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Biometric and condition index of *Anadara antiquata* (Bivalvia: Arcidae) from the intertidal area of Lhokseumawe, Indonesia

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Abstract

Although the biometric characteristics and condition indices of bivalves, including *Anadara antiquata*, are well-studied, their relationship with environmental factors in tropical intertidal zones, remains poorly understood. This study examined the biometric characteristics and condition index of the cockle *A. antiquata* in relation to water quality parameters in the intertidal zone of Lhokseumawe, Indonesia, from August 2014 to March 2015. Monthly sampling of 50 cockles during low tide in the estuarine reservoir measured cockle weight, shell length, shell height, condition index, and water quality parameters, including temperature, pH, and salinity. Strong positive relationships were observed between shell length and cockle weight (R^2 = 0.847, r = 0.920), shell height and shell length (R^2 = 0.861, r = 0.927), and cockle weight and shell height (R^2 = 0.887, r = 0.941). Allometric models indicated negative allometry in these relationships. Analysis of the condition index revealed continuous dribble spawning throughout the study period. Water quality parameters included temperatures ranging from 28.2 – 32.2 °C (mean 30.02 ± 1.62 °C), salinity levels between 34.4 – 35.5 ppt (mean 35.08 ± 0.32 ppt), and pH values of 6.77 – 6.86 (mean 6.82 ± 0.03), reflecting favourable environmental conditions for cockle growth and reproduction.

Keywords: Cockle, intertidal zone, allometric, water quality, spawning season

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Introduction

Bivalvia represents the second largest class within the phylum Mollusca, following Gastropoda in terms of species diversity (Araujo & de Jong, 2015). The class Bivalvia encompasses approximately 10,000 to 20,000 species globally (Gonzalez et al., 2015). Bivalves are distinguished by their bilaterally symmetrical, hinged shells, which are typically composed of two valves (Gosling, 2008). Among the various genera within this class, *Anadara* stands out as a prominent group of ark clams distributed primarily across tropical and subtropical marine environments (Ahyong et al., 2023). Members of the genus *Anadara* are commonly found in shallow coastal regions, where they inhabit sandy or muddy substrates; species play a vital ecological role as filter feeders, contributing to nutrient cycling, sediment stabilization, and overall water quality (Broom, 1985). In Indonesia, *Anadara* species have significant ecological and economic value, with several species harvested for human consumption, thus supporting local fisheries and livelihoods (Selly, 2014). Among the *Anadara* species utilized as a food source is *Anadara antiquata*, although biological research on this species remains limited due to its lower popularity compared to the commercially favoured *A. granosa*.

The cockle *A. antiquata* is a bivalve species with significant potential as a food source for coastal communities in Indonesia. As part of the edible and economically valuable, *A. antiquata* is distinguished by fine hair-like structures along the edge of its shell (Azmi et al., 2022). This species typically inhabits tidal zones or estuarine areas with muddy substrates, often in proximity to mangrove forests (Broom, 1985; Jahangir et al., 2014). Due to its palatable and marketable meat, *A. antiquata* has considerable economic value and serves as an important source of income for local populations. However, despite its use, detailed information on *A. antiquata* in Indonesia remains scarce. The increasing demand for this species poses a threat to natural populations, as overharvesting can lead to population declines. Beyond consumption, *A. antiquata* is also valued for its potential use in handicrafts and traditional medicine (Syukur et al., 2021; Sami, 2024). The continuous overexploitation of local farmers could significantly reduce the availability of this species, adversely affecting community livelihoods, particularly for those who depend on cockle harvesting for their income.

The increasing demand for *A. antiquata* can significantly affect natural populations, particularly when harvesting practices are not carefully managed. However, current fishing methods often do not consider the size or reproductive status of the cockles, leading to the capture of individuals who are still actively breeding. Continuous harvesting without size or reproductive considerations will ultimately result in a decline in cockle populations. This reduction would directly affect the income of communities that rely on the harvest of cockles as a primary source of income. Research focused on biometric data, condition indices, and cockle growth rates can provide valuable information to farmers, enabling them to adopt more sustainable harvest and cultivation practices. This information is critical to reducing overexploitation and ensuring the long-term availability of natural cockle resources.

Unregulated harvesting, especially of *A. antiquata* during its reproductive phase, can lead to a serious decline in populations. This not only threatens species but also negatively impacts communities that depend on it for their livelihoods. As natural stocks decrease, the availability of *A. antiquata* decreases, reducing the income of fishermen and local populations. Furthermore, the loss of this species could disrupt the balance of estuarine ecosystems, where it plays an important role in maintaining water quality and habitat structure. To address these issues, sustainable management practices are crucial to protect *A. antiquata*. Approaches like harvesting only mature, nonreproductive individuals and promoting aquaculture can reduce the strain on wild populations. Cultivating *A. antiquata* offers a reliable income source while helping to conserve natural stocks.

This study aims to link knowledge gaps by exploring biometric traits, condition indices, and growth patterns of *A. antiquata*. The insights gained will be invaluable for developing sustainable harvesting practices. Furthermore, understanding how *A. antiquata* interacts with its environment, especially factors such as water quality, will help guide better management and conservation efforts for the species.

Methods

Sampling location

This study was conducted from August 2014 to March 2015 at the Lhoksumawe City Reservoir (Figure 1). Cockle samples (*A. antiquata*) were collected monthly during low tide in the muddy intertidal zone using hand tools and a bamboo cockle grab. A total of 400 mature cockles were collected and transported to the Laboratory of Water Quality and Nutrition, Department of Aquaculture, Universitas Malikussaleh for analysis.

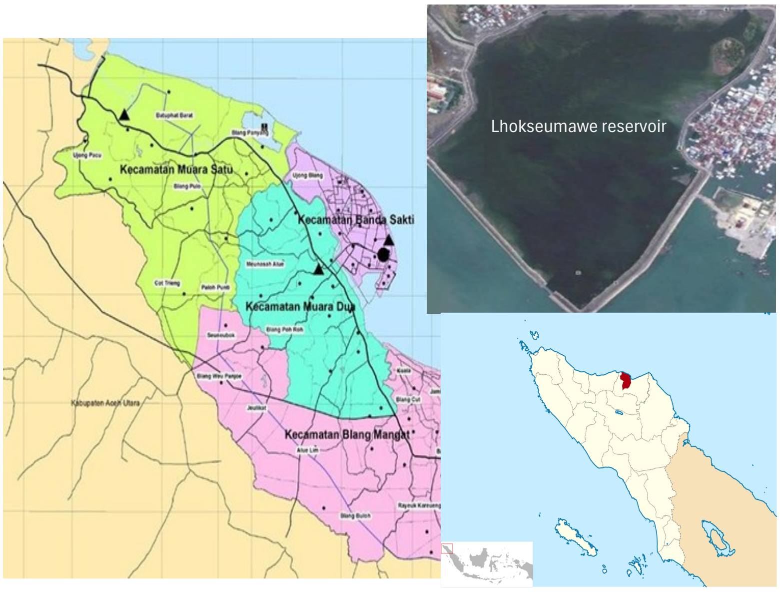

Figure 1. Sampling location in Lhokseumawe reservoir area.

Biometric measurement

Each month, 50 cockles of varying sizes (400 samples in total) were measured for shell length, shell height, and shell width using a Vernier calliper with 0.1 mm accuracy. The weight of each cockle was determined using an analytical balance (in grams). The length of the shell was measured from the posterior to the anterior margin, the width of the shell was measured from the most protruding part of the upper part to the bottom of the shell, and the height of the shell was recorded from the ventral to the dorsal margin.

Condition index analysis

The condition index (CI) was analysed by first weighing each cockle along with its aluminium foil support. Shell length, width, height, and total weight were recorded. The cockles were then

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dissected to separate the soft tissue from the shell, both of which were individually weighed. The shell and soft tissue were then dried in an oven at 100 °C for 48 hours. The condition index was calculated using the method outlined by Devenport and Chen (1987), employing the following formula:

CI = dry meat weight (g) / dry shell weight (g) x 100

Water quality measurement

Water quality measurements were taken every three days at 2:00 p.m. in the afternoon. Salinity, pH, and temperature were recorded at each sampling. The temperature was measured using a maximum-minimum thermometer to capture the highest and lowest daily temperatures during the sampling period.

Data analysis

The biometric relationships between shell length, width, height, total weight, and meat weight were analyzed using regression analysis in Microsoft Excel. The cockle growth pattern was determined by examining the relationship between shell length and body weight, using a quadratic equation (power regression) as described by Ricker (1975):

$Y = aX^b$

With the derivative relation: weight : $W = aL^b$,height: $H = aL^b$, width: $P = aL^b$

Where: W = total weight (gr), T = total height (mm), P = total width (mm), L = total length (mm), and *a*, *b* = constants.

The hypothesis used to see the relationship between shell dimensions and total weight of cockles is as follows.

H_0: $b = 3$, isometry relationship

H_1: $b \neq 3$, allometry relationship

In analysing the growth relationship, if the coefficient *b* is less than 3 ($b < 3$), it indicates minor or negative allometric growth, meaning that the cockle's weight increases at a slower rate than its length. If *b* is greater than 3 ($b > 3$), it indicates major or positive allometric growth, where weight increases faster than length. If *b* value equal to 3 ($b = 3$) represents isometric growth, where weight gain is proportional to an increase in shell length.

Results

Biometric relationship

Biometric measurements, including the length, width, height, and total weight of *A. antiquata*, revealed the following relationships:

Length and weight relationship

Analysis of the length and weight relationship of *A. antiquata* collected from the intertidal zone of Lhokseumawe City showed a strong linear correlation. The regression equation was $y = 1.070x^{0.299}$, with an R^2 value of 0.847 and r = 0.920. The calculated values of $a = 1.070$ and $b = 0.299$ indicate rejection of H_0 ($b \neq 3$), confirming a negative allometric relationship ($b < 3$), where weight increases at a slower rate than length (Figure 2).

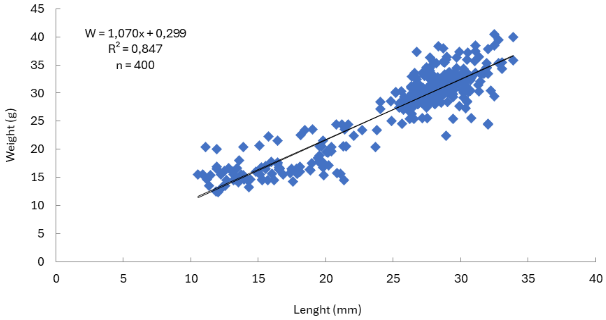

Figure 2. Relationship model between shell length and weight of cockles *A. antiquata*.

Length and width relationship

The analysis of the shell length-width relationship also demonstrated a strong linear correlation. The regression equation was $y = 1.207x^{-2.876}$, with $R^2 = 0.861$ and r = 0.927. With $a = 1.207$ and $b = -2.876$, the result showed a negative allometric relationship ($b < 3$), which means that the width of the shell increases more slowly than the length of the shell (Figure 3).

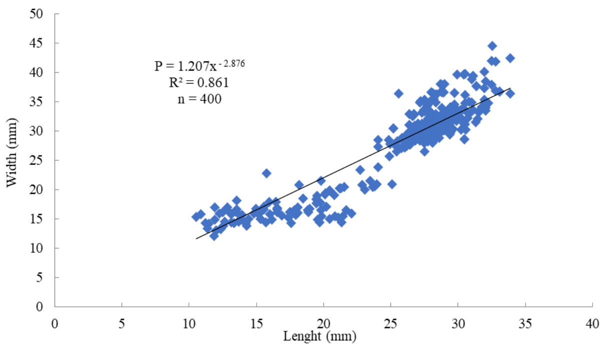

Figure 3. Relationship model between shell length and width of cockles *A. antiquata*.

Length and height relationship

The relationship between shell length and height was similarly strong. The regression equation was $y = 0.808x^{2.660}$, with $R^2 = 0.887$ and r = 0.941. The values of $a = 0.808$ and $b = 2.660$ again confirmed a negative allometric growth pattern ($b < 3$), indicating height increases at a slower rate relative to shell length (Figure 4).

Condition index of *A. antiquata*

The condition index analysis of *A. antiquata* was categorized into average, highest, and lowest values. The highest condition index was recorded in November 2014, with a value of 8.358 ± 5.465, while the lowest was in January 2015, with a value of 3.87 ± 5.72 (Figure 5).

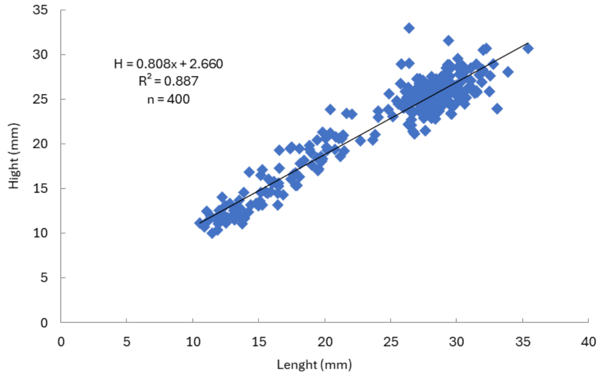

Figure 4. Relationship model between shell length and hight of cockles *A. antiquata*.

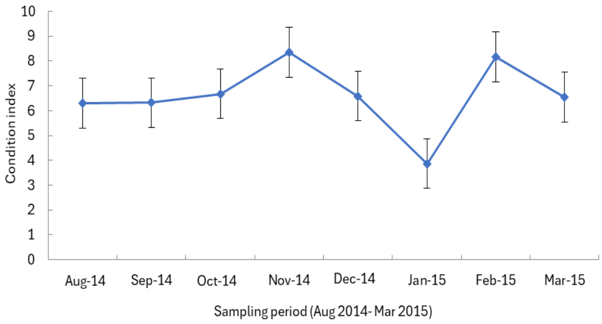

Figure 5. Condition index of cockle *A. antiquata* in Lhokseumawe.

Water quality parameter

The recorded environmental parameters revealed variations in temperature, salinity, and pH throughout the study period. The highest minimum temperature, 28.8 °C, was observed in August 2014, while the highest maximum temperature reached 32.3 °C during the same month. In contrast, the lowest minimum temperature, 28.2 °C, occurred in January 2015, with the lowest maximum temperature at 31.0 °C. On average, the minimum temperature was 28.4 ± 0.1669 °C, and the maximum temperature was 31.6 ± 0.3882 °C, indicating stable thermal conditions suitable for cockle growth.

Salinity ranged from a high of 35.5 ppt in September 2014 to a low of 34.6 ppt in November 2014, with an overall average of 35.0 ± 0.3240 ppt, remaining within the optimal range for cockles. The pH values ranged from 6.77 (lowest in November 2014) to 6.86 (highest in September 2014), with an average of 6.82 ± 0.0292, reflecting stable and favourable conditions for the cockle habitat.

Discussion

Biometric relationship of *A. antiquata*

The variations in the size of *A. antiquata* observed during this study were highly diverse, with individuals exhibiting a range of lengths and weights, from the shortest and lightest to the longest and heaviest. These size variations are influenced by environmental conditions, as noted by Azmi et al. (2022). To better understand the strength of the relationships between these variables, the following correlation categories, as defined by Schober et al. (2018), were applied: a strong negative relationship is indicated by -1.00 ≤ r ≤ -0.80, a medium negative relationship by -0.79 ≤ r ≤ -0.50, a weak relationship by -0.49 ≤ r ≤ 0.49, a medium positive relationship by 0.50 ≤ r ≤ 0.79, and a strong positive relationship by 0.80 ≤ r ≤ 1.00.

The weight-length relationship of *A. antiquata* showed an R^2 value of 0.847 and a correlation coefficient r = 0.920, indicating a strong positive relationship (0.80 ≤ r ≤ 1.00). The growth coefficient *b* = 0.299 suggests negative allometric growth, where the increase in shell length is proportionally greater than the increase in tissue weight. This pattern occurs because early in life, cockles prioritize survival, focusing on shell formation for protection while their weight increases at a slower rate. This growth strategy aligns with the deeper-water habitats of cockles, where environmental conditions such as food availability shape their development. Similarly, Siahainenia et al. (2018) reported that *A. antiquata* from Maluku waters exhibit negative allometric growth, with shell length increasing rapidly during growth phases, driven by abundant natural food. Weight growth remains slow as cockles prioritize shell development over reproduction.

The lack of distinction between male and female samples in this study could also influence these findings. Rangel et al. (2016) emphasized that reproductive factors affect growth, altering allometric relationships. Additionally, Purroy et al. (2018) highlighted that life strategy and environmental conditions largely determine growth patterns in bivalves.

The width-length relationship for the 400 cockles from the Lhokseumawe reservoir demonstrated an R^2 value of 0.861 and a correlation coefficient r = 0.927, reflecting a strong positive relationship (0.80 ≤ r ≤ 1.00). The growth coefficient *b* = -2.876 also indicates negative allometry, where increases in shell length are proportionally larger than increases in shell width. This linear growth pattern suggests that changes in shell length are closely mirrored by proportional changes in width. This finding corroborates the work of Siahainenia et al. (2018), who reported a similarly strong positive correlation between shell length and width, where 94% of the variation in width was attributed to changes in length, with environmental factors such as food availability accounting for the remaining variation.

The height-length relationship yielded an R^2 value of 0.887 and a correlation coefficient r = 0.941, denoting a strong positive relationship (0.80 ≤ r ≤ 1.00). The growth coefficient *b* = 2.660 reflects negative allometric growth, where the increase in shell length outpaces the increase in height. Shell height growth is functionally tied to environmental conditions and locomotion. For example, Richardson et al. (1997) observed that cockle growth is significantly influenced by factors such as food availability, temperature, substrate type, water currents, and salinity. Greater shell height can facilitate movement by improving jumping or leaping capability while also offering enhanced protection for internal tissues.

The observed patterns of growth align with life strategies aimed at maximizing survival and reproduction. Following the spawning season in November, cockles experience a rapid increase in length, reaching approximately 50 mm within 6-7 months and commercial sizes (>90 mm) within a year. Growth relationships, including weight-length, width-length, and height -length, are influenced by site-specific environmental and biological factors, underscoring the variability of cockle morphometric characteristics across different regions (Khalil et al., 2017; Mirzaei et al., 2017).

Condition index (CI) of cockle *A. antiquata*

The condition index (CI) is calculated as the dry weight of the cockle divided by its shell weight, multiplied by 100, serving as a measure of growth in relation to environmental factors and reproductive cycles (Filgueira et al., 2013; Joaquim et al., 2008; Marquardt et al., 2022). During gonadal development, the CI increases, reflecting enhanced energy allocation toward reproduction. Khalil et al. (2017) observed higher CI values in cockles with mature gonads or those actively reproducing, while individuals in earlier growth phases exhibit lower CI values.

In the analysis of blood cockles from Lhokseumawe, gonad development was observed in August, September, and October 2014, with maturity achieved by November 2014. Spawning occurred in December 2014 and January 2015, followed by another maturation and spawning phase in February and March 2015. These trends highlight the cyclical nature of the CI, where higher values correspond to gonadal maturity and lower values follow spawning events, as described by Chávez-Villalba et al. (2008). Cataldo et al. (2001) emphasized the significance of the CI as an indicator of growth during reproduction, while Martínez-Pita et al. (2011) highlighted the role of increased food availability in enhancing gonad size and overall body growth.

Environmental factors play a crucial role in influencing CI. For example, in January 2015, elevated salinity coincided with gamete release, supporting findings by Magaña-Carrasco et al. (2018), who noted that higher salinity levels often trigger gamete release, while sudden salinity drops can also induce spawning. Khalil et al. (2021); Neto et al. (2013) similarly reported that salinity, water conditions, and food availability impact growth and reproduction cycles in bivalves, influencing shell size and CI.

Water quality in *A. antiquata* habitat

Water quality is vital for the survival and growth of cockle *A. antiquata*, as it directly affects their physiological processes (Broom, 1985; Malham et al. 2012; Wanjeri et al., 2023). During the study, water temperature ranged from 28.4 ± 0.17 °C to 31.6 ± 0.39 °C, conditions deemed suitable for cockles under KLH (2014) guidelines, which define 28 - 31 °C as optimal. Temperature influences cockle metabolism and respiration, with excessively high temperatures potentially disrupting these processes (Boyden, 2009). The recorded salinity averaged 35.0 ± 0.32 ppt, within the optimal range of 32 - 38 ppt recommended by KLH (2014). Cockles thrive in a broader salinity range of 25 - 30 ppt (Broom, 1985) and can tolerate fluctuations from 5 to 35 ppt, demonstrating their adaptability to varying environments.

The average pH level was 6.82 ± 0.03, consistent with KLH (2014) recommendations of 6.5 - 8.5. Akhrianti et al. (2023) noted that a pH range of 7.0 - 8.5 is ideal for cockle development. Extreme pH levels (<5 or >9) are detrimental, creating unsuitable conditions for macrozoobenthic and potentially inhibiting cockle growth. These findings confirm that the water quality parameters during the study were favourable for the survival, growth, and reproduction of *A. antiquata*, aligning with environmental standards and supporting their observed biological cycles.

Conclusions

The study of the biometric relationship of *A. antiquata* in the Lhokseumawe waters indicates diverse growth patterns influenced by environmental conditions, with negative allometric relationships observed between length, weight, width, and height. Strong positive correlations (R^2 values) suggest that shell length significantly affects width and height, indicating a consistent growth pattern across measured dimensions. These findings are consistent with previous studies on similar species, which attribute such growth behaviours to environmental factors such as food availability and reproduction cycles.

The condition index analysis further demonstrates that the reproductive cycles of *A. antiquata* strongly influence growth, with higher condition index values indicating gonadal maturity. Spawning events, particularly in November and March, are associated with environmental factors such as salinity, which affect gamete release. The parameters of water quality, such as temperature, salinity and pH, remained within favourable ranges for the growth of the species throughout the study, confirming the suitability of Lhokseumawe waters to support cockle populations. Overall, biometric relationships, condition index variations, and favorable water quality conditions underscore the complex interaction between environmental factors and the growth and reproduction of *A. antiquata* in Lhokseumawe.

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Authorship contribution

Siti Umayyah Kafi: Conceptualization, methodology, investigation, resources, sample processing and analysis, data curation, formal analysis, visualization, original draft preparation writing, review and editing. **Zulfikar Zulfikar**: Writing - review and editing, supervision. **Munawar Khalil**: Conceptualization, writing - review and editing, supervision. All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Data availability

Datasets generated during and/or analysed throughout the present study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare no conflict of interest.

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