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Original Article

Current status of blood cockle (*Tegillarca granosa*) aquaculture off Myeik City, Myanmar

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Abstract
Blood cockle aquaculture has played a vital role in the local economy around Myeik City, a major fishing hub in southern Myanmar, in recent years. This study aimed to assess the current state of aquaculture grounds and to contribute to the development of sustainable blood cockle farming. To determine the status of sowing aquaculture grounds, the main fishing sites were identified through boat-based surveys and interviews with local fishermen. Environmental characteristics of these areas were estimated using satellite imagery, along with weather and sea condition data. Additionally, shell length and whole weight of blood cockles purchased from a market in Myeik City were measured, and their digestive tube contents were examined. These results revealed that farming grounds were located around coves and creeks on small islands along the east coast of Kadan Island. These areas were characterised by high turbidity, with salinity remaining stable year-round at over 20 PSU. The annual chlorophyll-*a* concentration, approximately 4 µg L^{-1}, indicated a consistent presence of phytoplankton, which was also confirmed by the digestive content analysis. However, compared to data on blood cockles from other regions reported in related studies, those collected after the rainy season were noticeably lighter in weight, indicating a leaner condition. These findings suggested that alternating the use of offshore and coastal aquaculture grounds according to the rainy and dry seasons may enhance farming efficiency and realise sustainable aquaculture practices.

Keywords: blood cockle; digestive tube content; Myeik Myanmar; sowing aquaculture

1 | INTRODUCTION

The blood cockle, *Tegillarca granosa* (also known by its synonym *Anadara granosa*), belongs to the family Arcidae. Uniquely among many bivalves, it contains haemoglobin in its body fluids, which contributes to its distinctive red colour (Narasimham 1988; Bao *et al.* 2011; Zhu *et al.* 2011; Yang *et al.* 2023). This species has numerous nodules and approximately 18 radial ribs on its shell surface, and the number of radial ribs may vary slightly depending on the sea area (Yongpu *et al.* 2004). This species is widely distributed in coastal areas, such as the Middle East, India, China, Australia, western Japan, and mainly in Southeast Asian countries (Chakrabarti and Khasim 1989; Nakamura and Shinotsuka 2007; Faulkner 2010; Ni *et al.* 2012; Jahangir *et al.* 2014; Bahtiar *et al.* 2022). Additionally, its habitat is a soft mud area where clay and fine silt are deposited, and fishing grounds and aquaculture farms can be established around mud tidal flats or estuaries, such as mangroves (Narasimham 1969; Yurimoto *et al.* 2014a, 2014b, 2014c). Among Southeast Asian countries, Malaysia, Thailand, and Vietnam have a long history of extensive aquaculture (Pathansali and Soong 1958; Ng 1984; Tuan and Phung 1997; Ratchatapattanakul *et al.* 2017). Young spats collected from natural seedlings are cultured for one to one and a half years in farming grounds established in shallow areas and are then shipped to the market. In particular, securing a stable supply of young spats for culturing is important for expanding production in such extensive aquaculture farms (McCoy and Chongpeepien 1988; Kechik 1995). If the domestic supply of seedlings is insufficient, they can be procured from other countries (Sahavacharin 1995).

Considering Myanmar, the target area of this study, only few studies have been conducted on blood-cockle fisheries and aquaculture. According to available references, cockles are edible and inhabit Rakhine State, located on the northern coast of the country (Oo 2021). Htun *et al.* (2021) also reported the presence of cockles in the intertidal waters of Thae Chaung in Rakhine State, where their main habitat was the muddy bottoms of the bay, estuary, and mangrove areas. Psomadakis *et al.* (2019) also described the habitat of cockles in Myanmar, where they were present in the intertidal zone and shallow waters up to 10 m deep, and were harvested using a rake. Oo (2020) surveyed the distribution of bivalves along the Mon coast, south of Yangon, and reported that blood cockles (*T. granosa* and *Anadara antiquata*) were abundant along the coast. They were actively fished as a local food and were the third most valuable target species after *Crassostrea belcheri* and *Perna viridis*. Information on the status of blood cockles in the Tanintharyi region, southern Myanmar, is limited. Myat *et al.* (2019) conducted a distribution survey of bi valves in the coastal areas of Maungmagan and Kyauk-KaMaunk from 2017 to 2018 but did not investigate blood cockles. Additionally, Yurimoto *et al.* (2019) did not confirm the sale of blood cockles in a market survey in Myeik City conducted from 2014 – 2015, and they were not included in the survey items. Subsequently, building on previous research by Saito and Teoh (2020), which utilised blood cockles cultivated around Linmalo Village in Kyunsu Township and those sold in markets within Myeik City as study materials, it has become evident that blood cockle farming has recently emerged as a significant component of the local fishing industry in the Tanintharyi Region. In response to this development, the present study aimed to clarify the status of blood cockle aquaculture specifically in the coastal area of Myeik City, located in the northern part of Kyunsu Township. To achieve this, detailed information on local blood cockle farms was collected, and their characteristics were analysed. Additionally, live specimens were obtained locally to assess their growth and feeding conditions, with the broader goal of exploring sustainable farming practices for blood cockles in the region.

2 | METHODOLOGY

2.1 Field and interview surveys

On 25 January 2023, we boarded a small boat and visually surveyed blood-cockle farming grounds in the creek area (12°23′11″N 98°29′11″E) off Myeik City (Figures 1a, 1b, 1e). Additionally, unstructured interviews were conducted with four local cockle farmers and a government officer involved in promoting blood cockle farming along the Myeik coast. These interviews took place at the university's laboratory and aimed to gather information on the location and characteristics of the farming grounds. While the sample size was limited, the selected individuals were directly involved in blood cockle farming and policy implementation, and thus provided highly relevant and practical insights into local aquaculture practices. The topography around each farming ground was analysed using images of Google Earth (https://earth.google.com/) and Mapcarta (https://mapcarta.com/) obtained on 28 April 2023.

To consider the aquatic environment around the farming grounds, we used a dropper tool (https://www.peko-step.com/tool/getcolor.html) published on the Internet. Using this tool, we obtained the red-green-blue (RGB) values and colour codes from each RGB value expressed in hexadecimal numbers around the farming grounds from the map image. Moreover, environmental information on the farming grounds, including literature reviews and meteorological data (horizontal distribution of chlorophyll-*a*, wind direction, wind speed, horizontal distribution of mean annual wind speed and wave height), was collected from the Internet. In particular, data from the following sites were used in this study:

- Global Eutrophication Watch (horizontal distribution of chlorophyll-*a*); https://eutrophicationwatch.users.earthengine.app/view/global-eutrophication-watch
- Windy (wind direction and speed); https://windy.app/forecast2/spot/4715367/transl%40smarteam.dev/statistics
- Global Wind Atlas (horizontal distribution of mean annual wind speed); https://globalwindatlas.info/en/
- Umitron Pulse (wave height); https://www.pulse.umitron.com

2.2 Market survey

In late January 2023, we visited the Thiha Zeya Market in Myeik City (12°25′49.5″N 98°36′07.8″E), checked the seafood, and confirmed the sale of blood cockles. Blood cockles (n = 34) were purchased and the shell length, shell height, shell width, and whole weight were measured with a calliper or scale (accuracy: 0.01 mm and 0.01 g). Subsequently, we calculated a kind of polynomial regression curve (power regression curve) to determine the relationship between shell length and total weight by using Microsoft Excel 365 (Microsoft Corporation, USA), and compared the results by collecting the regression curve information from the literature for blood cockles inhabiting other countries.

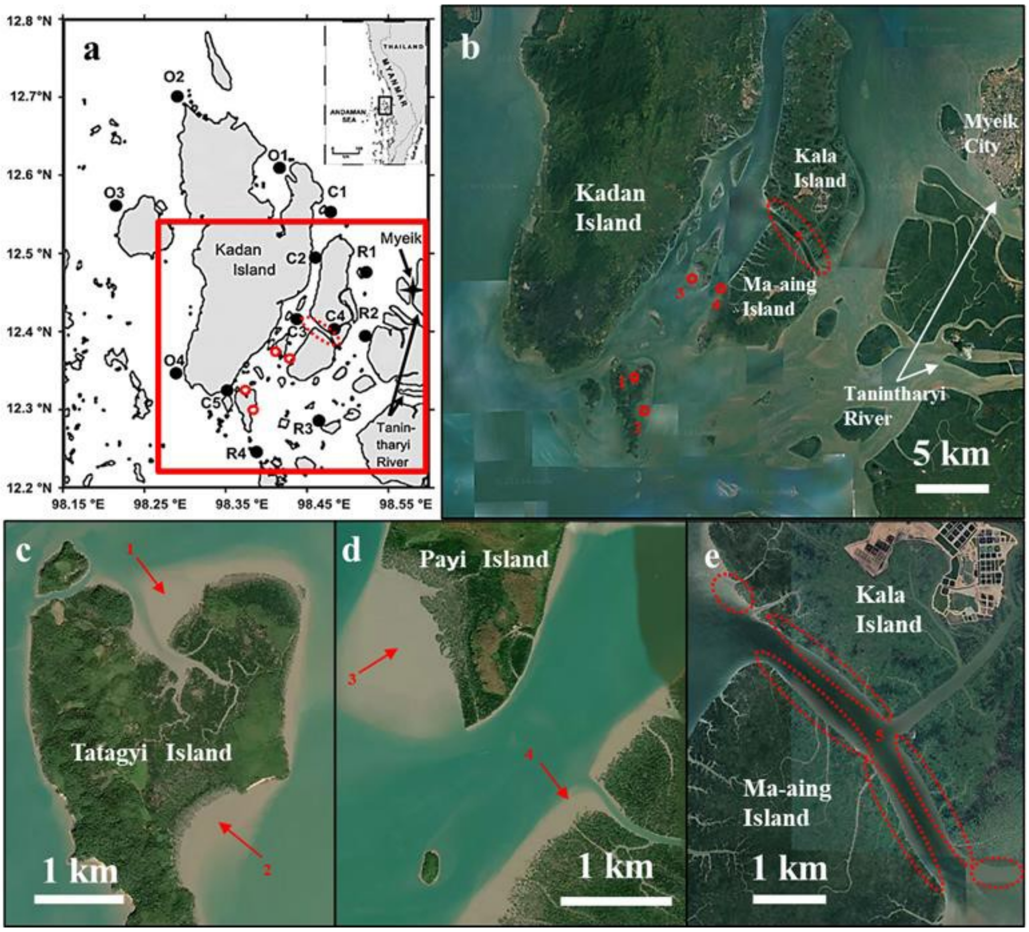

FIGURE 1 Location of blood-cockle farming grounds off Myeik City (a), location of farming grounds based on the satellite image (b), and enlarged images of each fishing ground (c–e). Stations 1-4 were identified through interviews with local fishermen, and station 5 was identified through a boat based survey. Sources: a, Modified from Htoo-Thaw *et al.* (2017) with additional farming ground locations. b, e: Google Earth. c, d: Mapcarta.

Moreover, the shell morphology was observed to confirm the characteristics of the blood cockles in this region, and the number of radiating ribs in each individual was counted (Narasimham 1988; Faulkner 2010; Doinsing *et al.* 2021). Additionally, the shells of a portion of the samples (n = 10) were opened, and the contents of the digestive tubes were collected according to the procedure described by Yurimoto *et al.* (2014b). After Congo red staining and microscopic observation of the specimens, the composition of the contents was examined using optical microscopy. In particular, the shells of the cockle were opened, and the digestive tube contents were aspirated and collected from the lips and other parts using a micropipette equipped with a 200-µl tip. Subsequently, the contents were immersed in 1% (w/v) Congo red solution for 1 – 2 h; excess staining solution was removed with an alkaline alcohol solution [1 ml of 1% (w/v) sodium hydroxide and 100 ml of 50% (v/v) alcohol], and the con tents were washed with deionised water. The contents in the microtube were first bleached in an alkaline alcohol solution and subsequently repeatedly washed with deionised water twice or thrice. When exchanging the solutions, the contents were precipitated by centrifugation at 3,000 rpm for 1 min and the supernatant was exchanged. Finally, the sample was diluted with a predetermined amount (500 µl) of distilled water, dropped onto a sliding glass, covered with a cover glass, and observed under an optical microscope. Particles larger than 5 µm were counted across multiple fields of view to ensure representative quantification.

3 | RESULTS

3.1 Field and interview surveys

A survey of the fishing grounds revealed that the blood cockle farm was located between Kala and Ma-aing Islands, approximately 14 km southwest of Myeik City. The farming grounds were divided into numerous pens, and the overall area of the aquaculture site was extensive, covering a wide stretch of coastal waters estimated to span several tens of hectares. This large-scale arrange ment reflects the growing importance of blood cockle farming in the region (Figures 1a, 1b, 1e and 2). According to interviews with local cockle farmers, the scale of blood cockle farming has been expanding off Myeik City since

2019, and farming procedures are in accordance with Thailand's aquaculture methods.

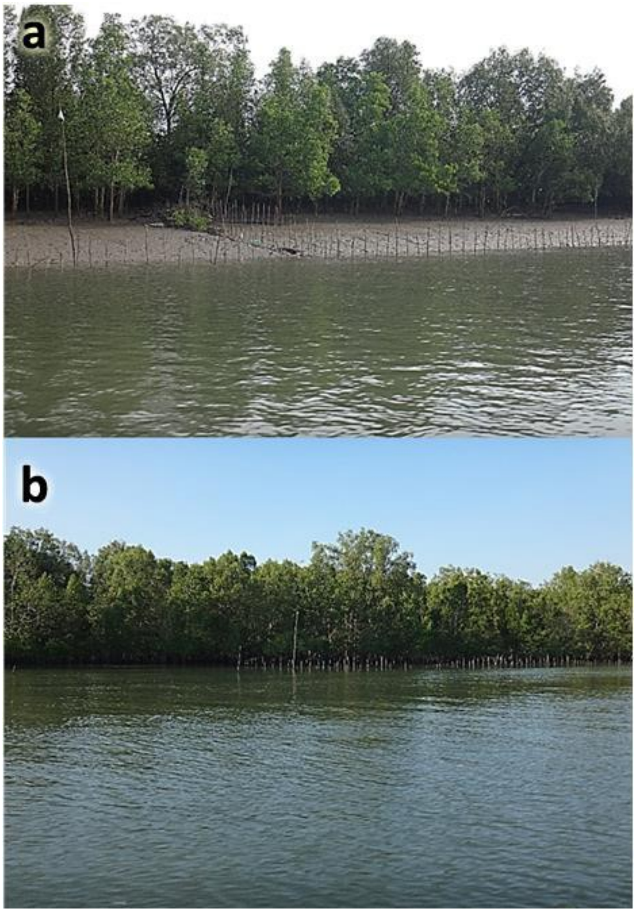

FIGURE 2 A sectioned farming ground for blood-cockle aquaculture observed in a boat-based survey off Myeik City. (a) A sectioned farming ground dried up at low tide. (b) A sectioned farming ground submerged at high tide.

Farmers stated that cultured cockles were exported to Thailand through land routes. At present, although there is a problem of feeding damage caused by starfish, securing natural cockle spats and aquaculture are proceeding smoothly, and production is progressing in this area. However, fishermen remain uncertain about the long-term stability of the current conditions. In response, a monitoring system is gradually being established by local fishermen in collaboration with relevant government agencies to conduct resource surveys, including assessments of the number of newly generated cockle spat, in order to support sustainable management of the fishery. Moreover, we collected information from fisher men on the location of blood-cockle farming grounds of Myeik City, which were not visited during the boat-based survey (Figures 1a – 1d). Subsequently, we confirmed the topography of the areas surrounding these grounds from the satellite images recorded on Google Earth or Mapcarta to estimate the characteristics of each farming ground. These farms were located in the shallow waters of the coves and creeks surrounding the islands, particularly ear the mouths of creeks flowing into the sea (Figure 1c – 1e). Moreover, the RGB values of stations 1–4 around the farming ground, as determined from the satellite image, were 147 ± 5, 142 ± 5, and 119 ± 4, respectively, and the colour code was determined to be #938E77. For station 5, the RGB values were 90 ± 18, 106 ± 17, and 96 ± 37 17, respectively, and the colour code was #5A6A60.

To further investigate the environmental characteristics of blood cockle farming grounds, we referred to environmental data from Htoo-Thaw *et al.* (2017), which included measurements of water quality parameters such as surface temperature, surface salinity and vertical chlorophyll-*a* concentration in coastal waters off Myeik (Figure 3). The surface water temperatures exceeded 30°C on the east coast of Kadan Island, where farming grounds were distributed, in December and March, corresponding to the early and late dry seasons, respectively. Additionally, the temperatures around Kadan Island and near the river mouth area around Myeik City were approximately 29 and 28°C in September, respectively, corresponding to the rainy season (Figures 3a – 3c). In contrast, surface salinity values around the farming grounds were >25 and >30 PSU in December and March, respectively. Low salinity areas had a value of 10 – 15 PSU in the coastal areas, but areas of the farming ground were maintained at more than 20 PSU in September (Figures 3d – 3f). The chlorophyll-*a* concentration, which is an indicator of the amount of food for bivalves, was approximately 5 μg L^{-1} at stations C4 and R3 near the coast of Myeik City, and values below 3 μg L^{-1} 60 were detected at stations C3, C5, and R4, which are offshore areas, in December and March of the dry season. Stations C3, C4, and R3 showed values of approximately 4 μg L^{-1} in the rainy season in September, which were almost the same as those in the dry season (Figures 3g – 3i). Additionally, to determine the developmental characteristics of phytoplankton in the waters surrounding the farming grounds, the horizontal distribution of chlorophyll-*a* based on satellite image data was obtained from the 'Global Eutrophication Watch' database, in accordance with Maúre *et al.* (2021). Consequently, although data were missing in some areas around the farming grounds, the surrounding waters were found to be low stable, with chlorophyll-*a* concentrations below the lower limit of 4 μg L^{-1} (Figure 4a). Additionally, the chlorophyll-*a* concentrations from 2018 to 2022 were 3.1 – 5.2 μg L^{-1} near the farming grounds (white asterisk and plot in Figures 4a and 4b) and 4.9 – 18.6 μg L^{-1} in the coastal areas (red asterisk and plot in Figures 4a and 4b). Conversely, to elucidate the local wind-blowing conditions, according to the annual average wind speed (WS) distribution map created by the Global Wind Atlas, the WS was approximately 3 m s^{-1} from the west to northwest areas of Kadan Island (Figure 5a). Additionally, according to Windy data, the dominant wind directions were WSW-SW, WNW-NW, and ENE-NE, and the dominant WS was 4 m s^{-1} or less in the area surrounding Myeik City (Figure 5b). Furthermore, winds with a WS of above 6 m s^{-1} and 4 – 6 m s^{-1} were observed increasing from May to August, which is the rainy season (Figure 5c). On the other hand, according to Umitron Pulse data for 2022, the wave height around the farming grounds was less than 0.2 m mainly from January to April, often exceeded 0.4 m from May to October, and was less than 0.2 m mainly after November (Figure 5d).

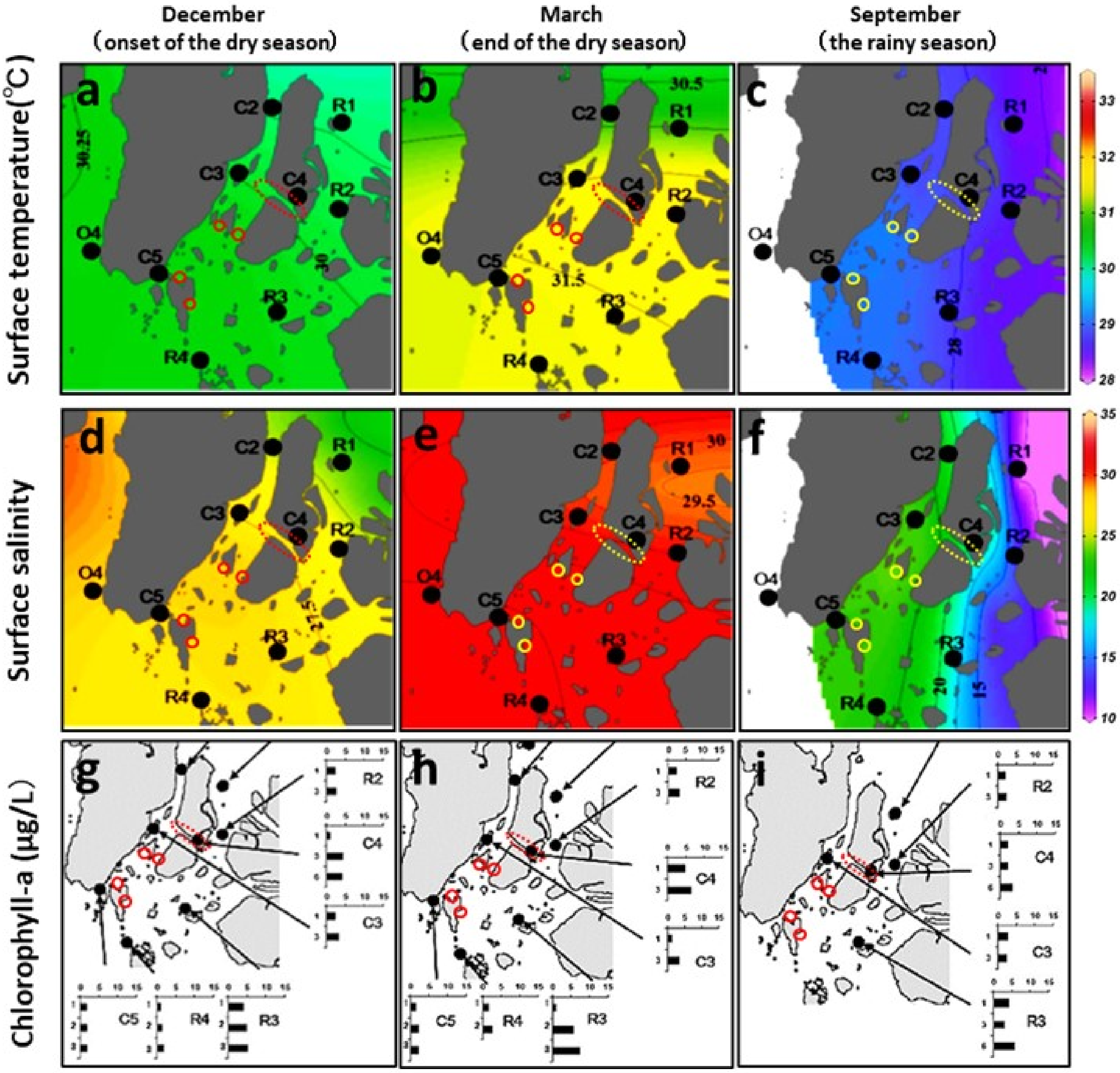

FIGURE 3 The location of blood cockle farming grounds was determined using a boat-based survey and interviews with fishermen, and their relationship with coastal environments (water temperature, salinity, and chlorophyll-*a* concentration) across different seasons were based on reference data (Htoo-Thaw *et al.* 2017). The figure illustrates the farming grounds' locations from the survey (dotted circle) and interviews (solid circle). Panels (a – c) show surface water temperature distribution, (d – f) show surface salinity distribution, and (g – i) display vertical chlorophyll-*a* concentration distribution at various stations across early dry, late dry and rainy seasons, with water depth on the vertical axis.

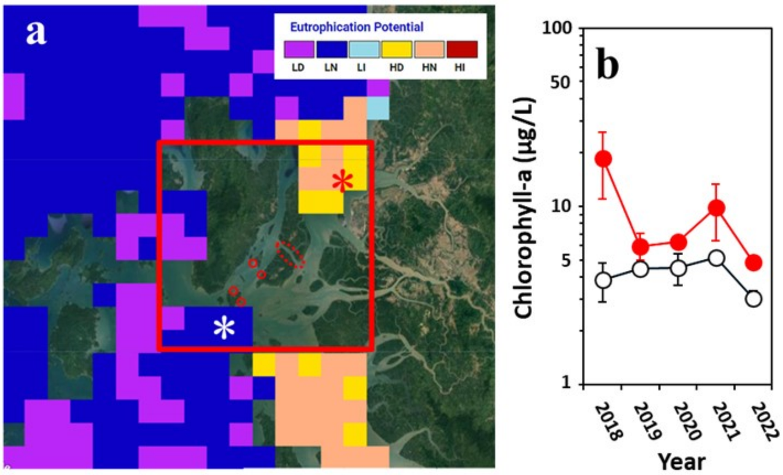

FIGURE 4 Chlorophyll-*a* concentrations off Myeik City were studied using Global Eutrophication Watch (white asterisk: farming grounds; red asterisk: coastal area) and summarised chlorophyll-*a* graphs of both sites (b). The horizontal distribution map, based on satellite data from 2018-2022, uses a cutoff of 4 μg L^{-1} and categorizes areas as LD, LN, LI, HD, HN, and HI, indicating varying trends. Trends are marked as decreasing (D), stable (N), or increasing (I) of combined with the cutoff level low (L) or high (H). The square frame in Figure 4a highlights blood cockle farming grounds. Graphs in Figure 4b show annual changes of both sites with mean ± SD, sourced from Global Eutrophication Watch.

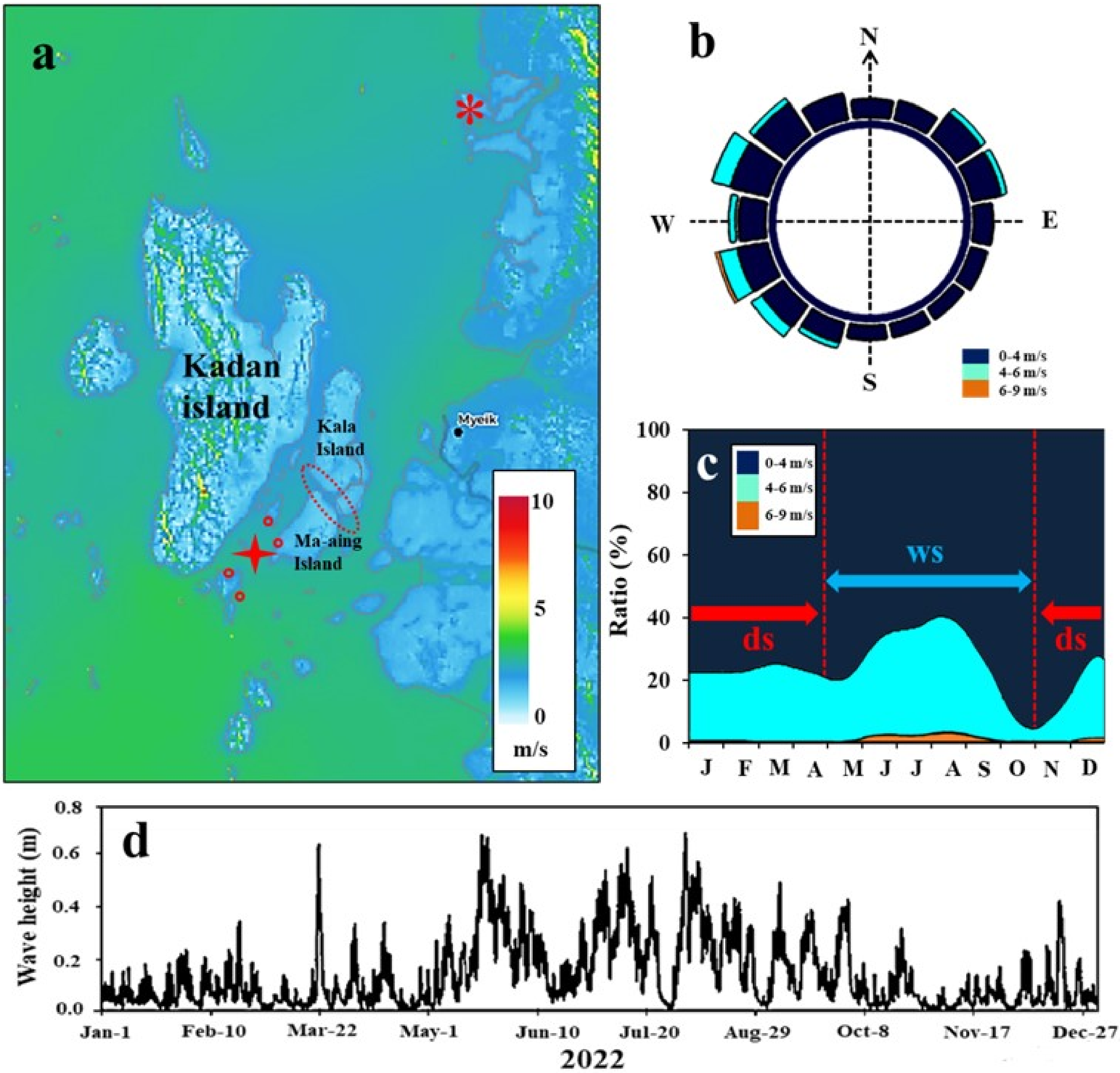

FIGURE 5 Annual average horizontal wind speed and direction around Myeik City, monthly average wind speed (2011 – 2022), and annual wave height change in 2022. a: Low annual average wind speeds observed from the east to northeast around Kadan Island. b: Annual winds mainly came from the southwest, northwest, and northeast. c: Wind speeds were higher 6–9 m s^{-1}) during the rainy season (ws) and lower (≤6 m s^{-1}) during the dry season (ds). d: Annual wave height changes around farming grounds. The asterisk in Figure 5a shows the wind observation site, and the cross mark shows the wave height data position. Data from Global Wind Atlas, Windy and Umitron Pulse.

3.2 Market survey

The local market mainly sold marine fish (*Caranx* sp., *Ferdauia* sp., *Lethrinus* sp., *Lutjanus* spp., *Megalaspis* sp., *Parastromateus* sp., *Sardinella* cf. *tawilis*, *Sphyraena* sp., *Scatophagus* sp., *Scomberomorus* cf. *commerson*, *Stolephorus* sp., *Tylosurus* sp., among others), freshwater fish (*Hemibagrus* cf. *wyckii* and *Piaractus* cf. *brachypomus*), prawn or shrimp (*Macrobrachium* sp. and *Penaeus* sp.), bivalve, such as Manila clam (*Ruditapes* cf. *philippinarum*), pen shells (*Atrina* sp.), and blood cockle (*T. granosa*) (Table 1). Blood cockles were sold in baskets (Figure 6a), some of which were bought for 500 Myanmar Kyats (MMK). The purchased plastic bags contained 34 cockles with a total weight of 234 g. After price conversion, the price for 1 kg of cockles was 2137 MMK (1 USD = ~2128). Additionally, the largest, lowest, and mean ± standard deviation (SD) values of the number of radial ribs on the shell surface of the purchased cockles were 21, 17, and 18.97 ± 0.97 ribs (n = 34), respectively (Figure 6b). The shell length, shell height, shell width, and whole weight of these blood cockles (Figures 6c, 6d, and 6e) were 26.7 ± 3.5 mm, 21.0 ± 2.7 mm, 18.8 ± 3.0 mm, and 6.9 ± 2.9 g, respectively. Therefore, the modes of the distribution of shell length and whole weight were 25 – 30 mm and 4 – 6 g (Figures 7a and b), and the regression curve for the relationship between shell length and whole weight was $y = 0.0003X^{3.0758}$ (R^2 = 0.94) (Figure 7c). Additionally, when the results were compared with the regression curves of blood cockles inhabiting Malaysia and Bangladesh (Doinsing *et al.* 2021; Hasan *et al.* 2022), the weights of cockles in our study were lower than those of other studies (cockles with a shell length of 20 mm were 1.2 – 1.7 g lighter in our study) (Figure 7d).

Optical microscopy images of the digestive tube contents collected from blood cockles in Myeik City are shown in Figures 8a – 8c. Fragments derived from plankton, such as diatoms (Figure 8a), wood chips (Figure 8b), and particles strongly stained with Congo red (Figure 8c), were mainly observed in the tube. We aimed to sample the digestive tube contents from ten cockles, but could not obtain a sufficient amount from two samples (S8 and S9), and the contents of these samples were discarded. It is considered that these individuals had insufficient feeding activity, which likely resulted in the low volume of digestive tube contents. Thus, tube contents were successfully collected from eight cockles; the total number of particles were n = 215 – 443 per individual and they were separated into respective categories (Congo red-positive: plankton cells; Congo red-positive: other particles; Congo red-negative: plankton cells; and Congo red-negative: other particles) under a light microscope. The percentage of Congo red-negative plankton fragments was the highest at above 55%. Congo red-negative non-plankton particles accounted for 5 – 40%, followed by Congo red positive non-plankton particles, which accounted for the highest proportion (33%) in sample S2, and other individuals accounted for 18%. Congo red-positive plankton particles were not detected in any individuals in this study. Additionally, according to the total composition of tube contents of the eight individuals, Congo red-negative plankton, Congo red-negative non-plankton, and Congo red-positive non-plankton particles accounted for 75, 18, and 7%, respectively.

TABLE 1 List of aquatic species sold in the local market, categorised by habitat type and product group. Scientific names and corresponding English common names are provided for each species.

Scientific Name	English Name
Marine fish	
Caranx sp.	Jack
Ferdauia sp.	Ferdauia
Lethrinus sp.	Emperor
Lutjanus sp.	Snapper
Megalaspis sp.	Megalaspis
Parastromateus sp.	Pomfret
Sardinella cf. *tawilis*	Sardinella
Sphyraena sp.	Barracuda
Scatophagus sp.	Scat
Scomberomorus cf. *commerson*	Narrow-barred Spanish mackerel
Stolephorus sp.	Anchovy
Tylosurus sp.	Needlefish
Freshwater fish	
Hemibagrus cf. *wyckii*	Asian redtail catfish
Piaractus cf. *brachypomus*	Pacu
Shrimps	
Macrobrachium sp.	Giant river prawn
Penaeus sp.	Penaeid shrimp
Other shellfish	
Ruditapes cf. *philippinarum*	Manila clam
Atrina sp.	Pen shell
Tegillrarca granosa	Blood cockle

4 | DISCUSSION

4.1 Weather and coastal environment

Khin-May-Chit-Maung *et al.* (2023) summarised the monthly temperature and rainfall amount for 2017 – 2018 from meteorological data around Myeik City. According to the data, the maximum temperature remained approximately 30°C in the rainy season but increased to approximately 35°C in the late dry season from March to May. Additionally, if fishing grounds are exposed during the day owing to low tides, direct sunlight can expose them to even higher temperatures. However, the monthly rainfall varied slightly by year. The rainy season, with monthly rainfall exceeding 250 mm, lasted from May to

October 2017 and from June 1 to September 2018. Periods with high rainfall (more than 1000 mm month^{-1}) were recorded in July 2017 and July – August 2018. Therefore, there is a long rainy season of 4 – 6 months along the coast of Myeik.

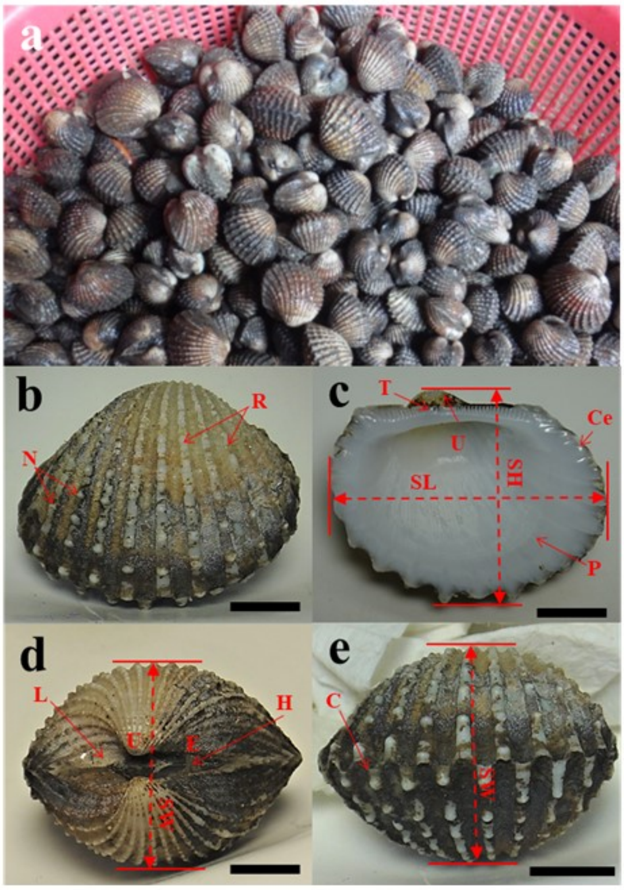

FIGURE 6 Blood cockles sold at a market in Myeik City (a), and the shell morphology of blood cockles from each direction (b-e). b: right valve (outside); c: right valve (inside); d: dorsal view; and e: ventral view. C: commissure; Ce: crenulated edge; E: escutcheon; H: hinge ligament; L: lunule; N: nodule; P: pallial sinus; R: rib; T: teeth; and U: umbo. SL: shell length; SH: shell height; and SW: shell width. Scale bars: 5 mm.

Additionally, the data of wind direction and wind speed obtained in this study indicated that winds increased during the rainy season and that winds blew easily from the southwest. All blood-cockle farming grounds were present in locations not exposed to wind from the island and were not easily affected by seasonal wind waves. According to the wave height data, the wave height in the rainy season was low, with small waves with heights of less than 0.6 m. Moreover, the wave height in the dry season was even lower, at approximately 0.1 m. Therefore, the calm environment is one of the factors determining the establishment of blood-cockle fishing grounds. However, as all these fishing grounds were present in shallow waters, changes in tide levels tended to cause sediment resuspension, and fishing grounds can easily experience high turbidity. Moreover, in this study, the colour codes of RGB values obtained from the satellite image around the farming grounds off Myeik City were #938E77 and #5A6A60 for stations 1 – 4 and 5, respectively. These roughly correspond to Forel and Ule colour code numbers 17 and 13, respectively (Toyota and Nakashima 1979; Iwayama *et al.* 2004). The greenish brown to brownish-green colour (14 – 17 FU scale) indicates that these waters usually have high concentrations of nutrients, phytoplankton, sediment, and dissolved organic matter. This is typical of nearshore areas and tidal flats (Ceccaroni *et al.* 2020). Greenish (10 – 13 FU scale) coastal waters typically display high nutrient and phytoplankton levels and contain minerals and dissolved organic materials (Ceccaroni *et al.* 2020). These indicators suggest that these waters have high biological productivity compared to offshore areas.

4.2 Environment of cockle farming grounds

The range of water temperatures in the area where the blood-cockle farming grounds were distributed was 28 – 31.5°C throughout the dry and rainy seasons. According to Shin and Moon (2005), a temperature resistance experiment on blood cockles (large group: 35 ± 3 mm; small group: 15 ± 3 mm) indicated that mortality occurred when breeding cockles at water temperatures of 32°C or higher. Notably, more than half the cockles died if bred at 31°C for more than two days. From filtration activity experiments, Nakamura and Shinotsuka (2007) also observed that the feeding activity of blood cockles decreased when the rearing temperature increased from 29 to 31°C. Therefore, the high water temperatures in the late dry season in the farming grounds off Myeik City are a cause for concern. Furthermore, as the farming grounds were in the intertidal zone, attention should be paid to the increase in temperature owing to direct sunlight during low tide.

The salinity during the dry season was between 27 and 33 PSU, which is sufficient for cockle growth (Davenport and Wong 1986). Moreover, during the rainy season, the salinity was less than 10 PSU around the Tanintharyi River Estuary and less than 15 PSU in the waters surrounding the coastal area. However, stations 1 – 4 and the western area of station 5 had salinity values of more than 20 PSU, suggesting that the effect of the decrease in salinity on cockle growth was not as serious (Davenport and Wong 1986). Yurimoto *et al.* (2021a) reported a mass mortality event associated with a low-salinity environment (<10 PSU) during the rainy season in blood-cockle farms in Thailand, where histological observations of the cockles indicated poor feeding conditions. Therefore, a prolonged low-salinity environment can lead to poor feeding and death of cockles. Moreover, according to

Moon and Shin (2010), rearing blood cockles at a water-temperature of 25°C and salinity of 20 PSU or less for more than six days resulted in a decrease in filtration activity. Notably, both juvenile (19.5 ± 1.3 mm) and adult (36.0 ± 1.5 mm) individuals showed clear signs of mortality under these conditions, with a mortality rate exceeding 60% after 11 days. In the farming grounds off Myeik City, the rainy season is prolonged, and low-salinity conditions may persist, particularly in the eastern area of station 5, raising concerns about potential mass mortality. While the main farming grounds are generally less affected by salinity reduction, fishing grounds located near the estuaries of small rivers on the island may be more vulnerable to freshwater inflow. Therefore, the impact of local freshwater input must be carefully considered in these areas.

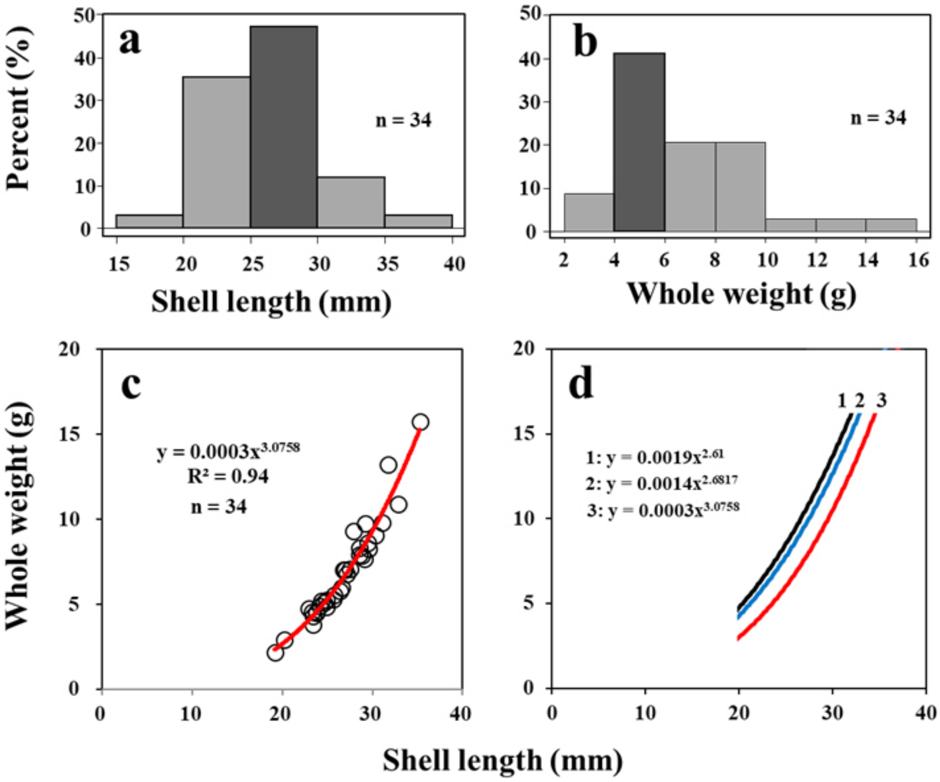

FIGURE 7 Shell length (a), whole weight distribution (b), the relationship between shell length and whole weight (c), and comparison between the relationship curves of blood cockles derived from this study and previous studies (d). 1: Bay of Bengal, Bangladesh (Hasan *et al.* 2022); 2: Murdu Bay in Malaysia (Doinsing *et al.* 2021); and 3: this study.

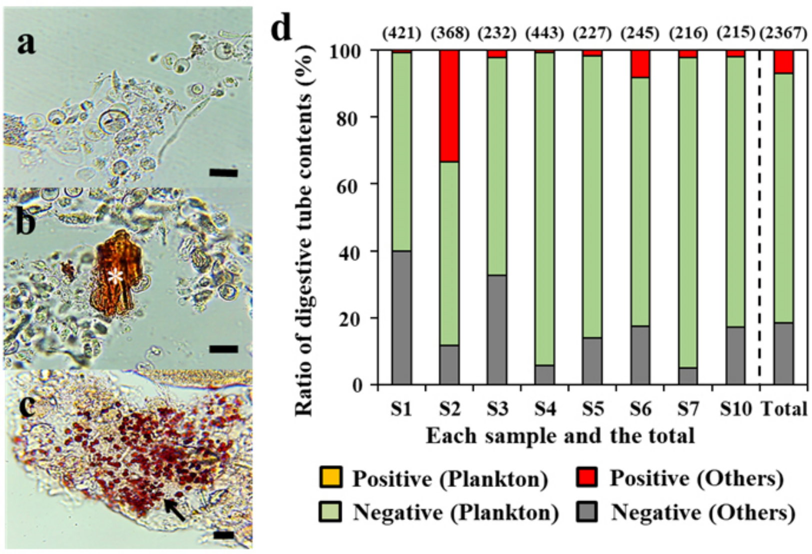

FIGURE 8 Photographs of the digestive tube contents of blood cockles obtained from a market in Myeik City (a – c), and composition of the digestive tube contents of each individual (d). a: Fragments of phytoplankton; b: fragments of plants (marked with asterisks); and c: digested particles strongly stained with Congo red (arrow). Positive (plankton): stained in Congo red; morphology is plankton. Positive (others): stained in Congo red; morphology is not plankton. Negative (plankton): no particle stained with Congo red; morphology is plankton. Negative (others): no particle stained with Congo red; its morphology is not plankton but it also contains mineral particles. The numbers in both parentheses in the graph indicate the counted number of particles with a diameter of ≥ 5 µm. Also, the "Total" in the graph refers to the composition based on the total value of the eight samples to the left of the dotted line. Scale bar: 30 µm.

The chlorophyll-*a* concentration in the water column, which is an index for understanding the food environment of bivalves, in the sea area around the farming grounds was approximately 4 μg L^{-1}. Yurimoto *et al.* (2021b) monitored the relationship between the chlorophyll-*a* concentrations in the water and phyto-pigment in the digestive gland tissue of cockles on the blood-cockle farms, and found that the suitable chlorophyll-*a* concentration in the environment for ingestion by blood cockles was approximately 12 μg L^{-1}. Therefore, mesotrophic or eutrophic waters are generally considered suitable for cockles (Nakamura and Shinotsuka 2007), and the chlorophyll-*a* concentrations in the farming grounds near Myeik City were found to be low. Notably, protozoa and bacteria play a significant role in primary production in the coastal waters of Myeik City, especially during the rainy season (Htoo-Thaw *et al.* 2017). Since blood cockles are known to feed on detritus, bacteria, and protozoa (Hawkins *et al.* 2013), the cockles near Myeik City may have adapted to this type of food environment.

4.3 Blood cockles of Myeik City

Yongpu *et al.* (2004) reported that the number of radial ribs on the shell surface of a blood cockle differs depending on the location; the data were presented as mean ± SD (range) as follows: 18.77 ± 0.06 (17 – 22) for Guangxi, China; 19.51 ± 0.07 (18 – 21) for Zhejiang, China; 20.20 ± 0.09 (18 – 22) for Shandong, China; and 22.22 ± 0.07 (20 – 24) for Korea. This indicated that the number of radial ribs tended to be higher in blood cockles collected from high-latitude fishing grounds. The number of radial ribs of cockles inhabiting a farming ground off Myek City was found to be 18.97 ± 0.97 (17 – 21), which is similar to that in Guangxi in southern China. Although the latitudinal distance from north to south between Myeik and Guangxi is more than 1000 km, the morphological characteristics of the cockles are similar in both areas.

The shell length of blood cockles from Myeik City was 25 – 30 mm, and that of nearly 40% of the specimens was lower than 25 mm. However, in Malaysia and Indonesia, as the shell length of sexually mature cockles were 18-20 mm (Pathansali and Soong 1958), that of cockles targeted for fishing was set to 25 mm or longer for stock management (Pahri *et al.* 2016; Soegianto *et al.* 2020). Therefore, the early catch of small cockles off Myeik City may affect their reproduction; thus, the harvested shell length must be set to 25 mm or more, as in other countries. Additionally, when comparing the relationship between shell length and whole weight of blood cockles from Myeik City with the relationship curve of cockles caught in other countries, the weights of cockles from Myeik City with respect to shell length were lower than those in other countries. This may be related to the aforementioned food environment of the blood-cockle farming grounds. Nwe *et al.* (2021) indicated that a tidal cycle-induced salinity and turbidity mixture affects the distribution and abundance of phytoplankton in the Tanintharyi River estuary, and that diatoms (especially chain-forming diatoms) tend to be dominant throughout the year. On the other hand, Gyi *et al.* (2020) periodically surveyed the occurrence of phytoplankton in the coastal area near Myeik City; they found that the cell density remained above 300000 cells L^{-1} from March to June and was approximately 100000 cells L^{-1} from November to January. The dominant phytoplankton species were diatoms (*Thalassionema nitzschioides*, *Ditylum sol*, *Melosira borreri*, *Bellerochia horologicalis*, and *Odontella sinensis*). Moreover, Gyi *et al.* (2020) conducted similar surveys in other regions of Myanmar and found that phytoplankton in Kawthaung, located south of Myeik City, varied seasonally to the same extent as those in Myeik City. Additionally, At Kampani, Ye, and Setse, located north of Myeik City, the phytoplankton density was approximately 15000 cells L^{-1}, and both the density and seasonal variations were lower than those at the two southern stations. Therefore, high turbidity was found to be the limiting factor for the growth of phytoplankton at the northern sites. Additionally, from the graph of phytoplankton variation in Myeik City based on Gyi *et al.* (2020), blood cockles in this study were obtained in January, which represented the early to the middle dry season when corresponding to a low-density period of phytoplankton. Moreover, as the farming grounds off Myeik City were located more offshore compared with the survey point of Gyi *et al.* (2020), the former areas were more influenced by open seawater. Notably, it is thought that the phytoplankton density in the water column is low on the farming grounds by dilution with offshore water.

Yurimoto *et al.* (2014b) examined the digestive tube contents of blood cockles collected in Malaysia using an optical microscope after staining with Congo red solution. The presence of cellulose-containing particles stained with Congo red was also observed, indicating that blood cockles ingested plant fragments that were observed as organic-suspended particles in the digestive tube. Additionally, cellulase, a cellulolytic digestive enzyme, is known to exist in the digestive tubes of blood cockles (Niiyama *et al.* 2012), suggesting that cockles may also digest and feed on plant pieces. In this study, the digestive tube contents of cockles were collected from eight out of ten individuals. Although the detailed amount was unclear in our study, we found that two individuals had almost empty digestive tubes, and the other eight individuals were sufficiently ingesting. Moreover, based on the composition of their tube contents, phytoplankton was the main food source of the blood cockles at that time, and the ratio of Congo red-positive plant particles was low compared with that in Malaysia (Yurimoto *et al.*

2014b). This result demonstrates the growing environment of blood cockles in the farming grounds off Myeik City at that time. Therefore, during the dry season, as the amount of rainfall decreased and the inflow of freshwater from the rivers reduced, the presence of land-derived plant fragments and mineral particles as suspended matter also decreased. This relates to the feeding environment for blood cockles was mainly dominated by phytoplankton.

5 | CONCLUSIONS

Blood-cockle farming grounds off Myeik City are situated in sheltered areas behind islands and creeks, protected from seasonal winds and less affected by freshwater in flow. These conditions provide a stable habitat with relatively high salinity, even during the rainy season. However, chlorophyll-*a* levels remain low throughout the year due to the influence of offshore water, indicating limited phytoplankton availability. During the dry season, coastal areas near the river mouth show stable occurring phytoplankton even with reduced river inflow and stable salinity, while off shore sites help prevent cockle mortality during salinity drops in the rainy season. Thus, seasonal shifts in rainfall suggest that optimal farming grounds vary between dry and rainy seasons, and production efficiency may improve by adjusting site use accordingly. However, this study has limitations. Interviews were limited to four farmers and one government officer, and environmental data relied partly on satellite imagery, which may miss short-term or local variations. Biological data were based on market samples, which may not represent all farming sites. Future research should expand stakeholder input, conduct field monitoring, and collect samples directly from farms.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

TY collected ecological and reference data on the cockles in the region and wrote the initial draft for publication. AAA and CA gathered local aquaculture information and managed the field research. KM and KK secured the MEXT/JSPS Grants-in-Aid and organized the field research as a total project. All authors have read and approved the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on a reasonable request from the corresponding author.

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