometric data analysis of *T. granosa* from the northern region of the Strait of Malacca showed that the cockle growth model was negative allometry. The growth of shell length was more dominant than the growth of cockle weight. The growth model generated from the three sampling sites showed that the value of the b coefficient was less than 3 ($b < 3$). The balance value of the b coefficient generally has a range between 2.4 and 4.5 (Wilbur and Owen 1964), and when the b value is equal to 3 ($b = 3$), the relationship of shell length and cockle weight is isometric (Carlander 1969). In this study, the b coefficient differs within a population or when compared to other populations. The cockle population from Lhokseumawe had a higher b coefficient ($b = 2.7629 \pm 0.3894$) compared to the cockle population from Banda Aceh ($b = 2.6178 \pm 0.2095$) and the cockle population from Pulau Pinang ($b = 2.2018 \pm 0.5866$). According to sexual orientation, a similar condition was presented, although both male and female *T. granosa* from Lhokseumawe had the highest b coefficient (male $b = 2.7713 \pm 0.567$, female 2.7559 ± 0.3838) compared to other sampling locations (Banda Aceh male $b = 2.6306 \pm 0.2831$, female $b = 2.5695 \pm 0.3368$; Pulau Pinang male $b = 2.0043 \pm 0.889$, female $b = 2.3697 \pm 0.7607$). These b coefficient results indicated that the cockle growth rate in Lhokseumawe was more appropriate or suitable compared to the other two sampling areas. The b coefficient value of biometric relationships is characteristically compared between dimensional growth of related or similar species in various geographical areas (Ramesha and Sophia 2015).

The contrary conditions could be found among cockles from the Pulau Pinang area, where the value of the b coefficient was lower than the range value of the b coefficient for most bivalves at 2.4–4.5 that was described by Wilbur and Owen (1964), causing the cockle shell length against cockle weight showed an unbalanced conditioncausing the cockle shell length against cockle weight showed an unbalanced condition. Shell length growth was faster than the increase of the cockle body volume, causing the cockle to be unhealthy. Factors such as reproductive biology (Rueda and Urban 1998) and the physical and biological variables of a habitat (Seed 1968; Thorarinsdottir and Johannesson 1996) are recognized as affecting growth and can change the allometry relationship between the shell length and the cockle weight in bivalvia. Water quality analysis showed that a faster increase in shell length compared to body weight was due to the fluctuation in environmental conditions in cockle habitats. Furthermore, the environmental circumstances were unsuitable for cockle growth due to an increased level of nutrients that exceeded the standard rate for marine life. Based on observations, the high concentration of nutrients is potentially toxic to the cockles and could affect cockle growth. Environmental aspects have been identified as the main factor that affects shell development in bivalves. The shell size and shape are affected by the variation of ambient environmental constraints (Wilbur and Owen 1964; Seed 1968).

Furthermore, the variety of growth patterns of *T. granosa* highly correlates to factors of food availability, temperature, salinity, pollution materials, and reproductive activities (Broom 1982; Day and Fleming 1992; Tarr 1995). The phytoplankton density changes were expected to be the primary regulator of the fluctuation of the b coefficient from all sampling areas. The Pearson correlation test showed the opposite circumstance: the b coefficient was strongly correlated

Table 3 Ranges of the seasonal environmental parameter at the sampling areas (average ± st.dev)

Environmental parameter	June 2009	July 2009	August 2009	September 2009	November 2009	October 2010	December 2009	January 2010	February 2010	March 2010	April 2010	May 2010	June 2010	July 2010	August 2010	September 2010	Average ± st.dev
Temperature (°C)																	
Banda aceh																	
Minimum	26.32	24.27	24.29	25.43	26.90	25.00	25.39	25.79	22.96	22.84	25.47	21.87	25.90	22.82	25.27	26.00	24.78 ± 1.98
Maximum	30.97	30.44	30.45	29.88	32.61	31.93	31.95	32.48	32.93	32.10	31.40	31.03	30.93	32.11	30.98	30.38	31.41 ± 1.37
Lhokseumawe																	
Minimum	28.82	28.82	26.81	28.07	27.71	27.03	28.45	28.06	28.96	28.48	28.60	28.23	27.95	28.23	27.23	27.40	28.05 ± 2.02
Maximum	31.08	31.71	30.06	31.17	30.87	30.33	30.81	30.68	30.75	31.10	30.90	31.65	31.27	31.39	30.84	31.17	30.99 ± 1.28
Pulau Pinang																	
Minimum	27.23	27.52	26.65	27.10	25.87	27.93	26.05	23.68	25.61	26.74	26.37	26.29	26.67	26.74	26.65	27.37	26.53 ± 1.94
Maximum	31.63	31.10	31.45	30.60	30.90	31.43	30.58	28.35	30.46	31.71	31.13	30.68	31.53	31.32	31.45	31.30	30.98 ± 1.32
Salinity (ppt)																	
Banda aceh	32.27	31.35	29.98	27.47	30.06	27.20	26.45	29.68	31.50	31.16	29.30	30.71	30.85	31.29	30.45	28.27	29.87 ± 3.23
Lhokseumawe	31.00	30.97	31.16	31.20	31.03	29.07	30.94	31.16	31.46	31.84	30.57	31.26	30.90	30.81	30.65	31.27	30.95 ± 1.04
Pulau Pinang	29.33	28.52	26.39	26.87	27.35	26.13	25.23	28.06	29.00	28.94	28.67	26.48	29.70	29.32	31.06	30.40	28.22 ± 2.97
pH																	
Banda aceh	7.65	8.02	8.03	8.17	7.80	8.02	7.91	8.17	8.08	8.06	8.02	7.97	7.74	8.27	7.94	8.23	8.01 ± 0.17
Lhokseumawe	8.13	7.88	8.04	8.06	8.17	8.13	7.98	8.21	7.89	8.18	7.91	7.84	8.08	7.93	7.99	8.13	8.03 ± 0.13
Pulau Pinang	8.02	7.49	7.85	8.14	8.04	8.07	7.79	8.02	7.95	7.86	8.08	8.21	7.91	7.86	7.33	7.54	7.89 ± 0.25
Dissolved oxygen (mg/L)																	
Banda aceh	6.53	6.81	6.96	6.05	5.97	6.12	6.05	5.95	6.10	5.84	6.23	5.86	6.68	5.84	6.32	5.47	6.17 ± 0.40
Lhokseumawe	6.01	6.38	6.47	6.14	6.28	6.04	6.07	6.10	6.97	6.02	6.17	5.98	6.02	5.89	6.28	6.13	6.18 ± 0.25
Pulau Pinang	7.20	5.20	5.20	4.90	5.13	5.21	5.09	5.29	5.20	5.64	5.87	5.39	7.67	5.64	6.29	5.87	5.67 ± 0.78
Turbidity (NTU)																	
Banda aceh	17.40	29.30	8.61	9.02	10.86	9.12	19.16	14.09	16.03	10.27	18.98	13.83	10.27	34.29	9.74	10.48	15.09 ± 7.43
Lhokseumawe	43.20	30.50	36.50	66.90	31.60	15.18	103.00	93.67	29.13	37.30	64.92	38.95	35.30	49.98	46.90	98.30	51.33 ± 25.24
Pulau Pinang	29.30	17.36	15.11	13.09	17.27	74.30	57.80	77.10	109.67	107.00	98.00	76.00	103.40	107.00	76.65	93.12	67.01 ± 36.44
Orthophospate (mg/L)																	
Banda aceh	0.05	0.03	0.04	0.13	0.03	0.02	0.00	0.40	0.00	0.07	0.13	0.07	0.03	0.09	0.08	0.53	0.11 ± 0.15
Lhokseumawe	0.05	0.01	0.02	0.07	0.01	0.01	0.01	0.70	0.00	0.04	0.06	0.04	0.04	0.08	0.07	0.01	0.08 ± 0.17
Pulau Pinang	0.10	0.05	0.08	0.06	0.03	0.01	1.00	0.01	0.16	0.13	0.09	0.08	0.52	0.13	0.15	0.81	0.21 ± 0.29
Nitrate (mg/L)																	
Banda aceh	0.71	0.03	0.11	0.73	0.75	0.01	0.04	0.05	0.05	0.09	0.23	0.63	0.18	0.05	0.53	0.65	0.30 ± 0.31
Lhokseumawe	0.68	0.14	0.03	0.03	0.20	0.01	0.00	0.03	0.01	0.10	0.77	0.58	0.10	0.17	0.07	0.98	0.24 ± 0.24
Pulau Pinang	0.80	0.02	1.30	0.73	0.03	2.02	0.03	1.02	0.11	0.14	0.61	0.42	0.64	0.14	0.65	1.76	0.65 ± 0.62
Nitrite (mg/L)																	
Banda aceh	0.05	0.02	0.02	0.03	0.75	0.01	0.03	0.03	0.03	0.03	0.05	0.05	0.05	0.03	0.04	0.05	0.08 ± 0.17

Table 3 (continued)

Environmental parameter	June 2009	July 2009	August 2009	September 2009	Novem-ber 2009	October 2010	December 2009	January 2010	February 2010	March 2010	April 2010	May 2010	June 2010	July 2010	August 2010	Septem-ber 2010	Average ± st.dev
Lhokseumawe	0.03	0.03	0.04	0.04	0.05	0.03	0.44	0.03	0.43	0.02	0.08	0.07	0.02	0.08	0.03	0.04	0.09 ± 0.14
Pulau Pinang	0.03	0.03	0.04	0.06	1.09	1.68	0.18	1.00	0.13	0.12	0.09	0.03	0.14	0.12	0.39	0.87	0.37 ± 0.50
Ammonia (mg/L)																	
Banda aceh	0.87	0.20	0.16	0.15	0.11	0.68	0.06	0.13	0.08	0.09	0.19	0.79	0.18	0.06	0.59	0.13	0.28 ± 0.27
Lhokseumawe	0.19	0.17	0.25	0.25	0.14	0.35	0.23	0.30	0.19	0.27	0.39	0.49	0.27	0.21	0.43	0.24	0.27 ± 0.10
Pulau Pinang	0.24	0.18	0.14	0.25	0.42	0.11	0.61	0.15	0.68	0.54	0.65	0.98	0.65	0.54	0.82	0.65	0.48 ± 0.27
Phytoplankton density (cell/L)																	
Banda aceh	1831.67	1446.67	851.67	1178.33	630.00	991.67	1201.67	385.00	1773.33	1388.33	1516.67	1785.00	1738.33	1283.33	1341.67	1108.33	1278.23 ± 433.14
Lhokseumawe	1656.67	1365.00	711.67	2601.67	3010.00	1435.00	4001.67	1365.00	2986.67	2415.00	2333.33	2298.33	2415.00	1050.00	1003.33	2310.00	2059.90 ± 225.33
Pulau Pinang	4340.00	4001.67	1470.00	11,713.33	4340.00	4281.67	2636.67	4561.67	4235.00	5751.67	5693.33	6090.00	5728.33	5751.65	2905.00	7910.00	5088.12 ± 937.89

to phytoplankton density in Banda Aceh ($r = 0.766$). In comparison, the phytoplankton density showed a moderate correlation with the *b* coefficient for cockles from Lhokseumawe ($r = 0.532$) and Pulau Pinang ($r = 0.579$). The phytoplankton density was expected to be a limiting factor for growth activity. Phytoplankton is used as an energy source for the growth process of shell length and cockle weight. The supply of food sources is considered an essential factor for sustainable growth (Seed and Suchanek 1992; Widdows and Johnson 1988).

Changes in the *b* coefficient fluctuation were also expected to reveal a relationship with the reproduction period. Sudden changes in the value of the *b* coefficient meant that there was a rapid change in the cockle weight tissue due to the meager biomass of cockles. Weight reduction of the cockle volume could be caused by the reproduction process, such as the gamete production process and gonad or gamete process being in a state of inactivity. In bivalve animals, gonadal growth and gonadal maturation process results in increased tissue mass density and increased tissue weight. Changes in the value of the *b* coefficient indicates the beginning of the activities of gonadal maturation and growth in bivalve animals (Hemachandra and Thippeswamy 2008; Hickman and Illingworth 1980).

The total cockle weight is described as the total shell weight, including the weight of cockle meat. In *T. granosa*, the shell weight was generally heavier than the meat weight. When the shell size increased, then the overall weight of the cockle also increased linearly. However, the analysis of the samples showed no significant weight increase despite the increased shell size. This condition was assumed to be the result of the increased volume of cockle meat that did not gain or develop linearly, causing the shell length growth was not in-line with the cockle weight.

The growth pattern is not always fixed for species. Differences in growth models might appear in the same or different species, among sex, indifferent or the same locations and in different seasons. The difference in latitudinal gradient is also related to the shell size, reproduction level and reproductive cycle in bivalves (Kanazawa and Sato 2008; Mirzaei et al. 2017) as well as the growth pattern models of cockles in these three sampling areas. Cockles from Banda Aceh and Lhokseumawe had morphological differences compared to the cockles from Pulau Pinang. *T. granosa* from Banda Aceh and Lhokseumawe had special shell features that were thicker and wider compared to *T. granosa* cockles from Pulau Pinang. Other studies on the relationship in length and weight regarding some *Tegillarca* species have demonstrated diversity and differences in growth patterns (Table 4).

The value of the *b* coefficient on the relationship of shell length and cockle weight noted in this study was lower than that recorded in other species in the same family, namely *Tegillarca granosa* ($b = 2.82$) from Korean waters. Another

Table 4 The length-weight relationship model for Arcidae

Family/species	*n*	Allometric models	R^2	Relationship model	Location	References
Arcidae						
Scapharca broughttonii	88	$W = 0.000073L^{3.31}$	0.943	(+) Allometric	Korea	Park and Oh (2002)
Scapharca subcrenata	114	$W = 0.0004L^{2.97}$	0.935	Isometric	Korea	Park and Oh (2002)
Tegillarca granosa	377	$W = 0.00068L^{2.82}$	0.960	(−) Allometric	Korea	Park and Oh (2002)
Tegillarca granosa	640	$W = 0.0016L^{2.618}$	0.884	(−) Allometric	Banda Aceh, Indonesia	Current research
Tegillarca granosa	640	$W = 0.009L^{2.763}$	0.924	(−) Allometric	Lhokseumawe, Indonesia	Current research
Tegillarca granosa	640	$W = 0.061L^{2.202}$	0.735	(−) Allometric	Pulau Pinang, Malaysia	Current research

difference was also found in their relationship model, namely *Scapharca* from Korean water, which had positive allometry and isometric relationships, while *T. granosa* from the northern region of the Strait of Malacca displayed negative allometry. Different growth patterns at different latitudes might be caused by the influence of environmental factors, changes in the composition of the food, and competition between individuals in a particular habitat.

4.2 Relationships of the Biometric Component of *T. granosa*

Analysis of the relationship of each biometric parameter of *T. granosa* through dendrogram or classification methods (hierarchy) was used to assess the growth patterns of the three *T. granosa* populations in the northern region of the Strait of Malacca. The dendrogram was designed to clarify the relationship of each biometric component in cockles. Figure 3 shows the relationship between the biometric components of *T. granosa*. Through this analysis, the degree of dissimilarity between generated clusters is shown. The relationship between a biometric component in one cluster compared to another biometric component in a different cluster within the dendrogram was generated by the distance of the scale, e.g., if the scale value was found to be high, it is assumed that the distinction between two biometric components in two different clusters was correspondingly high.

Dendrogram analysis showed that cluster A had two sub-clusters; namely, A1 represented the biometric component of *T. granosa* from Lhokseumawe and A2 represented the biometric component of *T. granosa* from Banda Aceh, which was separated on a scale of 16. Cluster B was a hierarchy cluster of biometric components of *T. granosa* from Pulau Pinang. Cluster B was separated by cluster A on a scale of 25. The larger recorded scale means the dissimilarity of elements forming the component were higher. It showed that the growth pattern based on the biometric parameter was very different from the high level of inequality among the clusters (population) and sub-clusters (subpopulations). This condition was interpreted to mean that the *T. granosa* populations from Lhokseumawe and Banda Aceh (Indonesia) and Pulau Pinang (Malaysia) had significant differences in shell form and growth pattern and further correlated to the biometric relationship models. Gaspar et al. (2002, 2001) and Popa et al. (2010) stated that the population can be explained in particular by the growth characteristics through the measurement of biometric morphology.

It is thought that the factor that could cause variances in biometric components and thus affect *T. granosa* growth patterns between cluster A and cluster B is spatial differentiation. The source of *T. granosa* from cluster A was distinct from cluster B, where *T. granosa* populations within cluster A came from the northern region of Sumatra island, while *T. granosa* in cluster B originated from the western region of Peninsular Malaysia. Sub-clusters of A were also known to have differences in growth patterns of the biometric component; they even had close proximity. *T. granosa* of sub-clusters A1 and A2 were expected to come from the same population source. Differences in the pattern of biometric components may have occurred because of the differences in environmental factors that were local in nature, affecting the growth patterns. Differences in the range of salinity (Carmichael et al. 2004; Schöne et al. 2003), temperature (Goodwin et al. 2001; Jones et al. 1989; Kennish and Olsson 1975; Pilditch and Grant 1999; Schöne et al. 2002), and density of phytoplankton (Alunno-Bruscia et al. 2001; Carmichael et al. 2004; Grant 1996; Lorrain et al. 2000; Miyaji et al. 2007) also play a role in determining the growth pattern of cockles in the three sampling areas.

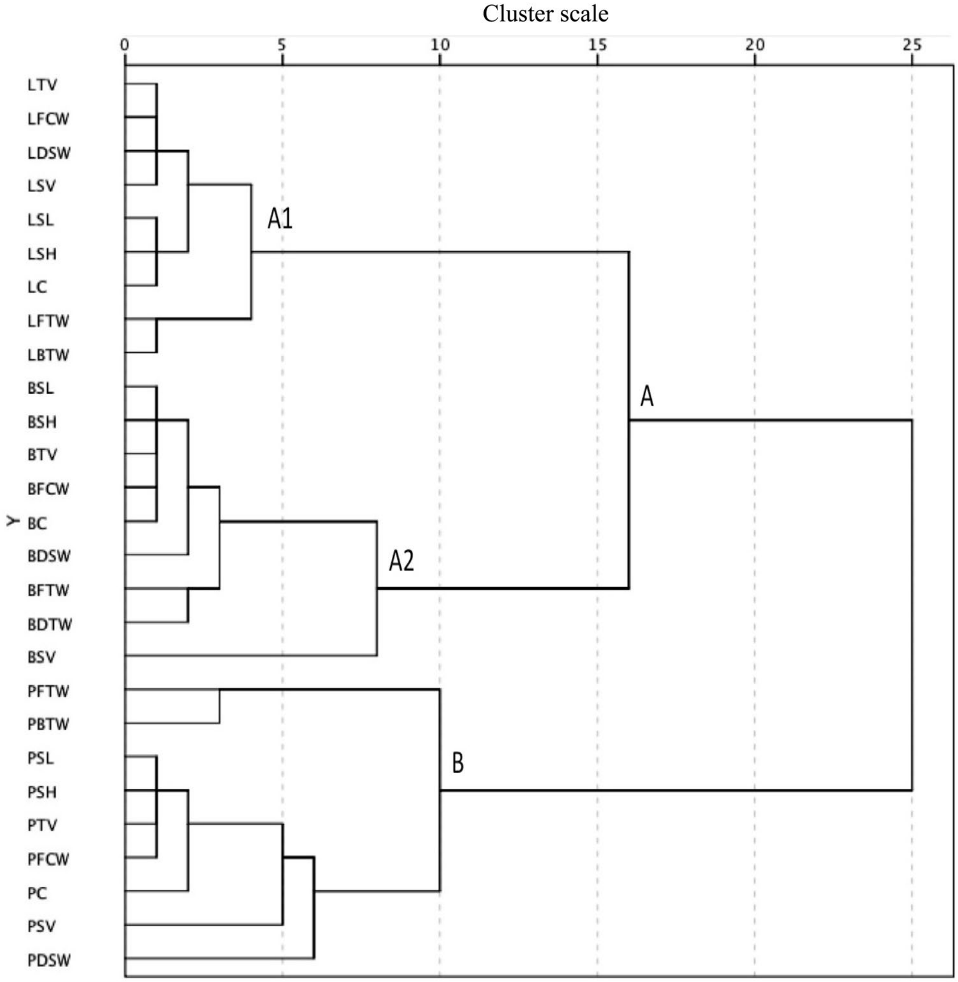

Fig. 3 Dendrogram parameter of *Tegillarca granosa* biometric relationship from the northern region of the Strait of Malacca (*A* Cluster of *Tegillarca granosa* population A, *A1 and A2* Sub-cluster of *Tegillarca granosa* population A, *B* Cluster of *Tegillarca granosa* population B). (*BSL* Banda Aceh *Tegillarca granosa* shell length, *BSH* Banda Aceh *Tegillarca granosa* shell height, *BC* Banda Aceh *Tegillarca granosa* shell thickness, *BTV* Banda Aceh *Tegillarca granosa* total volume, *BSV* Banda Aceh *Tegillarca granosa* shell volume, *BFCW* Banda Aceh *Tegillarca granosa* flesh weight, *BFTW* Banda Aceh *Tegillarca granosa* tissue weight, *BDSW* Banda Aceh *Tegillarca granosa* dry shell weight, *BDTW* Banda Aceh *Tegillarca granosa* dry tissue weight, *LSL* Lhokseumawe *Tegillarca granosa* shell length, *LSH* Lhokseumawe *Tegillarca granosa* shell height, *LC* Lhokseumawe *Tegillarca granosa* shell thickness, *LTV* Lhokseumawe *Tegillarca granosa* total volume, *LSV* Lhokseumawe *Tegillarca granosa* shell volume, *LFCW* Lhokseumawe *Tegillarca granosa* flesh weight, *LFTW* Lhokseumawe *Tegillarca granosa* tissue weight, *LDSW* Lhokseumawe *Tegillarca granosa* dry shell weight, *LDTW* Lhokseumawe *Tegillarca granosa* dry tissue weight, *PSL* Pulau Pinang *Tegillarca granosa* shell length, *PSH* Pulau Pinang *Tegillarca granosa* shell height, *PC* Pulau Pinang *Tegillarca granosa* shell thickness, *PTV* Pulau Pinang *Tegillarca granosa* total volume, *PSV* Pulau Pinang *Tegillarca granosa* shell volume, *PFCW* Pulau Pinang *Tegillarca granosa* flesh weight, *PFTW* Pulau Pinang *Tegillarca granosa* tissue weight, *PDSW* Pulau Pinang *Tegillarca granosa* dry shell weight, *PDTW* Pulau Pinang *Tegillarca granosa* dry tissue weight)

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