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--Manuscript Draft--

Manuscript Number:	OSJO-D-20-00110
Full Title:	Biometric relationship of Anadara granosa (Bivalvia: Arcidae) from the northern region of the Strait of Malacca
Article Type:	Article
Keywords:	blood cockle; bivalvia; growth model; Malacca Strait; morphometric
Abstract:	The study on the growth pattern of blood cockle Anadara granosa focused on the aspects of biometric prints on the shell, which aimed to predict the growth of A. granosa population in the northern region of Malacca straits. 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 A. granosa populations in this region indicated that the cockle population generally had a negative allometric growth pattern (b < 3) or shell length is more dominant compare to shell weight. Therefore, the result showed that the growth performance of A. granosa was not ideal, where the b value (the coefficient of biometric relationship) was highest recorded in Lhokseumawe, followed by Banda Aceh and Pulau Pinang. The value of coefficient b could be affected by various factors such as environmental conditions, adaptation and dietary patterns. Cluster analysis displayed that the population of A. granosa from the northern region of the Strait of Malacca was divided into two clusters, which were A. granosa from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and population of A. 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 geographical level on the source of population and the locality of the environmental parameter.

Abstract

The study on the growth pattern of blood cockle *Anadara granosa* focused on the aspects of biometric prints on the shell, which aimed to predict the growth of *A. granosa* population in the northern region of Malacca straits. 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 *A. granosa* populations in this region indicated that the cockle population generally had a negative allometric growth pattern (b < 3) or shell length is more dominant compare to shell weight. Therefore, the result showed that the growth performance of *A. granosa* was not ideal, where the *b* value (the coefficient of biometric relationship) was highest recorded in Lhokseumawe, followed by Banda Aceh and Pulau Pinang. The value of coefficient *b* could be affected by various factors such as environmental conditions, adaptation and dietary patterns. Cluster analysis displayed that the population of *A. granosa* from the northern region of the Strait of Malacca was divided into two clusters, which were *A. granosa* from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and population of *A. 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 geographical level on the source of population and the locality of the environmental parameter.

Keywords: blood cockle; bivalvia; growth model; Malacca Strait; morphometric

1. Introduction

Anadara 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 still harvested directly from nature (Broom 1983; Khalil et al. 2017). Nevertheless, annual harvested-cockle data designate a reduction in natural stocks in the last decade. The huge demand for this species as a protein source marks the natural stocks significantly diminished. This condition is possibly caused by insufficient controlling of wild cockle population stock. Therefore, the management of this species is required for the sustainability of this important species. Comprehensive information on biometric (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 important variable to compare among growth, physiological processes and environmental factors that affect the lives of aquatic organisms (Hemachandra and Thippeswamy, 2008). Growth of bivalves can be defined as the increase of the length size of the shell and body fweight (body mass) that have also been used extensively as the corresponding parameters to assess the growth of them (Bailey and Green 1988; Bayne and Worrall 1980; Garton and Haag 1991; Smit at al. 1992). Measuring the length and weight of aquatic species is used to evaluate the growth patterns of this species qualitatively. Such relationships are expressed via the data distribution of length and weight of the shell. 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 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 also allow the life history and morphological differences to be identified between species and among populations of different habitats and areas (Beukema and Meehan 1985; Gaspar at al. 2002; Holopainen and Hansk 1986; Morton 1985; Peters 1985). This study aimed to analyze the biometric relationship of *A. granosa* by 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 *A. granosa* (120 specimens/month) were collected monthly from June 2009 till September 2010 from the muddy natural habitat in Banda Aceh (5°32'34.67"N - 95°17'2.54"E), Lhokseumawe (05°09'35.3"N - 097°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 total number of specimens sampled was 1,920, with cockle sizes ranged from 38–71 mm in length. The sampling areas were characterized by muddy substrate surrounding by mangroves patch, no wave action and high in salinity. The specimens were collected at a depth of 5-30 cm and salinity ranged from 10-33 ppt. The live specimens were collected manually with the aid of a harrow during the low tide period. After collecting, the specimens were stowed in isotherm containers and directly transferred to the laboratory.

Insert figure 1.

In the laboratory, the samples were cleaned from mud and organisms attached to the shell. The recorded biometric values (Fig. 2) were the results of the morphological measurement of blood cockle collected from the sampling sites. The data were taken including shell length, shell thickness, cockle height, the weight of fresh tissue, wet cockle weight and sex category. The measurement instrument of length and width of the cockle was by using a digital vernier caliper with an accuracy of 0.1 mm and 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 cockle); the thickness was measured on inflating position, which was from the most protruding part on the top of cockle to the most protruding part on the bottom of cockle. The height was measured from the highest ventral margin of the cockle towards the dorsal margin of the cockle.

Insert figure 2.

2.2 *Morphometric relationship*

The morphometric ratio of *A. granosa* between length : height, length : thickness and height: thickness 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 cockle was able to be designated through a relationship of shell length and cockle body weight (wet weight), which analyzed through the equation relationship of power regression (Ricker, 1975). From the analysis results, then it was informed that if the growth rate of cockle length balanced with the cockle weight or in the mathematical expression $b = 3$, then it was said that the cockle growth was isometric. Whereas if $b \neq 3$, it was called allometric which means the growing of cockle length imbalanced with the weight. To test whether the values of 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 statistical *t*-test, the hypothesis used was:

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 $b < 3$ mean the growth of shell length was faster than the cockle weight).

2.3 Statistical Analysis

The raw data obtained was collected and put into a package of Microsoft Excel 2011 software Macintosh version to be processed and analyzed. Statistical analysis of Co-Variant Analysis 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* analyzed by observing at 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 ensure which factor significantly differed in one particular parameter.

The parametric statistical test of Co-Variant Analysis was analyzed by using the package of SPSS (Statistical Package for the Social Science) software release 23.0 Macintosh version. The relationships existed both of two variables: the relationship between the b coefficient (relationship of shell length and cockle weight) and environmental factors in the sampling area would be analyzed by this test. Hypothesis testing was then performed on the sample parameters to test whether the correlation was significant or not significant 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 growing 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) on the blood cockle so it could show the relationship between the biometric components of *A. granosa* from the northern region of the Strait of Malacca. Cluster analysis was processed by using SPSS (Statistical Package for the Social Science) software release 23.0 of the Macintosh version.

3. Results

3.1 Equality a and b coefficients from different populations

The biometric studies of *A. granosa* (from June 2009-September 2010) from the northern region of Straits of Malacca ~~had~~ involved 1920 individuals in total, consisted of 756 males, 974 females, 190 neuters. The statistical analysis showed that *A. granosa* shell height : shell length relationship from three sampling areas showed dissimilar in coefficient *a*, but there was similar to the coefficient *b*. Furthermore, The relationship of shell thickness : shell length of *A. granosa* populations showed an identical in coefficient *a* and *b* between populations. In contrast, The relationship of shell thickness : shell height coefficient (*a* and *b*) values in term of their allometric equations showed differences between populations (Table 1).

Insert Table 1

3.2 Morphometric coefficients model from different populations

A. granosa weight and shell length relationship analysis showed that there are no differences in coefficient *a* and *b* value between populations, comprised between sexes (Table 2). A statistical test was performed on the coefficient *b* through *t*-test indicating the coefficient $b < 3$ or negative allometry in all *A. 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 means the growth rate of shell length and cockle weight overall was imbalanced.

Insert Table 2

3.3 Environmental parameter

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

Insert Table 3.

4. Discussion

4.1. Biometric relationship model of Anadara granosa

Biometric data analysis of *A. granosa* from the northern region of the Strait of Malacca had shown that in general, the cockle growth model was negative allometry, in which 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 to 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 in a population or when compared to other populations. The cockle population from Lhokseumawe had a higher *b* coefficient (b = 2.7629±0.3894) compared to the cockle population from Banda Aceh (b = 2.6178±0.2095) and the cockle population from Pinang (b = 2.2018±0.5866). In the sexes level, a similar condition was presented, whereas both male and female *A. granosa* from Lhokseumawe had highest *b* coefficient (male b = 2.7713±0.567, female 2.7559±0.3838) compared to other sampling locations (Banda Aceh male b = 2.6306±0.2831, female b = 2.5695±0.3368; Pulau Pinang male b = 2.0043±0.889, female b = 2.3697±0.7607). These conditions 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 contras conditions could be seen on the cockle found from the Pulau Pinang sampling area, where the value of the *b* coefficient was lower than the range value of the *b* coefficient 2.4-4.5 that described by Wilbur and Owen (1964), causing the shell length to become imprecise. It was faster than the increase of the body volume of the cockle, causing the cockle to be unhealthy. Water quality-analyzed showed that this condition was impacted by the highest fluctuation in the environmental condition in cockle habitats. Other, the environment quality was unsuitable for cockle ~~life~~ due to increased pollution that exceeded the standards rate for marine life (Table 3). ~~At a high level, it was recognized that the nutrient could potentially be toxic to the cockle~~. Environmental aspects have been recognized as the main factor that effects 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 *A. granosa* highly correlates to factors of food availability, temperature, salinity, pollution materials and reproductive activities (Broom 1982; Day and Fleming,992; Tarr, 995). The main factor, which expected to affect changes in the value of the *b* coefficient of cockle on the sampling area, was the change of the concentration value of phytoplankton. Pearson correlation test showed the opposite condition that the *b* coefficient had a strong correlation to the density of phytoplankton in Banda Aceh (r = 0.766). While the density of the phytoplankton factor showed a moderate correlation with the *b* coefficient for cockle from Lhokseumawe (r = 0.532) and Pulau Pinang (r = 0.579). The density of phytoplankton was expected as a limiting factor for growth activity, where the phytoplankton was used as an energy source for the growth process of shell length and cockle weight. The supply of food sources is considered as an important factor for sustainable growth (Seed and Suchanek 1992; Widdows and Johnson 1988).

Changes in the fluctuation of the *b* coefficient were also expected to have 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 a few biomass of cockle. Weight reduction of the cockle volume could be caused by the reproduction process, such as gamete production process and gonad or gamete process that were in a state of inactivity. In bivalve animals, the gonadal growth and the results of the gonadal maturation process can increase the mass density of tissue as well as causes an increase in the weight of tissue overall. Exchange of the value of the *b* coefficient also 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 described as the total of shell weight, including the weight of cockle meat. In *A. 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 samples analyzed from the northern region of the Strait of Malacca showed no significant weight despite the shell size increased. This condition was assumed to be the result of the increased volume of cockle meat that did not grow or develop linearly, causing the shell length was not in line with the cockle weight overall.

The growth pattern was not always fixed for species. Differences in growth models could be found on 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 cockle in these three sampling areas. Cockles from Banda Aceh and Lhokseumawe had morphological differences compared to the cockles from Pinang. *A. granosa* from Banda Aceh and Lhokseumawe had special shell features which were thicker and wider compared than *A. granosa* cockles from Pinang. The other studies on the relationship in length and weight on some Anadara species had demonstrated diversity and differences in growth patterns (Table 4).

Insert table 4

The value of the *b* coefficient on the relationship of shell length and cockle weight noted in this study was lower than the recorded one in other species in the same family, namely *Tegilarca granosa* (*b* = 2.82) from Korean waters. Another difference was also found in their relationship model, namely Scapharca from Korean water, which had positive allometry and isometric relationships, while *A. granosa* from the northern region of the Strait of Malacca was 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 that were locality in habitat.

4.2. Relationships of the biometric component of Anadara granosa

Analysis of the relationship of each biometric parameter of *A. granosa* through dendrogram or classification methods (hierarchy) was used to analysis the growth patterns of the three *A. granosa* populations in the northern region of the Strait of Malacca. Dendrogram diagram was designed to clarify the relationship of each biometric component in blood cockles. Fig. 3 showed the relationship between the biometric component of *A. granosa*. Through this analysis, the degree of dissimilarity between generated clusters had shown. The higher the value of the generated scale, the more distance the relationship of the biometric component in a cluster with another cluster. Dendrogram analysis showed that cluster A had two sub-clusters namely A1 represented the biometric component of *A. granosa* from Lhokseumawe and A2 represented the biometric component of *A. granosa* from Banda Aceh which was separated on a scale of 16. ~~B cluster~~ was a hierarchy cluster of biometric components of *A. granosa* from ~~Pinang~~. The ~~B cluster~~ was separated by ~~A~~ on a scale of 25. The higher recorded scale means the dissimilarity elements forming the component were larger. It showed 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). Gaspar et al. (2002, 2001) and Popa ~~et~~ al. (2010) ~~state~~ that the population can be explained in particular by the growth characteristics through the measurement of biometric morphology.

Insert fig. 3.

The factor that might cause differences in biometric components between *A. granosa* populations from A and B cluster was the geographical differences of the population source to give effect on the growth pattern of the cockle. The basic source of cockle populations of A cluster was different from the B cluster population, namely *A. granosa* populations of cluster A cluster came from the northern region of Sumatra island while B cluster came from the eastern region of Sumatra or the western region of Peninsular Malaysia. A sub-clusters, they were also known to have differences in growth patterns of the biometric component; they even had close proximity. *A. granosa* cockles of A1 and A2 sub-cluster was expected to come from the same source of population. Differences in the pattern of biometric components were possible because of the differences in environmental factors that were locality in nature, affecting the growth patterns. Differences 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) are expected to play a role in determining the growth pattern of cockle in three sampling areas.

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Captions for figures

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

(Insert after line 63, page 3)

Fig. 2. Biometric of *Anadara grannosa*

(Insert after line 75, page 4)

Fig. 3. Dendrogram parameter of *Anadara granosa* biometric relationship from the northern region of Strait of Malacca

(Insert after line 241, page 10)

Captions for table

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

(Insert after line 130, page 6)

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

(Insert after line 139, page 6)

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

(Insert after line 144, page 6)

Table 4. The length-weight relationship model for Archidae.

(Insert after line 214, page 9)

Figure 1

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

Figure 2

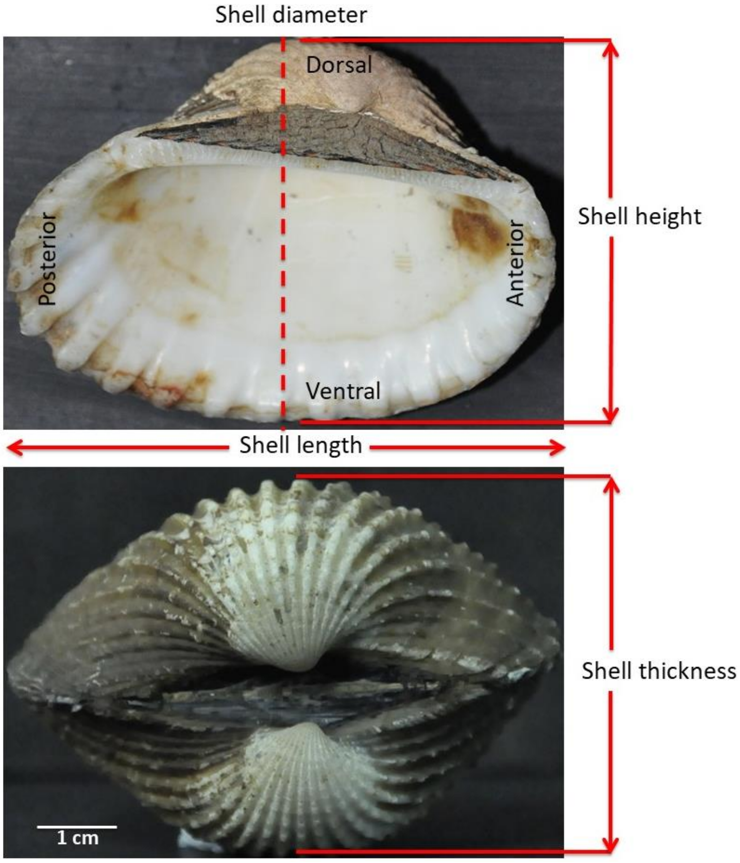

Fig. 2. Biometric of *Anadara grannosa*

Figure 3

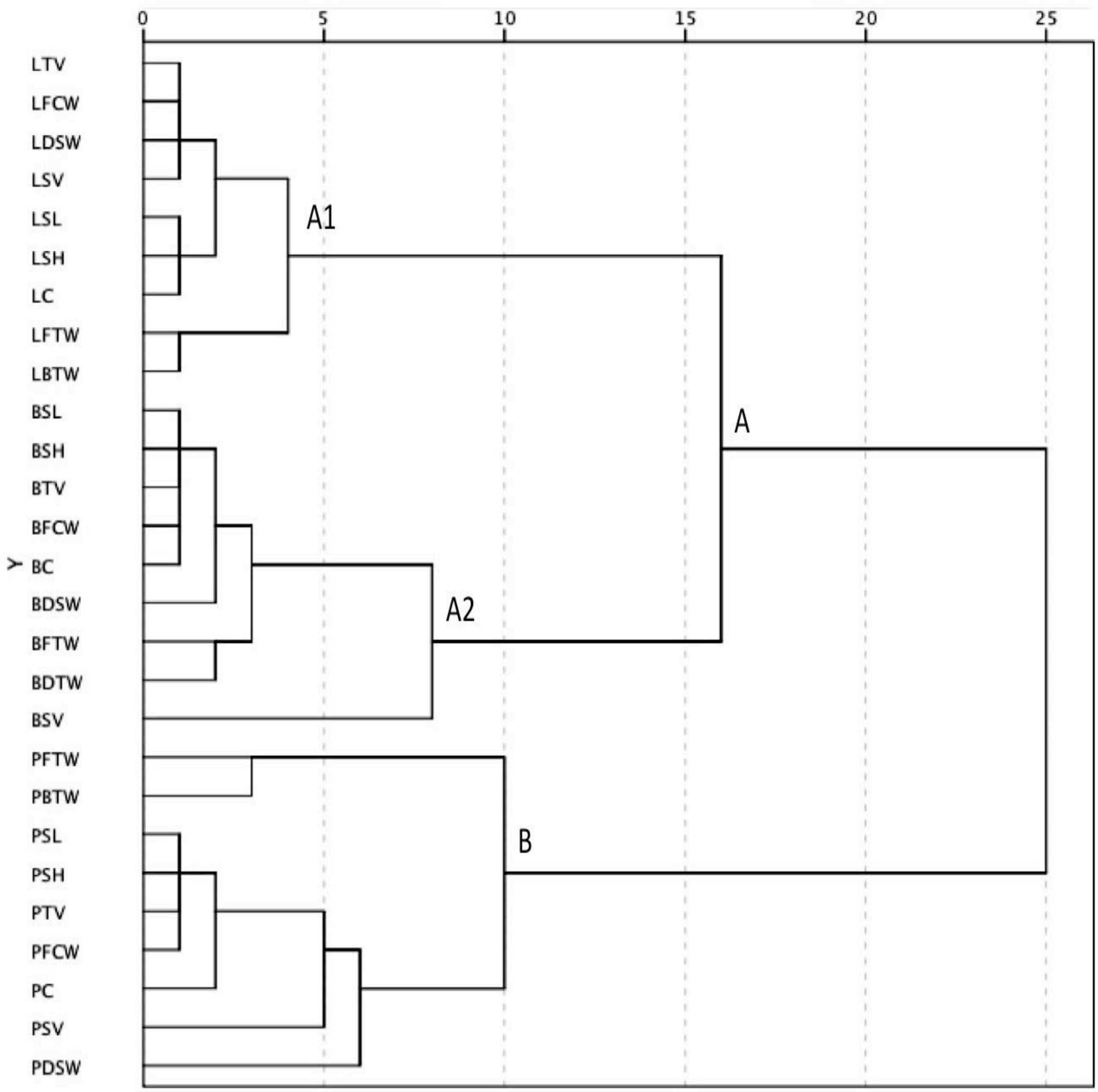

Figure 3. Dendogram parameter of *Anadara granosa* biometric relationship from the northern region of Strait of Malacca

(A: Cluster of *Anadara granosa* population A; A1 and A2: Sub-cluster of *Anadara granosa* population A; B : Cluster of *Anadara granosa* population B).

(BSL: Banda Aceh *Anadara granosa* shell length; BSH: Banda Aceh *Anadara granosa* shell height; BC: Banda Aceh *Anadara granosa* shell thickness; BTV: Banda Aceh *Anadara granosa* total volume; BSV: Banda Aceh *Anadara granosa* shell volume; BFCW: Banda Aceh *Anadara granosa* flesh weight; BFTW: Banda Aceh *Anadara granosa* tissue weight; BDSW: Banda Aceh *Anadara granosa* dry shell weight; BDTW : Banda Aceh *Anadara granosa* dry tissue weight; LSL: Lhokseumawe *Anadara granosa* shell length; LSH: Lhokseumawe *Anadara granosa* shell height; LC: Lhokseumawe *Anadara granosa* shell thickness; LTV: Lhokseumawe *Anadara granosa* total volume; LSV: Lhokseumawe *Anadara granosa* shell volume; LFCW: Lhokseumawe *Anadara granosa* flesh weight; LFTW: Lhokseumawe *Anadara granosa* tissue weight; LDSW: Lhokseumawe *Anadara granosa* dry shell weight; LDTW: Lhokseumawe *Anadara granosa* dry tissue weight; PSL: Pulau Pinang *Anadara granosa* shell length; PSH: Pulau Pinang *Anadara granosa* shell height; PC: Pulau Pinang *Anadara granosa* shell thickness; PTV: Pulau Pinang *Anadara granosa* total volume; PSV: Pulau Pinang *Anadara granosa* shell volume; PFCW: Pulau Pinang *Anadara granosa* flesh weight; PFTW: Pulau Pinang *Anadara granosa* tissue weight; PDSW: Pulau Pinang *Anadara granosa* dry shell weight; PDTW: Pulau Pinang *Anadara granosa* dry tissue weight).

Table 1

Table 1. Equality of coefficients *a* and *b* in allometric model from populations

Model	Banda Aceh		Lhokseumawe		Pulau Pinang		ANCOVA's F, df, p	
	a ± SEa	*b ± SEb*	*a ± SEa*	*b ± SEb*	*a ± SEa*	*b ± SEb*	*a*	*b*
$SH=a*SL^b$	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
$ST=a*SL^b$	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
$ST=a*SH^b$	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

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

Model $W=a*L^b$	Banda Aceh		Lhokseumawe		Pulau Pinang		ANCOVA's F, df, p	
	a ± SEa	*b ± SEb*	*a ± SEa*	*b ± SEb*	*a ± SEa*	*b ± 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	-	-

Table 4

Table 2. The length-weight relationship model for Archidae.

Family/Species	n	Allometric models	R^2	Relationship model	location	Reference
Archidae						
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, 2003
Tegilarca granosa	377	$W=0.00068L^{2.82}$	0.96	(-) Allometric	Korea	Park and Oh, 2004
Anadara granosa	640	$W=0.0016L^{2.618}$	0.884	(-) Allometric	Banda Aceh, Indonesia	Current research
Anadara granosa	640	$W=0.009L^{2.763}$	0.924	(-) Allometric	Lhokseu mawe, Indonesia	Current research
Anadara granosa	640	$W=0.061L^{2.202}$	0.735	(-) Allometric	Pulau Pinang, Malaysia	Current research

Table 3

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 (^0C)																	
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
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	11713.33	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

COVER LETTER FOR SUBMISSION OF REVISION MANUSCRIPT

Ocean Sciences Journal (OSJ)

COVER LETTER FOR SUBMISSION OF MANUSCRIPT
Date: December, 5th 2020

We appreciate the opportunity to revise our manuscript. With this cover letter, we will submit the revised manuscript (Ms. No. OSJO-D-20-00110) entitled "Biometric relationship of *Anadara granosa* (Bivalvia: Arcidae) from the northern region of the Strait of Malacca" for publication in OSJ. We carefully considered the comments offered by the reviewers. We would like to thank the referees for the careful and constructive reviews. Detailed corrections have been listed below point by point, and the major revised parts are highlighted in **red** color in the revised manuscript. We want to extend our appreciation for taking the time and effort necessary to provide such insightful guidance.
Based on the comments from the referees, we have made changes to the manuscript, which are detailed below.

Reply to the evaluation by the First Referee:
We would like to express our appreciation for your incredibly thoughtful comments and constructive criticisms of our manuscript. As you will see below, we have been able to revise and improve the paper as a result of your valuable feedback. Detailed corrections have been listed point by point, and the major revised parts are highlighted in **red** color in the revised manuscript.

General comment:
Reviewer #1: It's a good manuscript that can contribute information related to this species, growth and environment impact. But there are certain point or method that are not clearly mention in the manuscript. There are certain term used in this paper are not standardize. Few amendments need to be made to produce a good paper. Please rephrase any highlighted phrases to be easier understand by reader. I would like to suggest the author to proofread before submission.
Answer: *The author revised the manuscript following referee comment directly in the paper. Proofread was made during revision process.*

Specific comment:
Comment on manuscript and response:

1. There are certain term used in this paper are not standardize.
   Answer: The author was revised the 'term' that suggested by reviewer in the manuscript.

2. Please rephrase any highlighted phrases to be easier understand by reader
   Answer: The author revised the highlighted phrases that suggested by reviewer in the manuscript. e.g., The consideration that could cause variances in biometric components and thus affected A. granosa growth patterns between cluster A and cluster B were spatial differentiation. The source of A. granosa from cluster A was distinct from the cluster B, where A. granosa populations within cluster A came from the northern region of Sumatra island, while A granosa in the cluster B originated from the western region of the Peninsular Malaysia.
3. I would like to suggest the author to proofread before submission.

Answer: the manuscript was checked and corrected by professional English translator in biological sciences and native speakers.

4. Typos and other grammatical errors (suggested by reviewer) were changed directly in the manuscript (highlighted in red color)
5. Before you start with your sample collection, justify a bit about the study sites for example, three locations of the muddy natural of habitat of Anadara granosa were selected at the Strait of Malacca. Why? then you can explain about the procedure:
   Answer: *the author added: The selection of these three sampling areas was based on the geographical distribution aspect of A. granosa in the northern region of the Malacca Strait. Banda Aceh and Lhokseumawe sampling areas shared similar characteristics by larger coastal mudflat areas exposed during all low tides, minimum wave action, high salinity surrounding by mangroves patch and it becomes a natural habitat for A. granosa. Meanwhile, Pulau Pinang sampling area differentiated by larger cockle culture plots, continuously submerged underwater and composited by muddy substrate with no wave action, located bordering industrial zones and considered being disturbed by human activities.*
6. *Environmental paremeter did not mention in method.*
   Answer: the author added subchapter 2.3.Environmental parameter measurement

Reply to the evaluation by the Second Referee:

<u>General comment:</u>

Reviewer #2: A well prepared article which findings are supported by the statistical analysis. The manuscript is acceptable.

Answer: We would like to thank you for your time to read and respond to the manuscript and finally gave 'accepted decision' for our manuscript.

<u>Specific comment:</u>

No specific comment was made by second referee

Abstract

The study on the growth pattern of blood cockle *Anadara granosa* focused on the aspects of biometric prints on the shell, which aimed to predict the growth of *A. 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 *A. granosa* populations in this region indicated that the cockle population generally had a negative allometric growth pattern (b < 3) or shell length is more dominant compare to shell weight. Therefore, the result showed that the growth performance of *A. granosa* was not ideal, where the *b* value (the coefficient of biometric relationship) was highest recorded in Lhokseumawe, followed by Banda Aceh and Pulau Pinang. The value of coefficient *b* could be affected by various factors such as environmental conditions, adaptation, and dietary patterns. Cluster analysis displayed that the population of *A. granosa* from the northern region of the Strait of Malacca was divided into two clusters, which were *A. granosa* from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and population of *A. 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 geographical level on the source of population and the locality of the environmental parameter.

Keywords: blood cockle; bivalvia; growth model; Strait of Malacca; morphometric

1. Introduction

Anadara 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 still harvested directly from nature (Broom 1983; Khalil et al. 2017). Nevertheless, annual harvested-cockle data designate a reduction in natural stocks in the last decade. The huge demand for this species as a protein source marks the natural stocks significantly diminished. This condition is possibly caused by lack in management of controlling wild cockle population stock. Therefore, the management of this species is required for the sustainability of this important species. Comprehensive information on biometric (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) that have also been used extensively as the corresponding parameters to assess the growth of them (Bailey and Green 1988; Bayne and Worrall 1980; Garton and Haag 1991; Smit at al. 1992). Measuring the length and weight of aquatic species is used to evaluate the growth patterns of this 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 at al. 2002; Holopainen and Hansk 1986; Morton 1985; Peters 1985). This study aimed at analyzing the biometric relationship of *A. granosa* by 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 *A. granosa* (120 specimens/month) were collected monthly from June 2009 till September 2010 from the muddy natural habitat in Banda Aceh (5°32'34.67"N - 95°17'2.54"E), Lhokseumawe (05°09'35.3"N - 097°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 aspect of *A. granosa* in the northern region of the Malacca Strait. Banda Aceh and Lhokseumawe sampling areas shared similar characteristics by larger coastal mudflat areas exposed during all low tides, minimum wave action, high salinity surrounding by mangroves patch and it becomes a natural habitat for *A. granosa*. Meanwhile, Pulau Pinang sampling area differentiated by larger cockle culture plots, continuously submerged underwater and composited by muddy substrate with no wave action, located bordering industrial zones and considered being disturbed by human activities.

Insert figure 1.

The total number of specimens sampled was 1,920, with cockle sizes ranged 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 collecting, the specimens were stowed in isotherm containers and directly transferred to the laboratory. The samples were cleaned from mud and organisms attached to the shell in the laboratory, reared in the aquarium, and continued with the recorded biometric values (Fig. 2), including shell length, shell thickness, cockle height, fresh tissue weight, wet cockle weight, and sex category. The measurement instrument of length and width of the cockle used 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 cockle to the most protruding portion on the bottom of cockle. The height was measured from the highest ventral margin of the cockle towards the dorsal margin of the cockle.

Insert figure 2.

2.2 Morphometric relationship

The morphometric ratio of *A. granosa* between length : height, length : thickness and height: thickness 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 a relationship of shell length and cockle body weight (wet weight), which was analyzed through the equation of power regression (Ricker 1975). From the results, then it was informed that if the growth rate of cockle length balanced with the cockle weight or in the mathematical expression $b = 3$, then it was assumed that the cockle growth was isometric. Whereas if $b \neq 3$, it was called allometric, which means the growth of cockle length imbalanced with the weight. To test whether the constants $b = 3$ 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 hypothesis 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 $b < 3$ mean 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 device fixed in the sample area. Seawater salinity, pH, and dissolved oxygen were assessed regularly using a handheld Multiparameter Portable Meter (Hanna HI-9828) at the study site, 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 minutes 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 was collected and put into a package of Microsoft Excel 2011 software Macintosh version to be processed and analyzed. Statistical analysis of Co-Variant Analysis 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* 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 ensure which factor significantly differed in one particular parameter.

The parametric statistical test of Co-Variant analysis was analyzed by using the package of SPSS (Statistical Package for the Social Science) software release 23.0 Macintosh version. The 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 growing 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) on *A. granosa* from the northern region of the Strait of Malacca. Cluster analysis was processed by using SPSS (Statistical Package for the Social Science).

3. Results

3.1 Equality a and b coefficients from different populations

The biometric studies of *A. granosa* (from June 2009-September 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 *A. granosa* shell height : shell length relationship from three sampling areas showed dissimilar coefficient *a*, but there was similar to the coefficient *b*. Furthermore, the relationship of shell thickness : shell length of *A. granosa* populations showed an identical in coefficient *a* and *b* 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).

Insert Table 1

3.2 Morphometric coefficients model from different populations

A. granosa weight and shell length relationship analysis showed no differences in coefficient *a* and *b* value between populations (Table 2). A statistical test was performed on the coefficient *b* through *t*-test indicating the coefficient $b < 3$ or negative allometry in all *A. 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 means the growth rate of shell length and cockle weight overall was imbalanced.

Insert Table 2

3.3 *Environmental parameter*

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

Insert Table 3.

4. Discussion

4.1. *Biometric relationship model of Anadara granosa*

Biometric data analysis of *A. 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 to 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 in 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 ($b = 2.2018 \pm 0.5866$). In the sexes level, a similar condition was presented, whereas both male and female *A. granosa* from Lhokseumawe had the highest *b* coefficient (male *b* = 2.7713±0.567, female 2.7559±0.3838) compared to other sampling locations (Banda Aceh male *b* = 2.6306±0.2831, female *b* = 2.5695±0.3368; Pulau Pinang male *b* = 2.0043±0.889, female *b* = 2.3697±0.7607). These conditions 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 contras conditions could be seen on the cockle found 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 2.4-4.5 that was described by Wilbur and Owen (1964), causing the shell length against cockle weight becomes imprecise. Shell length was growth faster than the increase of the cockle body volume, affecting the cockle to be unhealthy. Factors such as the reproductive biology (Rueda and Urban 1998), physical and biological variables of habitat (Seed 1968, Thorarinsdittir and Johannesson 1996) are recognize affected the growth and be able to change the allometry relationship between the shell length and the cockle weight in bivalvia. Water quality analysis showed that this condition due to the fluctuation in the environmental condition in cockle habitats. Furthermore, the environment quality was unsuitable for cockle growth due to an increased level of nutrients that exceeded the standards rate for marine life (Table 3). From observation, high concentration of nutrients potentially toxic to the cockle and affected 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 *A. 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 concentration changes were expected as the primary regulator of the fluctuation of the *b* coefficient from all sampling areas. The Pearson correlation test showed the opposite condition: the *b* coefficient strongly correlated to phytoplankton density in Banda Aceh (r = 0.766). In comparison, the phytoplankton density showed a moderate correlation with the *b* coefficient for cockle from Lhokseumawe (r = 0.532) and Pulau Pinang (r = 0.579). The phytoplankton density was expected as a limiting factor for growth activity. The phytoplankton was 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 have 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 a few biomass of cockle. Weight reduction of the cockle volume could be caused by the reproduction process, such as the gamete production process and gonad or gamete process in a state of inactivity. In bivalve animals, gonadal growth and gonadal maturation process results increase the tissue mass density and increase tissue weight. Exchange of 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 *A. 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 despite the shell size increased. 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 was not always fixed for species. Differences in growth models could be found 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 cockle in these three sampling areas. Cockles from Banda Aceh and Lhokseumawe had morphological differences compared to the cockles from Pinang. *A. granosa* from Banda Aceh and Lhokseumawe had special shell features that were thicker and wider compared to *A. granosa* cockles from Pulau Pinang. The other studies on the relationship in length and weight on some Anadara species had demonstrated diversity and differences in growth patterns (Table 4).

Insert table 4

The value of the *b* coefficient on the relationship of shell length and cockle weight noted in this study was lower than the recorded one in other species in the same family, namely *Tegilarca granosa* (*b* = 2.82) from Korean waters. Another difference was also found in their relationship model, namely Scapharca from Korean water, which had positive allometry and isometric relationships, while *A. granosa* from the northern region of the Strait of Malacca was 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 that were locality in habitat.

4.2. Relationships of the biometric component of Anadara granosa

Analysis of the relationship of each biometric parameter of *A. granosa* through dendrogram or classification methods (hierarchy) was used to analyze the growth patterns of the three *A. 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. Fig. 3 showed the relationship between the biometric component of *A. granosa*. Through this analysis, the degree of dissimilarity between generated clusters had shown. The relationship between a biometric component in one cluster compared to another biometric component in the different cluster within the dendrogram was generated by the distance of the scale, e.g., if the scale value found high, it is assumed that the distinction between two biometric components in two different clusters was correspondingly high.

Insert fig. 3.

Dendrogram analysis showed that cluster A had two sub-clusters; namely, A1 represented the biometric component of *A. granosa* from Lhokseumawe and A2 represented the biometric component of *A. granosa* from Banda Aceh, which was separated on a scale of 16. Cluster B was a hierarchy cluster of biometric components of *A. granosa* from Pulau Pinang. Cluster B was separated by cluster A on a scale of 25. The larger recorded scale means the dissimilarity elements forming the component were higher. It showed 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 that *A. granosa* population 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) state that the population can be explained in particular by the growth characteristics through the measurement of biometric morphology.

The consideration that could cause variances in biometric components and thus affected *A. granosa* growth patterns between cluster A and cluster B were spatial differentiation. The source of *A. granosa* from cluster A was distinct from cluster B, where *A. granosa* populations within cluster A came from the northern region of Sumatra island, while *A granosa* in the cluster B originated from the western region of Peninsular Malaysia. Sub-clusters A was also known to have differences in growth patterns of the biometric component; they even had close proximity. *A. granosa* cockles of sub-cluster A1 and A2 were expected to come from the same source of population. Differences in the pattern of biometric components were possible because of the differences in environmental factors that were locality in nature, affecting the growth patterns. Differences 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) are playing a role in determining the growth pattern of cockle in three sampling areas.

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Captions for figures

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

(Insert after line 63, page 3)

Fig. 2. Biometric of *Anadara grannosa*

(Insert after line 78, page 4)

Fig. 3. Dendrogram parameter of *Anadara granosa* biometric relationship from the northern region of Strait of Malacca

(Insert after line 248, page 11)

Captions for table

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

(Insert after line 141, page 6)

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

(Insert after line 150, page 7)

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

(Insert after line 155, page 7)

Table 4. The length-weight relationship model for Archidae.

(Insert after line 228, page 10)

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Biometric relationship of *Anadara 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 *Anadara granosa* focused on the aspects of biometric prints on the shell, which aimed to predict the growth of the *A. 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 *A. 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 *A. 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 *A. granosa* from the northern region of the Strait of Malacca was divided into two clusters, which were *A. granosa* from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and *A. 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.

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Keywords: blood cockle; bivalvia; growth model; Malacca Strait; morphometric

1. Introduction

Anadara 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 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 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).

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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 *A. granosa* by 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 *A. granosa* (120 specimens/month) were collected monthly from June 2009 till September 2010 from the muddy natural habitat in Banda Aceh (5°32'34.67"N - 95°17'2.54"E), Lhokseumawe (05°09'35.3"N - 097°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 *A. 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 *A. 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.

Insert figure 1.

The total number of specimens sampled was 1,920, 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 and mud and organisms attached to the

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Commented [MOU8R7]: plots which were continuously submerged underwater 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 cockle to the most protruding portion on the bottom of cockle. The height was measured from the highest ventral margin of the cockle towards the dorsal margin of the cockle.

Insert figure 2.

2.2 Morphometric relationship

The morphometric ratio of *A. 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 ~~in balance~~ 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:

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Commented [MOU12R11]: 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

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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 device fixed in the sampling areas. Seawater salinity, pH, and dissolved oxygen were assessed regularly using a handheld 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 minutes 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 Analysis 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* were analyzed by observing the growth differences in population and sex differences in the sample (male, female, or neutral).

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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 by 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 *A. granosa* from the northern region of the Strait of Malacca. Cluster analysis was processed by using SPSS (Statistical Package for the Social Science).

3. Results

3.1 Equality a and b coefficients from different populations

The biometric studies of *A. granosa* (from June 2009-September 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 *A. 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 *A. 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).

Insert Table 1

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3.2 Morphometric coefficients model from different populations

A. 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 *A. 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.

Insert Table 2

3.3 Environmental parameter

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

Insert Table 3.

4. Discussion

4.1. Biometric relationship model of Anadara granosa

Biometric data analysis of *A. 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 to 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 ($b =$

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2.6178±0.2095) and the cockle population from Pulau Pinang (*b* = 2.2018±0.5866). According to sexual orientation, a similar condition was presented, although both male and female *A. granosa* from Lhokseumawe had the highest *b* coefficient (male *b* = 2.7713±0.567, female 2.7559±0.3838) compared to other sampling locations (Banda Aceh male *b* = 2.6306±0.2831, female *b* = 2.5695±0.3368; Pulau Pinang male *b* = 2.0043±0.889, female *b* = 2.3697±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 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 (Table 3). Based on observations, the high concentration of nutrients are potentially toxic to the cockles and could affect cockle growth. Environmental aspects have been identified as the main factor that affects shell

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Furthermore, the variety of growth patterns of *A. 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 concentration 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 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 are 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 meagre 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 *A. granosa*, the shell weight was generally heavier than the meat weight. When

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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 Pinang. *A. granosa* from Banda Aceh and Lhokseumawe had special shell features that were thicker and wider compared to *A. granosa* cockles from Pulau Pinang. Other studies on the relationship in length and weight regarding some Anadara species have demonstrated diversity and differences in growth patterns (Table 4).

Insert 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 *Tegilarca granosa* ($b = 2.82$) from Korean waters. Another difference was also found in their relationship model, namely Scapharca from Korean water, which had positive allometry and isometric relationships, while *A. 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 particular to a particular habitat.

4.2. Relationships of the biometric component of Anadara granosa

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Analysis of the relationship of each biometric parameter of *A. granosa* through dendrogram or classification methods (hierarchy) was used to assess the growth patterns of the three *A. 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. Fig. 3 shows the relationship between the biometric components of *A. 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.

Insert fig. 3.

Dendrogram analysis showed that cluster A had two sub-clusters; namely, A1 represented the biometric component of *A. granosa* from Lhokseumawe and A2 represented the biometric component of *A. granosa* from Banda Aceh, which was separated on a scale of 16. Cluster B was a hierarchy cluster of biometric components of *A. 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 *A. 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.

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It is thought that the factor that could cause variances in biometric components and thus affect *A. granosa* growth patterns between cluster A and cluster B is spatial differentiation. The source of *A. granosa* from cluster A was distinct from cluster B, where *A. granosa* populations within cluster A came from the northern region of Sumatra island, while *A granosa* in the 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. *A. granosa* cockles 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.

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Acknowledgments

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Captions for figures

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

(Insert after line 85, page 4)

Fig. 2. Biometric of *Anadara grannosa*

(Insert after line 102, page 5)

Fig. 3. Dendrogram parameter of *Anadara granosa* biometric relationship from the northern region of Strait of Malacca

(Insert after line 283, page 12)

Captions for table

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

(Insert after line 167, page 7)

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

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

(Insert after line 183, page 8)

Table 4. The length-weight relationship model for Archidae.

(Insert after line 263, page 11)

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Table 4 The length-weight relationship model for Arcidae

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Article

Biometric Please change the running title in the article header to: **Biometric relationship of *Tegillarca granosa***

Relationship of ~~*Anadara*~~*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 ~~Anadara~~*Tegillarca granosa* focused on the aspects of biometric prints on the shell, which aimed to predict the growth of the ~~A~~*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 ~~A~~*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 ~~A~~*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 ~~A~~*T. granosa* from the northern region of the Strait of Malacca was divided into two clusters, which were ~~A~~*T. granosa* from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and ~~A~~*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.

AQ1

AQ2

Keywords

Blood cockle
Bivalvia
Growth model
Malacca Strait
Morphometric Please insert 'Morphometric' after 'Bivalvia'

1. Introduction

~~*Anadara*~~*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 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 and Reiss 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 ~~A~~*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 ~~A~~*T. granosa* (120 specimens/month) were collected monthly from June 2009 till September 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 ~~A~~*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 ~~A~~*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.

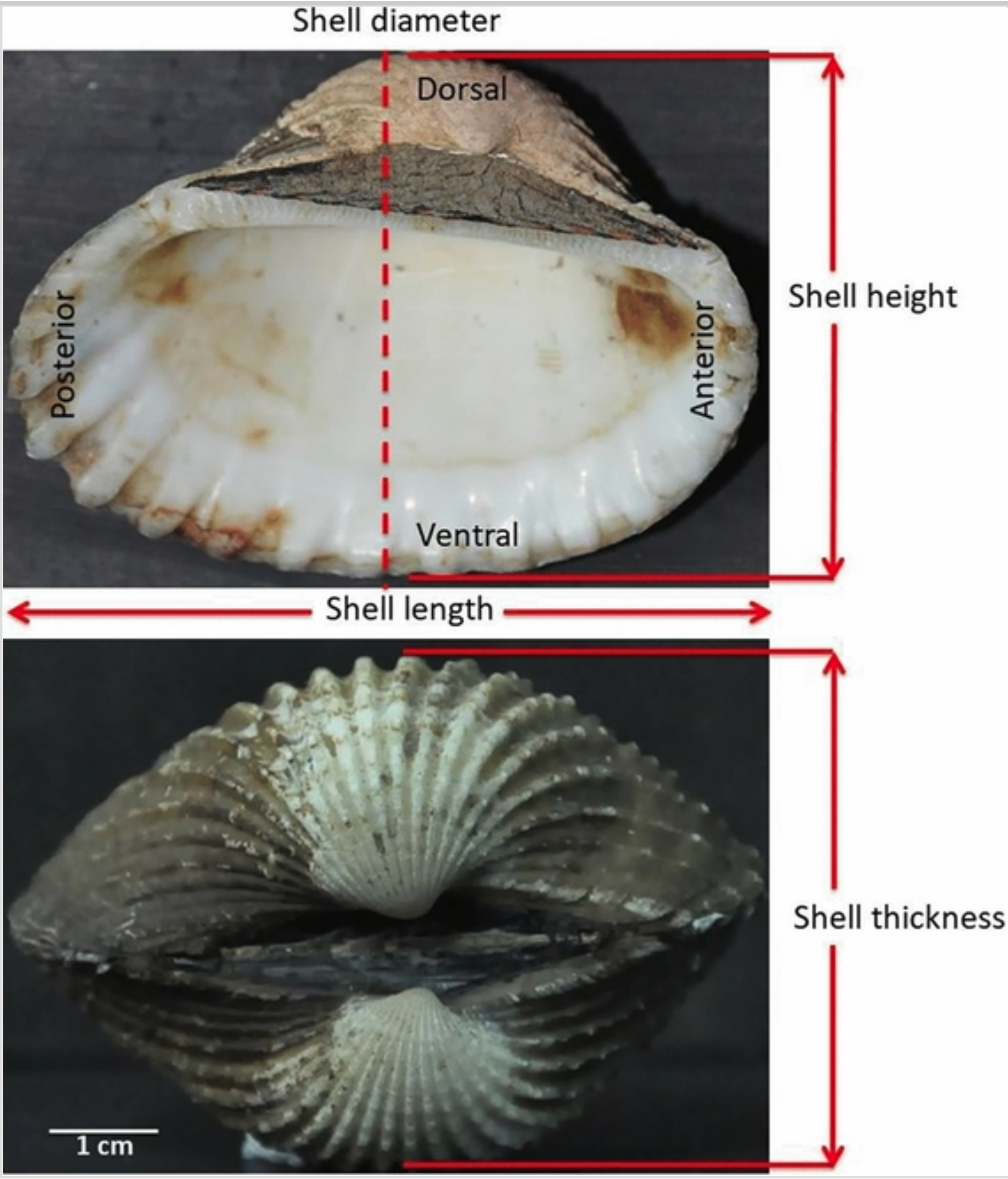
Fig. 1 Please change the Map with the new one in attached file

~~*Anadara*~~*Tegillarca granosa* sampling location in the northern region of the Strait of Malacca

The total number of specimens sampled was 1920, with cockle sizes ranging from 38 to 71 mm in length. The specimens were collected at a depth of 5–30 cm, and salinity ranged from 10 to 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 ~~and~~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.

Fig. 2

Biometric of ~~*Anadara*~~*Tegillarca granosa*



2.2. Morphometric Relationship

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

$$a = L/H, \; a = L/C \text{ and } a = H/C,$$

where L is the shell length, H is the shell height, C is the shell thickness, and a is the 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 ~~device~~ fixed in the sampling areas. Seawater salinity, pH, and dissolved oxygen were assessed regularly using a handheld Multiparameter Portable Meter (Hanna HI-9828) at the study sites, where turbidity was measured with a turbidity meter (Turbidity meter 800-ESD). Monthly analyses 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 ~~Analysis~~ 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* 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~~*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~~*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 *~~A~~T. granosa* from the northern region of the Strait of Malacca. Cluster analysis was processed using SPSS software~~(Statistical Package for the Social Science)~~.

3. Results

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

The biometric studies of ~~A~~T. *granosa* (from June 2009 to September 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 ~~A~~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 ~~A~~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).

Table 1

Equality of coefficients *a* and *b* in allometric model from populations

Model	**Banda Aceh**		**Lhokseumawe**		**Pulau Pinang**		**ANCOVA's *F* *df*, *P***	
	a* ± SE*a	***b* ± SE*b***	***a* ± SE*a***	***b* ± SE*b***	***a* ± SE*a***	***b* ± SE*b***	***a***	**~~B~~*b***
SH = *a* × SL^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	3.22 1, 0.08
ST = *a* × SL^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	1.09 1, 0.30
ST = *a* × SH^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	16.4 1, 0.

3.2. Morphometric Coefficients Model from Different Populations

~~A~~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 ~~*A*~~*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 2

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

Model $W = a \times L^b$	**Banda Aceh**		**Lhokseumawe**		**Pulau Pinang**		**AN** ***F, ...***
	a **± SE*a***	***b*** **± SE*b***	***a*** **± SE*a***	***b*** **± SE*b***	***a*** **± SE*a***	***b*** **± *SE*** SE is not *italic* ***b***	~~*A*~~***a***
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	0.5 1, 0.4
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	0.0 1, 0.9
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	0.1 1, 0.7
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 ~~concentration~~ fluctuated significantly compared to other environmental parameters during the study period.

Table 3

Ranges of the seasonal environmental parameter at the sampling areas (average

Environmental parameter	June 2009	July 2009	August 2009	September 2009	November 2009
Temperature (°C)					
Banda Aceh					
Minimum	26.32	24.27	24.29	25.43	26.90
Maximum	30.97	30.44	30.45	29.88	32.61
Lhokseumawe					
Minimum	28.82	28.82	26.81	28.07	27.71
Maximum	31.08	31.71	30.06	31.17	30.87
Pulau Pinang					
Minimum	27.23	27.52	26.65	27.10	25.87
Maximum	31.63	31.10	31.45	30.60	30.90
Salinity (ppt)					
Banda Aceh	32.27	31.35	29.98	27.47	30.06
Lhokseumawe	31.00	30.97	31.16	31.20	31.03
Pulau Pinang	29.33	28.52	26.39	26.87	27.35
pH					
Banda Aceh	7.65	8.02	8.03	8.17	7.80
Lhokseumawe	8.13	7.88	8.04	8.06	8.17
Pulau Pinang	8.02	7.49	7.85	8.14	8.04

Environmental parameter	**June 2009**	**July 2009**	**August 2009**	**September 2009**	**November 2009**
Dissolved oxygen (mg/L)					
Banda Aceh	6.53	6.81	6.96	6.05	5.97
Lhokseumawe	6.01	6.38	6.47	6.14	6.28
Pulau Pinang	7.20	5.20	5.20	4.90	5.13
Turbidity (NTU)					
Banda Aceh	17.40	29.30	8.61	9.02	10.86
Lhokseumawe	43.20	30.50	36.50	66.90	31.60
Pulau Pinang	29.30	17.36	15.11	13.09	17.27
Orthophospate (mg/L)					
Banda Aceh	0.05	0.03	0.04	0.13	0.03
Lhokseumawe	0.05	0.01	0.02	0.07	0.01
Pulau Pinang	0.10	0.05	0.08	0.06	0.03
Nitrate (mg/L)					
Banda Aceh	0.71	0.03	0.11	0.73	0.75
Lhokseumawe	0.68	0.14	0.03	0.03	0.20
Pulau Pinang	0.80	0.02	1.30	0.73	0.03
Nitrite (mg/L)					
Banda Aceh	0.05	0.02	0.02	0.03	0.75
Lhokseumawe	0.03	0.03	0.04	0.04	0.05

Environmental parameter	June 2009	July 2009	August 2009	September 2009	November 2009
Pulau Pinang	0.03	0.03	0.04	0.06	1.09
Ammonia (mg/L)					
Banda Aceh	0.87	0.20	0.16	0.15	0.11
Lhokseumawe	0.19	0.17	0.25	0.25	0.14
Pulau Pinang	0.24	0.18	0.14	0.25	0.42
Phytoplankton density (cell/L)					
Banda Aceh	1831.67	1446.67	851.67	1178.33	630.00
Lhokseumawe	1656.67	1365.00	711.67	2601.67	3010.00
Pulau Pinang	4340.00	4001.67	1470.00	11,713.33	4340.00

4. Discussion

4.1. Biometric Relationship Model of ~~*Anadara*~~*Tegillarca granosa*

Biometric data analysis of ~~*A*~~*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 AT. *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 condition causing 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 ~~(Table 3)~~. 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 ~~A~~*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~~concentration~~ 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 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 ~~are~~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 meagre 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 indicate 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 ~~A~~*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. ~~A~~*T. granosa* from Banda Aceh and Lhokseumawe had special shell features that were thicker and wider compared to ~~A~~*T. granosa* cockles from Pulau Pinang. Other studies on the relationship in length and weight regarding some ~~Anadara~~*Tegillarca* species have demonstrated diversity and differences in growth patterns (Table 4).

Table 4

~~xxxx~~The length-weight relationship model for Arcidae

Family/species	*n*	Allometric models	R^2	Relationship model	Locatio
Arc~~h~~idae					
Scapharca broughttonii	88	$W = 0.000073L^{3.31}$	0.943	(+) Allometric	Korea
Scapharca subcrenata	114	$W = 0.0004L^{2.97}$	0.935	Isometric	Korea
Tegillarca granosa	377	$W = 0.00068L^{2.82}$	0.960	(–) Allometric	Korea
~~*Anadara*~~*Tegillarca granosa*	640	$W = 0.0016L^{2.618}$	0.884	(–) Allometric	Banda A Indonesi

Family/species	*n*	Allometric models	R^2	Relationship model	Locatio
~~*Anadara*~~*Tegillarca granosa*	640	$W = 0.009L^{2.763}$	0.924	(−) Allometric	Lhokseu Indonesi
~~*Anadara*~~*Tegillarca granosa*	640	$W = 0.061L^{2.202}$	0.735	(−) Allometric	Pulau Pi Malaysi

AQ3

AQ4

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 difference was also found in their relationship model, namely ~~Scapharca~~*Scapharca* from Korean water, which had positive allometry and isometric relationships, while ~~*A*~~*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 ~~particular to~~in a particular habitat.

AQ5

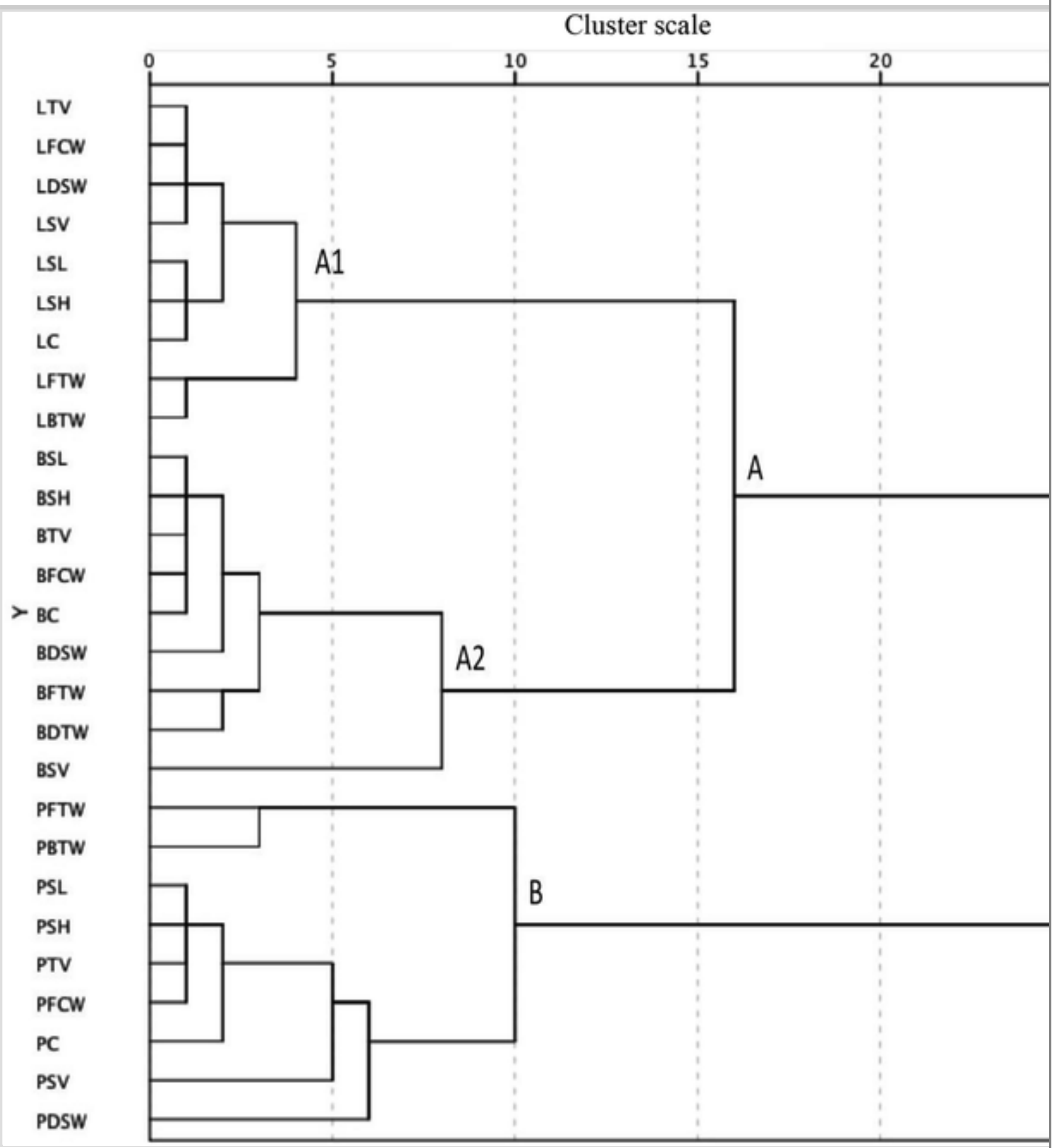
4.2. Relationships of the Biometric Component of *Anadara granosa*

Analysis of the relationship of each biometric parameter of ~~*A*~~*T. granosa* through dendrogram or classification methods (hierarchy) was used to assess the growth patterns of the three ~~*A*~~*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 ~~*A*~~*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.

Fig. 3

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

~~*Anadara*~~*Tegillarca granosa* dry tissue weight).



Dendrogram analysis showed that cluster A had two sub-clusters; namely, A1 represented the biometric component of ~~*A*~~*T. granosa* from Lhokseumawe and A2 represented the biometric component of ~~*A*~~*T. granosa* from Banda Aceh, which was separated on a scale of 16. Cluster B was a hierarchy cluster of biometric components of ~~*A*~~*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 ~~A~~*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 ~~A~~*T. granosa* growth patterns between cluster A and cluster B is spatial differentiation. The source of ~~A~~*T. granosa* from cluster A was distinct from cluster B, where ~~A~~*T. granosa* populations within cluster A came from the northern region of Sumatra island, while ~~A~~*T. granosa* in ~~the~~ 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. ~~A~~*T. granosa* ~~cockles~~ 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.

Publisher's Note

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