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Ocean Science Journal (2021) 56:156–166 https://doi.org/10.1007/s12601-021-00019-x ARTICLE Biometric Relationship of Tegillarca granosa (Bivalvia: Arcidae) from the Northern Region of the Strait of Malacca Munawar Khalil1,2 · Riri Ezraneti1 · Rachmawati Rusydi3 · Zulf?gar Yasin4,5 · Shau Hwai Tan4,5 Received: 20 July 2020 / Revised: 5 December 2020 / Accepted: 8 December 2020 / Published online: 7 May 2021 Abstract This study on the growth pattern of the blood cockle Tegillarca granosa focused on the aspects of biometric prints on the shell, which aimed to predict the growth of the T. granosa population in the northern region of Malacca Strait. The local sample populations of the cockle were collected in three dif?erent intertidal areas called Lhokseumawe and Banda Aceh in Indonesia and Pulau Pinang in Malaysia. The biometric analysis showed that the length–weight relationship model of T. granosa populations in this region indicated that the cockle population generally had a negative allometric growth pat- tern (b < 3) or that shell length is more dominant compared to shell weight.

Therefore, the result showed that the growth performance of T. granosa was not ideal, and the highest b value (the coef??cient of biometric relationship) was recorded in Lhokseumawe, followed by Banda Aceh and Pulau Pinang. The value of the coef??cient b could be af?ected by various factors such as environmental conditions, adaptation, and dietary patterns. Cluster analysis revealed that the population of T. granosa from the northern region of the Strait of Malacca was divided into two clusters, which were T. granosa from the northern Strait of Malacca (Banda Aceh and Lhokseumawe in Indonesia) and T.

granosa from the Western Strait of Malacca (Pulau Pinang in Malaysia). The factors that might cause the dif?erences in the biometric component of both clusters were at the geographical level on the source of population and local environmental parameters. Keywords Blood cockle · Bivalvia · Morphometric · Growth model · Malacca Strait 1 Introduction Tegillarca granosa is one of the important f?shery commodi- ties 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 signif?cant 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 pat- tern of the species) is necessary to predict the annual recruit - ment, 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; Zeld- itch et al. 2004).

Length–weight is an essential variable for comparing growth, physiological processes, and environmental fac- tors that af?ect aquatic organisms (Hemachandra and Thip- peswamy 2008). Growth of bivalves can be def?ned as the increase of the length size of the shell and body weight (body mass) and these indicators have also been used extensively Online ISSN 2005-7172 Print ISSN 1738-5261 * Munawar Khalil khalil@unimal.ac.id 1 Department of Marine Science, Faculty of Agriculture, Reuleut Main Campus, Universitas Malikussaleh, North Aceh 24351, Indonesia 2 Leibniz Centre for Tropical Marine Research (ZMT), Bremen 28359, Germany 3 Department of Aquaculture, Faculty of Agriculture, Reuleut Main Campus, Universitas Malikussaleh, North Aceh 24351, Indonesia 4 School of Biological Sciences, Universiti Sains Malaysia, Penang 11800, Malaysia 5 Centre for Marine and Coastal Studies, Universiti Sains Malaysia, Penang 11800, Malaysia 157 as corresponding parameters to assess their growth (Bailey and Green 1988; Bayne and Worrall 1980; Garton and Haag 1991; Smit et al. 1992). Measuring the length and weight of aquatic species is used to evaluate the growth patterns of species quantitatively.

Such relationships are expressed via the data distribution of shell length and cockle weight. These data also represent the ratio of the addition of an animal's body size by period. Length and weight relationships have several purposes, namely (1) for measuring the weight and length ratio of a species to the weight–length in Taxa class (Anderson and Neumann 1996; Shine 1990), and (2) for age (Pauly 1983). The length and weight relationship allows life history and morphological dif?erences to be identif?ed between species and populations from dif?erent habitats (Beukema and Mee- han 1985; Gaspar et al. 2002; Holopainen and Hanski 1986).

This study sought to analyze the biometric relationship of T. granosa using a morphometric relationship and dendrogram analysis of specimens collected from the northern region of the Strait of Malacca. 2 Materials and Methods 2.1 Samples Collection The specimens of T. granosa (120 specimens/ month) were collected monthly from Jun 2009 till Sep 2010 from the muddy natural habitat in Banda Aceh (5°32' 34.67" N–95°17' 2.54" E), Lhokseumawe (5°09' 35.3" N–97°08' 29.4" E) in Aceh Province, Indonesia and Pulau Pinang (5°16'9.66" N–100°23'27.37" E) in Malay- sia (Fig. 1). The selection of these three sampling areas was based on the geographical distribution characteristics of T.

granosa in the northern region of the Malacca Strait. Banda Aceh and Lhokseumawe sampling areas share similar fea- tures such as larger coastal mudf?at areas exposed during all low tides, minimum wave action, high salinity waters surrounded by mangroves patches and such locations are a natural habitat for T. granosa.

Meanwhile, Pulau Pinang sampling area is dif?erentiated by larger cockle culture plots which were continuously submerged underwater and com- posited by muddy substrate with no wave action, located near industrial zones and are thought to be disturbed by human activities. The total number of specimens sampled was 1920, with cockle sizes ranging from 38–71 mm in length. The speci- mens were collected at a depth of 5–30 cm, and salinity ranged from 10–33 ppt. The live samples were collected manually with the aid of a harrow during the low tide period. After collection, the specimens were stored in isotherm containers and directly transferred to the laboratory.

The samples were cleaned from mud and organisms attached to the shell were removed in the laboratory, then reared in the aquarium where biometric values were continuously recorded (Fig. 2), including shell length, shell thickness, cockle height, fresh tissue weight, wet cockle weight, and sex category. The measurement of length and width of the cockle was taken with a digital Vernier caliper with an accu- racy of 0.1 mm, and the cockle weight tissue was weighed using a digital weighing scale (in grams).

The length was def?ned as the maximum shell length (measured from the posterior margin to the anterior margin of the cockle); the thickness was measured on the inf?ating position, from the most protruding part on the top of the cockle to the most protruding portion on the bottom of the cockle. The height was measured from the highest ventral margin of the cockle towards the dorsal margin of the cockle. 2.2 Morphometric Relationship The morphometric ratio of T. granosa between length: height, length: thickness and height: thickness was analyzed using the following formula: a = L/H, a = L/C and a = H/Cwhere: L = shell length, H = shell height, C = shell thickness, a = index (coef??cient).

The growth pattern of the cockle was able to be desig- nated 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 mathemati- cal expression b = 3, and if so then it was assumed that the cockle growth was isometric. Whereas if b ? 3, it was allo- metric, which means the growth of cockle length was not proportionate to the weight.

To test whether the constants were b = 3 or b ? 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: H0: b = 3, shell length and cockle weight relationship was isometric H1: b ? 3 mean shell length and cockle weight relation- ship 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 f?xed in the sampling areas. Seawater salinity, pH, and dis- solved oxygen were assessed regularly using a handheld 158 M. Khalil et al. Multiparameter Portable Meter (Hanna HI-9828) at the study sites, where turbidity was measured with a turbid- ity 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; Grasshof? 1976; Man- toura and Woodward 1983; Kirkwood 1989; Zhang and Chi 2002).

Phytoplankton samples were obtained monthly from mid-surface water by towing a plankton net (mouth diameter 0.35 m) made of bolting silk (No. 30, mesh size: 48 μM) for 30 min and preserved using Lugol’s solution. Phytoplankton cell density was measured monthly using a hemocytometer and a compound microscope following the Martinez et al. (1975) protocol. 2.4 Statistical Analysis The raw data obtained were collected and put into a package of Microsoft Excel 2011 software Macintosh version to be processed and analyzed.

Statistical analysis of Co-Variant was used to determine signif?cant dif?erences in the values obtained in each collected group data. The determining fac- tor used in this study was the population dif?erences in the three dif?erent regions. Therefore, the coef??cients a and b Fig. 1 Tegillarca grannosa sampling location in the northern region of the Strait of Malacca 159 were analyzed by observing the growth dif?erences in popu- lation and sex dif?erences in the sample (male, female, or neutral).

The statistical test was continued by the post hoc test to determine which factor signif?cantly dif?ered 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 coef??cient (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 signif?cance of correlation at the level of 95% (P = 0.05). The statistical t test was used to f?nd signif?cant dif?erences in the pattern of change in the b coef??cient 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 biomet- ric component (Ramesha and Thippeswamy 2009) regard- ing T. granosa from the northern region of the Strait of Malacca.

Cluster analysis was processed using SPSS software. 3 Results 3.1 Equality a and b Coef??cients from Dif?erent Populations The biometric studies of T. granosa (from Jun 2009–Sep 2010) from the northern region of the Strait of Malacca involving 1920 individuals consisted of 756 males, 974 females, and 190 neuters. The statistical analysis showed that T. granosa shell height: shell length relationship from three sampling areas revealed a dissimilar coef??cient a , but the coef??cient b was similar. Furthermore, the relation- ship of shell thickness: shell length of T.

granosa popula- tions showed that the coef??cients a and b were identical between populations. In contrast, the relationship of shell thickness: shell height coef??cient (a and b) values in terms of their allometric equations showed dif?erences between populations (Table 1). 3.2 Morphometric Coef??cients Model from Dif?erent Populations T. granosa weight and shell length relationship analy - sis showed no dif?erences in coef??cient a and b values between populations (Table 2).

A statistical test was per - formed on the coef??cient b through a t test indicating the coef??cient b < 3 or negative allometry in all T. granosa populations. This condition showed that the growth of cockle shell length was faster or more dominant com- pared to the growth of cockle weight. A further test of the hypothesis also showed that H0 was rejected (P < 0.05) and indicates that the growth rate of shell length and cockle weight was in an overall imbalance. Fig.

2 Biometric of Tegillarca grannosa Table 1 Equality a and b coef??cients in the biometric model from dif?erent 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 × SLb 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 × SLb 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 × SHb 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, 0.00 160 M. Khalil et al. 3.3

Environmental Parameter Seasonal variations of environmental parameters in the sampling areas are presented in Table 3. Water tempera - ture, salinity, and phytoplankton density f?uctuated signif?- cantly compared to other environmental parameters during the study period. 4 Discussion 4.1 Biometric Relationship Model of Tegillarca granosa Biometric data analysis of T. granosa from the northern region of the Strait of Malacca showed that the cockle growth model was negative allometry. The growth of shell length was more dominant than the growth of cockle weight.

The growth model generated from the three sampling sites showed that the value of the b coef??cient was less than 3 (b < 3). The balance value of the b coef??cient 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 coef??cient dif?ers within a popu- lation or when compared to other populations. The cockle population from Lhokseumawe had a higher b coef??cient (b = 2.7629 ± 0.3894) compared to the cockle population from Banda Aceh (b = 2.6178 ± 0.2095) and the cockle pop- ulation from Pulau Pinang (b = 2.2018 ± 0.5866).

Accord- ing to sexual orientation, a similar condition was presented, although both male and female T. granosa from Lhokseu- mawe had the highest b coef??cient (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 coef??cient results indi- cated that the cockle growth rate in Lhokseumawe was more appropriate or suitable compared to the other two sampling areas.

The b coef??cient 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 coef- f?cient was lower than the range value of the b coef??cient 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 unbal- anced 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 af?ecting 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 f?uctuation in environmental condi- tions in cockle habitats.

Furthermore, the environmental circumstances were unsuitable for cockle growth due to an increased level of nutrients that exceeded the standard rate for marine life. Based on observations, the high concentra- tion of nutrients is potentially toxic to the cockles and could af?ect cockle growth. Environmental aspects have been iden- tif?ed as the main factor that af?ects shell development in bivalves. The shell size and shape are af?ected by the varia- tion of ambient environmental constraints (Wilbur and Owen 1964; Seed 1968). Furthermore, the variety of growth patterns of T.

granosa highly correlates to factors of food availability, temperature, salinity, pollution materials, and reproductive activities (Broom 1982; Day and Fleming 1992; Tarr 1995). The phy - toplankton density changes were expected to be the primary regulator of the f?uctuation of the b coef??cient from all sam- pling areas. The Pearson correlation test showed the oppo- site circumstance: the b coef??cient was strongly correlated Table 2 Equality a and b coef??cients in the biometric model from dif?erent 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 ANCO- VA’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 – – 161 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 Novem- ber 2009 October 2010 December 2009 January 2010 February 2010 March 2010 April 2010 May 2010 June 2010 July 2010 August 2010 Septem- ber 2010 Average ± st.dev Temperature (°C) Banda aceh Minimum 26.32 24.27 24.29 25.43 26.90 25.00 25.39 25.79 22.96 22.84 25.47 21.87 25.90 22.82 25.27 26.00 24.78 ± 1.98 Maximum 30.97 30.44 30.45 29.88 32.61 31.93 31.95 32.48 32.93 32.10 31.40 31.03 30.93 32.11 30.98 30.38 31.41 ± 1.37 Lhokseumawe Minimum 28.82 28.82 26.81 28.07 27.71 27.03 28.45 28.06 28.96 28.48 28.60 28.23 27.95 28.23 27.23 27.40 28.05 ± 2.02 Maximum 31.08 31.71 30.06 31.17 30.87 30.33 30.81 30.68 30.75 31.10 30.90 31.65 31.27 31.39 30.84 31.17 30.99 ± 1.28 Pulau Pinang Minimum 27.23 27.52 26.65 27.10 25.87 27.93 26.05 23.68 25.61 26.74 26.37 26.29 26.67 26.74 26.65 27.37 26.53 ± 1.94 Maximum 31.63 31.10 31.45 30.60 30.90 31.43 30.58 28.35 30.46 31.71 31.13 30.68 31.53 31.32 31.45 31.30 30.98 ± 1.32 Salinity (ppt) Banda aceh 32.27 31.35 29.98 27.47 30.06 27.20 26.45 29.68 31.50 31.16 29.30 30.71 30.85 31.29 30.45 28.27 29.87 ± 3.23 Lhokseumawe 31.00 30.97 31.16 31.20 31.03 29.07 30.94 31.16 31.46 31.84 30.57 31.26 30.90 30.81 30.65 31.27 30.95 ± 1.04 Pulau Pinang 29.33 28.52 26.39 26.87 27.35 26.13 25.23 28.06 29.00 28.94 28.67 26.48 29.70 29.32 31.06 30.40 28.22 ± 2.97 pH Banda aceh 7.65 8.02 8.03 8.17 7.80 8.02 7.91 8.17 8.08 8.06 8.02 7.97 7.74 8.27 7.94 8.23 8.01 ± 0.17 Lhokseumawe 8.13 7.88 8.04 8.06 8.17 8.13 7.98 8.21 7.89 8.18 7.91 7.84 8.08 7.93 7.99 8.13 8.03 ± 0.13 Pulau Pinang 8.02 7.49 7.85 8.14 8.04 8.07 7.79 8.02 7.95 7.86 8.08 8.21 7.91 7.86 7.33 7.54 7.89 ± 0.25 Dissolved oxy- gen (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

to phytoplankton density in Banda Aceh (r = 0.766). In comparison, the phytoplankton density showed a moderate correlation with the b coef??cient for cockles from Lhok - seumawe (r = 0.532) and Pulau Pinang (r = 0.579). The phy - toplankton density was expected to be a limiting factor for growth activity. Phytoplankton is used as an energy source for the growth process of shell length and cockle weight. The supply of food sources is considered an essential factor for sustainable growth (Seed and Suchanek 1992; Widdows and Johnson 1988). Changes in the b coefficient fluctuation were also expected to reveal a relationship with the reproduction period.

Sudden changes in the value of the b coef??cient meant that there was a rapid change in the cockle weight tis- sue due to the meager biomass of cockles. Weight reduction of the cockle volume could be caused by the reproduction process, such as the gamete production process and gonad or gamete process being in a state of inactivity. In bivalve animals, gonadal growth and gonadal maturation process results in increased tissue mass density and increased tissue weight.

Changes in the value of the b coef??cient indicates the beginning of the activities of gonadal maturation and growth in bivalve animals (Hemachandra and Thippeswamy 2008; Hickman and Illingworth 1980). The total cockle weight is described as the total shell weight, including the weight of cockle meat. In T. granosa, the shell weight was generally heavier than the meat weight. When the shell size increased, then the overall weight of the cockle also increased linearly. However, the analysis of the samples showed no signif?cant 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 f?xed for species. Dif?er - ences in growth models might appear in the same or dif?erent species, among sex, indif?erent or the same locations and in dif?erent seasons. The dif?erence in latitudinal gradient is also related to the shell size, reproduction level and repro- ductive 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 dif?erences compared to the cockles from Pulau Pinang. T. granosa from Banda Aceh and Lhokseumawe had special shell features that were thicker and wider compared to T. granosa cockles from Pulau Pinang. Other studies on the relationship in length and weight regarding some Tegillarca species have demon- strated diversity and dif?erences in growth patterns (Table 4). The value of the b coef??cient on the relationship of shell length and cockle weight noted in this study was lower than that recorded in other species in the same family, namely Tegillarca granosa (b = 2.82) from Korean waters.

Another Table 3 (continued) Environmental parameter June 2009 July 2009 August 2009 September 2009 Novem- ber 2009 October 2010 December 2009 January 2010 February 2010 March 2010 April 2010 May 2010 June 2010 July 2010 August 2010 Septem- ber 2010 Average ± st.dev Lhokseumawe 0.03 0.03 0.04 0.04 0.05 0.03 0.44 0.03 0.43 0.02 0.08 0.07 0.02 0.08 0.03 0.04 0.09 ± 0.14 Pulau Pinang 0.03 0.03 0.04 0.06 1.09 1.68 0.18 1.00 0.13 0.12 0.09 0.03 0.14 0.12 0.39 0.87 0.37 ± 0.50 Ammonia (mg/L) Banda aceh 0.87 0.20 0.16 0.15 0.11 0.68 0.06 0.13 0.08 0.09 0.19 0.79 0.18 0.06 0.59 0.13 0.28 ± 0.27 Lhokseumawe 0.19 0.17 0.25 0.25 0.14 0.35 0.23 0.30 0.19 0.27 0.39 0.49 0.27 0.21 0.43 0.24 0.27 ± 0.10 Pulau Pinang 0.24 0.18 0.14 0.25 0.42 0.11 0.61 0.15 0.68 0.54 0.65 0.98 0.65 0.54 0.82 0.65 0.48 ± 0.27 Phytoplankton density (cell/L) Banda aceh 1831.67 1446.67 851.67 1178.33 630.00 991.67 1201.67 385.00 1773.33 1388.33 1516.67 1785.00 1738.33 1283.33 1341.67 1108.33 1278.23 ± 433.14 Lhokseumawe 1656.67 1365.00 711.67 2601.67 3010.00 1435.00 4001.67 1365.00 2986.67 2415.00 2333.33 2298.33 2415.00 1050.00 1003.33 2310.00 2059.90 ± 225.33 Pulau Pinang 4340.00 4001.67 1470.00 11,713.33 4340.00 4281.67 2636.67 4561.67 4235.00 5751.67 5693.33 6090.00 5728.33 5751.65 2905.00 7910.00 5088.12 ± 937.89 163 dif?erence was also found in their relationship model, namely Scapharca from Korean water, which had positive allom- etry and isometric relationships, while T.

granosa from the northern region of the Strait of Malacca displayed negative allometry. Dif?erent growth patterns at dif?erent latitudes might be caused by the inf?uence of environmental factors, changes in the composition of the food, and competition between individuals in a particular habitat. 4.2 Relationships of the Biometric Component of T. granosa Analysis of the relationship of each biometric parameter of T. granosa through dendrogram or classif?cation methods (hierarchy) was used to assess the growth patterns of the three T.

granosa populations in the northern region of the Strait of Malacca. The dendrogram was designed to clarify the relationship of each biometric component in cockles. Figure 3 shows the relationship between the biometric com- ponents of T. granosa. Through this analysis, the degree of dissimilarity between generated clusters is shown. The relationship between a biometric component in one clus- ter compared to another biometric component in a dif?erent 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 com- ponents in two dif?erent clusters was correspondingly high. Dendrogram analysis showed that cluster A had two sub- clusters; namely, A1 represented the biometric component of T. granosa from Lhokseumawe and A2 represented the biom- etric component of T. granosa from Banda Aceh, which was separated on a scale of 16. Cluster B was a hierarchy cluster of biometric components of T. granosa from Pulau Pinang. Clus- ter 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 dif?erent from the high level of inequality among the clusters (population) and sub-clusters (subpopulations). This condition was interpreted to mean that the T. granosa populations from Lhokseumawe and Banda Aceh (Indonesia) and Pulau Pinang (Malaysia) had signif?cant dif?erences in shell form and growth pattern and further correlated to the biometric relationship models. Gas- par et al.

(2002, 2001) and Popa et al. (2010) stated that the population can be explained in particular by the growth char - acteristics through the measurement of biometric morphology. It is thought that the factor that could cause variances in biometric components and thus af?ect T. granosa growth pat- terns between cluster A and cluster B is spatial dif?erentiation. The source of T. granosa from cluster A was distinct from cluster B, where T. granosa populations within cluster A came from the northern region of Sumatra island, while T. granosa in cluster B originated from the western region of Peninsular Malaysia.

Sub-clusters of A were also known to have dif?er - ences in growth patterns of the biometric component; they even had close proximity. T. granosa of sub-clusters A1 and A2 were expected to come from the same population source. Dif?erences in the pattern of biometric components may have occurred because of the dif?erences in environmental factors that were local in nature, af?ecting the growth patterns. Dif?er - ences 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; Lor - rain et al. 2000; Miyaji et al. 2007) also play a role in determin- ing the growth pattern of cockles in the three sampling areas. Table 4 The length-weight relationship model for Arcidae Family/species n Allometric models R2 Relationship model Location References Arcidae Scapharca broughttonii 88 W = 0.000073L 3.31 0.943 (+) Allometric Korea Park and Oh (2002) Scapharca subcrenata 114 W = 0.0004L 2.97 0.935 Isometric Korea Park and Oh (2002) Tegillarca granosa 377 W = 0.00068L 2.82 0.960 (-) Allometric Korea Park and Oh (2002) Tegillarca granosa 640 W = 0.0016L 2.618 0.884 (-) Allometric Banda Aceh, Indonesia Current research Tegillarca granosa

640 W = 0.009L 2.763 0.924 (-) Allometric Lhokseumawe, Indonesia Current research Tegillarca granosa 640 W = 0.061L 2.202 0.735 (-) Allometric Pulau Pinang, Malaysia Current research 164 M. Khalil et al. Acknowledgements The authors would like to thank Marine Science Laboratory Universiti Sains Malaysia and Universiti Sains Malaysia for RU grant (award no.1001/PP/8011088), Directorate General of Higher Education—Ministry of Education and Culture of the Republic of Indonesia, Department of Marine Science - Universitas Malikus- saleh, Malaysia Quarantine, and Inspection Services (MAQIS) and Fish Quarantine and Inspection Agency - Ministry of Maritime Af?airs and Fisheries of the Republic of Indonesia for their continuous support in making this project a success.

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(BSL Banda Aceh Tegillarca granosa shell length, BSH Banda Aceh Tegillarca granosa shell height, BC Banda Aceh Tegillarca granosa shell thick - ness, BTV Banda Aceh Tegillarca granosa total volume, BSV Banda Aceh Tegillarca granosa shell volume, BFCW Banda Aceh Tegillarca granosa f?esh weight, BFTW Banda Aceh Tegillarca granosa tissue weight, BDSW Banda Aceh Tegillarca granosa dry shell weight, BDTW Banda Aceh Tegillarca granosa dry tissue weight, LSL Lhokseumawe Tegillarca granosa shell length, LSH Lhokseumawe Tegillarca granosa shell height, LC Lhokseumawe Tegillarca granosa shell thickness, LTV Lhokseumawe Tegillarca granosa total volume, LSV Lhokseumawe Tegillarca granosa shell volume, LFCW Lhokseumawe Tegillarca granosa f?esh weight, LFTW Lhokseumawe Tegillarca granosa tissue weight, LDSW Lhokseumawe Tegillarca granosa dry shell weight, LDTW Lhokseumawe Tegillarca granosa dry tissue weight, PSL Pulau Pinang Tegil- larca granosa shell length, PSH Pulau Pinang Tegillarca granosa shell height, PC Pulau Pinang Tegillarca granosa shell thickness, PTV Pulau Pinang Tegillarca granosa total volume, PSV Pulau Pinang Tegillarca granosa shell volume, PFCW Pulau Pinang Tegillarca granosa f?esh weight, PFTW Pulau Pinang Tegillarca granosa tissue weight, PDSW Pulau Pinang Tegillarca granosa dry shell weight, PDTW Pulau Pinang Tegillarca granosa dry tissue weight) 165 Bailey R, Green R (1988) Within-basin variation in the shell mor - phology and growth rate of a freshwater mussel.

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