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Original Article

Population structure of Pacific oysters *Crassostrea gigas* (Bivalvia, Ostreidae) from north-eastern waters of Aceh province, Indonesia

Estrutura populacional das ostras do Pacífico *Crassostrea gigas* (Bivalvia, Ostreidae) das águas do nordeste da província de Aceh, Indonésia

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Abstract

Oysters (*Crassostrea gigas*) are among the primary economic resources for coastal communities, while have a positive impact on the economies of fisherman families that have lower to middle incomes. This research aims to determine the population structure of *Crassostrea gigas* that are distributed in the north-eastern waters of Aceh Province, Indonesia. Sampling occurred in 9 areas along the northeastern coast of Aceh Province, with 50 oysters gathered from each region. The total length, width, and height of the morphometric characteristics were measured using a digital caliper with an error margin of 0.01 mm. The morphometric data underwent statistical analysis, encompassing ANOVA, discriminant analysis, and closest neighbor analysis. Results revealed that all the morphometric characters of the oysters at the 9 sampling locations were significantly different ($p < 0.05$). The results of discriminant and nearest neighbor analysis showed two different populations of *C. gigas* in Aceh. Whereas one population of *C. gigas* was only found in Banda Aceh, the other one population could be found in 8 other regencies. Results of this population structure analysis reflect the environmental conditions of the sampling locations as well as the evolution patterns of *C. gigas* in Aceh Province. This study revealed that there are several populations of *C. gigas* in Aceh Province which indicate morphological variations related to the species' evolutionary process.

Keywords: morphometric, discriminant analysis, evolutionary process, oysters, nearest neighbor analysis.

Resumo

Esta pesquisa tem como objetivo determinar a estrutura populacional das ostras *Crassostrea gigas*, que se distribuem nas águas do nordeste da província de Aceh, na Indonésia. A amostragem foi realizada em nove distritos ao longo da costa nordeste da província de Aceh e foram recolhidas 50 ostras em cada distrito. Com o recurso de um paquímetro digital (erro = 0,01 mm), foram medidos o comprimento total, a largura e a altura, para compor os caracteres morfométricos. Os dados morfométricos foram depois submetidos a análise estatística, incluindo ANOVA, análise discriminante e análise do vizinho mais próximo. Os resultados da ANOVA revelaram que todos os caracteres morfométricos das ostras, nos nove locais de amostragem, foram significativamente diferentes ($p<0,05$). Os resultados da análise discriminante e do vizinho mais próximo mostraram duas populações diferentes de *C. gigas* em Aceh. Enquanto uma população de *C. gigas* foi encontrada apenas em Banda Aceh, a outra população pôde ser encontrada em outros oito distritos. Os resultados desta análise da estrutura populacional refletem as condições ambientais dos locais de amostragem, bem como os padrões de evolução de *C. gigas* na província de Aceh.

Palavras-chave: morfométrica, análise discriminante, processo evolutivo, ostras, análise do vizinho mais próximo.

1. Introduction

Aceh Province has relatively diverse coastal resources, including fish (Batubara et al., 2017; Nur et al., 2019; Fadli et al., 2020; Octavina et al., 2021), seaweeds (Erniati et al., 2023; Gazali et al., 2023), lobsters (Akmal et al., 2023; Irfannur et al., 2024), crabs (Ulfa et al., 2018), and oysters (Kasmini et al., 2019; Kasmini and Batubara, 2023). The majority of Acehnese who reside in the province's coastline region rely heavily on this resource. Oysters (*Crassostrea gigas* Thunberg, 1793) are among the primary economic resources for coastal communities. While male fishermen catch the fish in the ocean, the females' catches have a positive impact on

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the economies of fisherman families that have lower to middle incomes (Dzikira et al., 2022). Therefore, in order to ensure the sustainability of oyster utilization, oyster resources must be managed.

Until recently, 25 species of the genus *Crassostrea* have been successfully identified around the world (WoRMS, 2021). Among them, *C. gigas* is the most dominant species in the province of Aceh (Sarong et al., 2015; Kasmini et al., 2019; Ramadhaniaty et al., 2021; Kasmini and Batubara, 2023). This species has the widest spread in the world compared to other species (Cognie et al., 2006), they typically stick to a variety of hard media in the coastal sea and can be cultivated throughout the year (Kasmini et al., 2019). *C. gigas* is also an important species in the estuary region as it serves as a shadowing, cultivation, nutrient cycle, and bioindicator in the ecology (Kasmini and Batubara, 2022).

Research on *C. gigas* that has been carried out includes morphology (Evseev et al., 1996), growth (Brusca and Ardil, 1974; Bae et al., 1978; Almeida et al., 1999; Bochenek et al., 2001; Borges et al., 2002; Harding and Mann, 2006), bioindicators (Huanxin et al., 2000; Geffard et al., 2003; Banker and Sumner, 2020), reproduction (Barber, 1996; Castaños et al., 2009; Enríquez-Díaz et al., 2009), physiology (Child and Laing, 1998; Beninger and Cannuel, 2006; Mai et al., 2012; González-Fernández et al., 2018; Zheng et al., 2021), and ecological function (Walles et al., 2015). In Aceh, research on this species is still limited to distribution (Fadli et al., 2012), bioindicators (Sarong et al., 2015; Astuti et al., 2016; Kasmini and Batubara, 2023), reproduction (Kasmini et al., 2019), biology (Kasmini and Batubara, 2022), and morphology (Kasmini et al., 2018). Studies related to the population structure have never been conducted.

Research related to morphology through various approaches has been conducted by Liu et al. (2024) on the geometric morphometric method of grouping *C. gigas* and *C. ariakensis*; Vialova (2020) on the comparative morphology of diploid and triploid *C. gigas*; Batista et al. (2008) on the comparison of shell and muscle shapes of *C. angulata* and *C. gigas*; Acarli et al. (2023) on the morphometric characteristics of *C. gigas* in Bandirma Bay, Marmara Sea; Aydin et al. (2021) on DNA identification and morphometric characteristics in the southern Black Sea. However, there have been no reports regarding the population structure of *C. gigas* in various locations in the north-eastern waters of Aceh Province, Indonesia.

Population structure is the identification of species based on their biogeographical spread (Kreft and Jetz, 2010). The history of life and population expansion can also be revealed in the population structure. In addition, the population structure is also related to mortality, birth rate, age, biotic potential, dispersion, growth patterns, and development (Zhang et al., 2015). As a result, this study is crucial to identify the *C. gigas* population in Aceh, allowing population management to be conducted based on the distribution regions themselves.

Population structure is identifying species based on their biogeographical spread (Kreft and Jetz, 2010). The population structure also provides insight into the evolution of life and population growth. Furthermore, mortality, birth rate, age, biotic potential, dispersion, growth patterns, and development are correlated with population structure (Zhang et al., 2015). In order to manage the population based on the actual distribution area, it is important to conduct research on the population structure of *C. gigas* in Aceh Province, Indonesia.

2. Materials and Methods

2.1. Location and time of study

The samples were taken along the north-east waters of the Province of Aceh, covering 9 regencies, including Banda Aceh, Aceh Besar, Pidie, Bireuen, Lhokseumawe, Aceh Utara, Aceh Timur, Langsa, and Aceh Tamiang (Figure 1 and Table 1). The sampling time was collected from June to August 2022. The samples that have been collected were measured in their morphometric characteristics at the Marine Biology Laboratory, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, Indonesia.

2.2. Sampling procedure

Oyster sampling amounted to 50 samples per location and all samples were then measured for morphometric characteristics. The body weight of *C. gigas* that has been collected were measured using a digital scale (accuracy 0.01 g). Morphometric measurements were then conducted using digital calibers (accuracy 0.01 mm), including three parameters that are total length, width, and height (Kasmini et al., 2018) (Figure 2).

2.3. Data analysis

Data analysis is performed using ANOVA test to determine the significance of the morphometric character based on the location of the sampling. While for population clustering (MANOVA) was used for the analysis of discriminant function and nearest neighbor. This statistical analysis was done using the SPSS program ver. 27.

Table 1. Location and coordinates of sampling of *Crassostrea gigas* along the North-East coast of Aceh Province, Indonesia.

No.	Location/Regency	Coordinate
1.	Banda Aceh	5º33'1.782" N; 95º17'12.128" E
2.	Aceh Besar	5º37'18.258" N; 95º23'53.407" E
3.	Pidie	5º24'18.663" N; 95º56'6. 853" E
4.	Bireuen	5º14'1.493" N; 96º41'42. 54" E
5.	Lhoksemawe	5º9'54.772" N; 97º8'32.899" E
6.	Aceh Utara	5º11'46.199" N; 97º22'5.571" E
7.	Aceh Timur	4º40'32.543" N; 97º55'0.465" E
8.	Langsa	4º51'89.082" N; 98º01'55.416" E
9.	Aceh Tamiang	4º45'52.175" N; 98º13'89.004" E

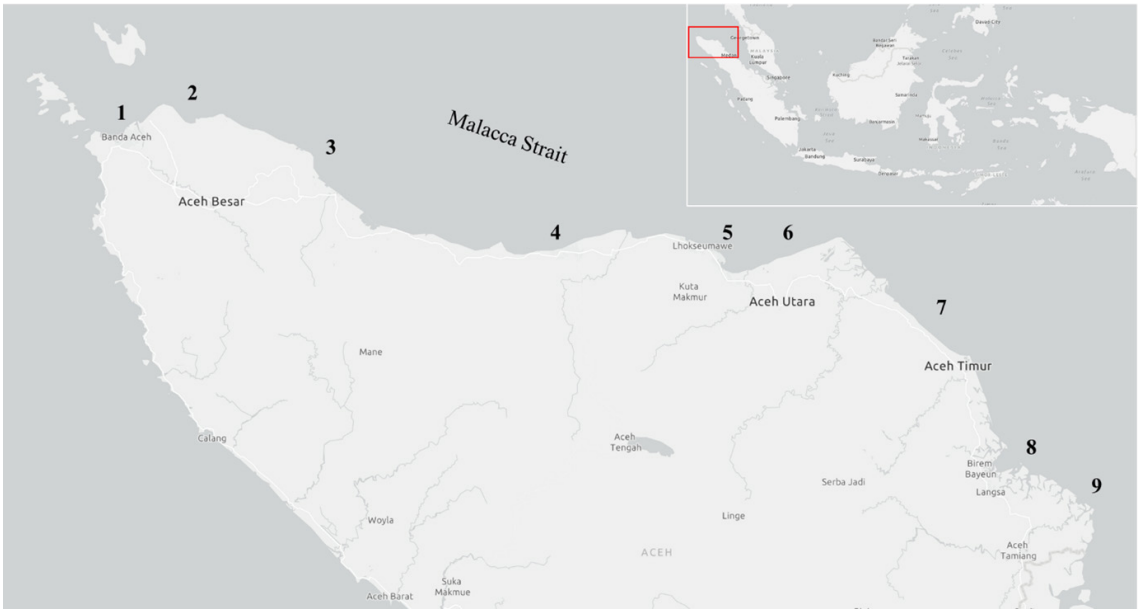

Figure 1. The map of sampling (*Crassostrea gigas*) locations, where (1) Banda Aceh, (2) Aceh Besar, (3) Pidie, (4) Bireuen, (5) Lhokseumawe, (6) Aceh Utara, (7) Aceh Timur, (8) Langsa, and (9) Aceh Tamiang.

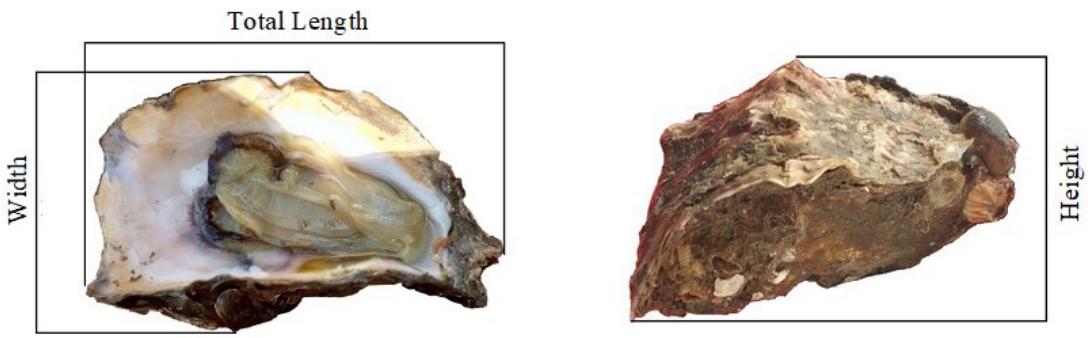

Figure 2. Measurement of three morphometric characters in *Crassostrea gigas*.

3. Results

The ANOVA analysis showed the entire morphometric character of the 9 sampling locations differs significantly ($p < 0.05$). The highest mean value of the total length found in the collections from Aceh Timur, that reached 66.8 ± 1.43 mm, while the lowest value was from Lhokseumawe (40.38 ± 0.74 mm) (Figure 3). The highest width ratio values are shown on collections from Banda Aceh (58.76 ± 0.82 mm), with the lowest values was 28.02 ± 0.61 mm. Higher height ratio is shown in collections of Aceh Timur, while the lowest found in Banda Aceh, 20.08 ± 0.72 mm and 4.98 ± 0.33 mm respectively (Table 2).

The discriminant analysis result showed there are two populations of *C. gigas* in Aceh (Figures 4 and 5). Whereas one population of *C. gigas* was only found in Banda Aceh, the other one population could be found in 8 other regencies. The morphometric characteristics of *C. gigas* collections from Banda Aceh had a relatively high variation compared to the other regencies, as *C. gigas* collections from Aceh Besar, Pidie, Bireun, Lhokseumawe, Aceh Utara, Aceh Timur, Langsa and Aceh Tamiang tend to have similar morphometric characteristics.

The eagenvalues in discriminant analysis indicates that only function 1 was eligible for further testing (values >1), whereas function 2 and 3 were not. Based on the value % variance shows that each value reaches 75.1% on function 1, 19.5% on function 2, and 5.4% on function 3. These results show the morphometric character that most contributes to discriminating any population, is the width on function 1 (Table 3).

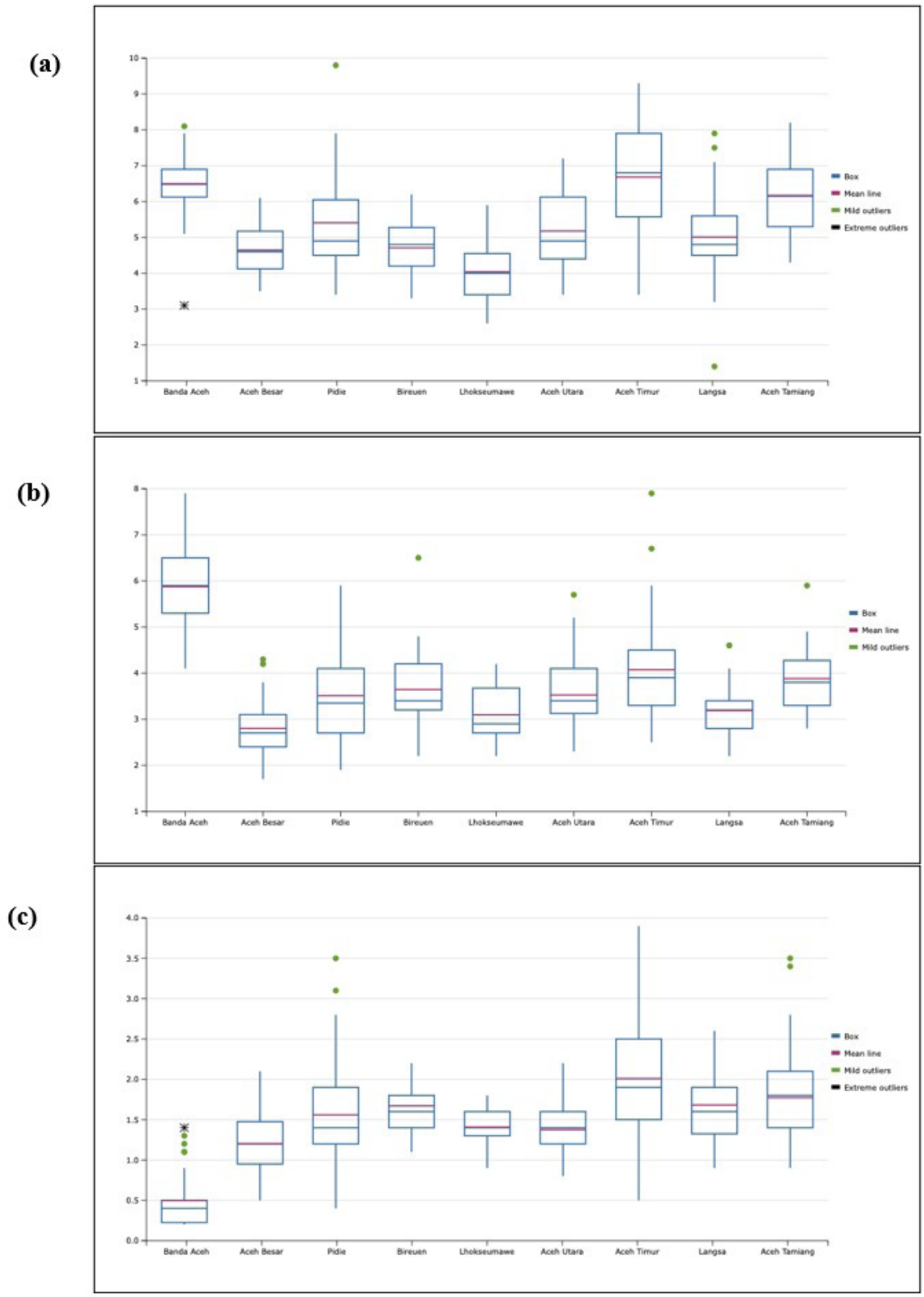

Figure 3. Stock chart of total length (a), width (b), and height (c) of pacific oyster (*Crassostrea gigas*) in 9 sampling locations.

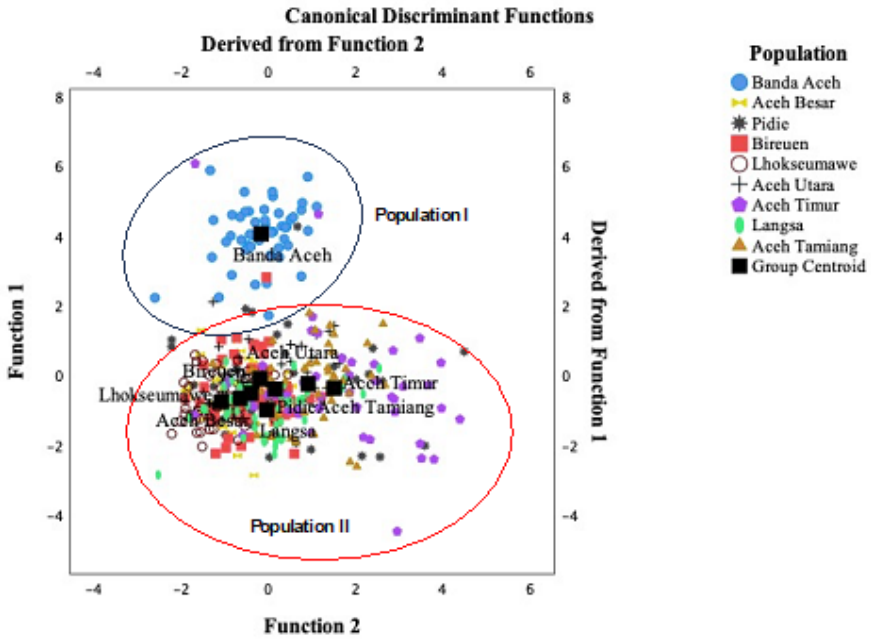

Figure 4. Discriminant functions analysis of *Crassostrea gigas* population structure based on scatter plot simulation.

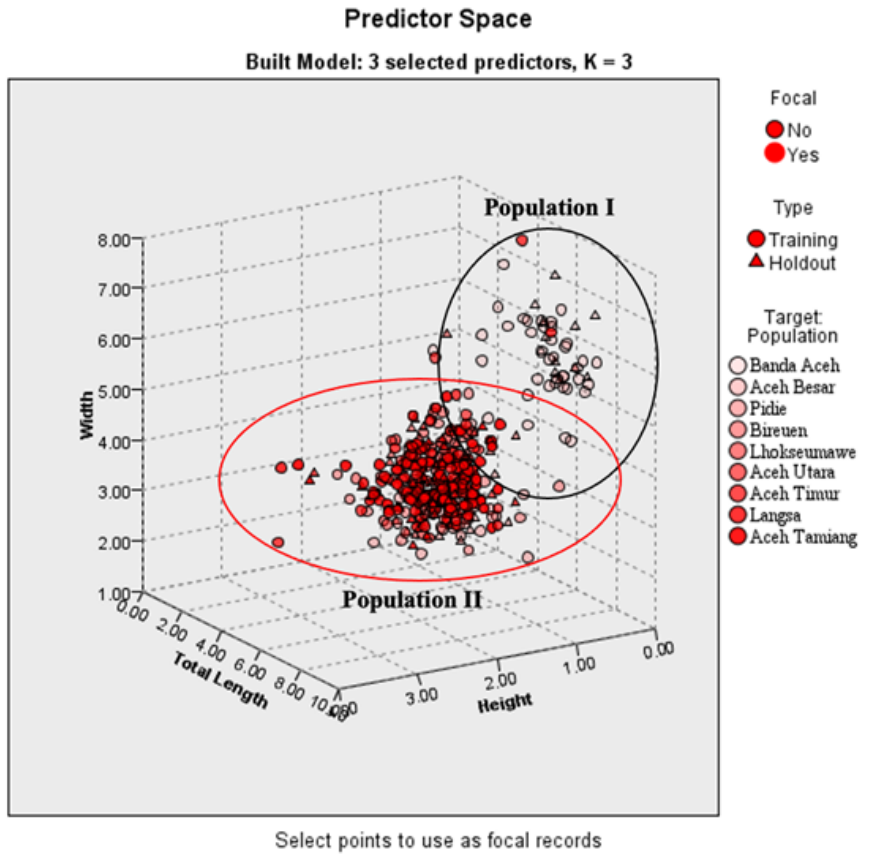

Figure 5. Nearest neighbor analysis of *Crassostrea gigas* population structure based on scatter plot simulation.

Table 2. ANOVA statistical test of morphometric characters of pacific oyster (*Crassostrea gigas*) in the 9 sampling locations.

Morphometric Characters	Sampling Location								
	Banda Aceh	**Aceh Besar**	**Pidie**	**Bireun**	**Lhokseumawe**	**Aceh Utara**	**Aceh Timur**	**Langsa**	**Aceh Tamiang**
Total Length (mm)	31–81 (64.82±0.83)^{de}	35–61 (46.44±0.67)^{b}	34–98 (54.08±1.39)^{c}	33–62 (47.08±0.74)^{b}	26–59 (40.38±0.74)^{a}	34–72 (51.78±1.04)^{c}	34–93 (66.8±1.43)^{e}	14–79 (50.1±1.07)^{bc}	43–82 (61.68±0.96)^{d}
Width (mm)	41–79 (58.76±0.82)^{f}	17–43 (28.02±0.61)^{a}	19–59 (35.10±0.99)^{c}	22–65 (36.44±0.79)^{cd}	22–42 (30.96±0.58)^{ab}	23–57 (35.26±0.74)^{c}	25–79 (40.72±1.07)^{e}	22–46 (31.88±0.52)^{b}	28–59 (38.82±0.66)^{de}
Height (mm)	2–14 (4.98±0.33)^{a}	5–21 (12.02±0.38)^{b}	4–35 (15.60±0.69)^{cd}	11–22 (16.70±0.31)^{de}	9–18 (14.08±0.18)^{c}	8–22 (13.76±0.26)^{bc}	5–39 (20.08±0.72)^{f}	9–26 (16.82±0.40)^{de}	9–35 (17.72±0.53)^{e}

Different superscripts in the same column indicate significant differences.

Table 3. Multivariate analysis on morphometric characteristics of *Crassostrea gigas* in 9 sampling location.

Function	1	2	3
Eagenvalues	2.157	0.560	0.155
% Variance	75.1	19.5	5.4
Canonical Correlation	0.827	0.599	0.367
Total length (TL)	0.309	0.941*	-0.140
Width (W)	0.700*	0.431	0.569
Height (H)	-0.494	0.631*	0.598

*Largest absolute correlation between each variable and any discriminant function.

4. Discussion

The morphometric analysis revealed that there are two populations of *C. gigas* in Aceh, one population was found only distributed in Banda Aceh, while the other population distributed in 8 other regencies. These results revealed there was a morphological variation that occurs in the population of *C. gigas* from Banda Aceh. The morphometric characteristics of the *C. gigas* population in Banda Aceh has significant different ratio values of total length, width, and height compared to other populations. A species' morphological variation demonstrates morphological adaptability to various circumstances in nature and represents a evolutionary pattern (Wang et al., 2020). Additionally, one of the factors causing variety in species is the availability of nutrients and food sources (Chen et al., 2010). Earlier studies have recorded morphological variation also found in *Cynodon dactylon* (Wang et al., 2020), *Caragana microphylla* (Chen et al., 2010), *Pinus tabulaeformis* (Ji et al., 2017), *Achnanthidium minutissimum* (Potapova and Hamilton, 2007), and *Tamarindus indica.* (Okello et al., 2018).

This morphometric research also revealed the range of distribution area of *C. gigas* in the Province of Aceh based on population. One population obtained the distribution area located in Banda Aceh, where the coastline extends for almost 14 km, meanwhile the other population is distributed over a wider region, encompassing 8 regencies and a coastline that is approximately 476 km long. Geographically, Banda Aceh is the centre government of the Aceh Province, in which have more massive industrial and human activity than the 8 other regencies. It is estimated that the corrosion factor affects the morphological differences of *C. gigas* between sampling areas, where Banda Aceh water is likely to be more polluted than other sampling areas. Previous research conducted showed that Banda Aceh's waters have been contaminated with heavy metals such as Cd, Pb, Zn, phosphate and nitrates (Rusydi et al., 2021; Ondara et al., 2022), and some of these heavy metals have also contaminated *C. gigas*, including Cd, Pb, and Zn (Sarong et al., 2015).

Based on the total length to width ratio, *C. gigas* from Banda Aceh was cumulatively higher than other regions with the values of 64.82 ± 0.83 mm and 58.76 ± 0.82 mm, respectively. However, the contradiction with the height ratio is significantly lower than other regions, with the value of 4.98 ± 0.33 mm, while the other 8 regencies have ratio values between 12.02–20.08 mm. These findings showed that *C. gigas* in Banda Aceh appears longer and wider, but thinner than other sample collections (Figure 3 and Table 2). As for *C. gigas* in the remaining 8 regions, it appears to be more proportional to their height, which directly affects the larger size of *C. gigas* meat than the population of Banda Aceh.

5. Conclusions

The study's findings demonstrated that there were substantial differences in all of the morphometric variables across all sampling locations. The results of discriminant and nearest neighbor analysis revealed there are two populations of *C. gigas* in Aceh, with one population of *C. gigas* is distributed in Banda Aceh and the other population found in other eight regencies of sampling locations. Therefore, it can be concluded that the Province of Aceh harbors two distinct populations of *C. gigas*, each of which reflects unique environmental features and evolutionary trends. Based on the results of this study, stakeholders can manage oysters based on 2 characteristic populations and further research is needed on the most optimal growth patterns between the 2 *C. gigas* populations from Aceh Province.

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Data Availability Statement

Data are available upon request.

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