

Environmental conditions and population patterns of the mangrove clam, *Geloina coaxans*, in U Minh Thuong zones, An Giang Province, Vietnam

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Abstract. The mangrove clam, *Geloina coaxans*, is known to be an important food source for inhabitants of both tropical and sub-tropical zones. In this study, water environmental parameters and key data on biomass, density, and condition index of *G. coaxans* were collected throughout the year in U Minh Thuong zones, An Giang Province, on the southwest coast of Vietnam to obtain the information about the pattern of *G. coaxans* population. The results showed that the measured parameters varied throughout the year, with a remarkable drop in salinity from 14 to 0.4‰ during the rainy months. The maximum length and weight of clams were 72.9 mm and 98.4 g, respectively. The estimated average biomass and density ranged from 0.8 to 2.1 kg 100⁻¹ m⁻² and 38.4 to 83.6 ind 100⁻¹ m⁻², respectively. Furthermore, it was observed that salinity and total organic matter were correlated with the clam condition index, which ranged from 4.45 to 7.02%. These results provide basic information on the environmental conditions of the mangroves and the population patterns of *G. coaxans* in the studied area.

Key Words: biomass, condition index, density, population.

Introduction. Mangrove clam, *Geloina coaxans*, is widely distributed in the Indo-Pacific region (Idris et al 2017). This species has been harvested in tropical and subtropical regions. It serves as a significant protein source and is highly regarded as a delicacy within numerous communities (Argente et al 2014; Sarong et al 2015). In Vietnam, they are also found in estuarine tidal flats of the Mekong Delta where they can tolerate water salinity fluctuations (Ngo et al 2019b). These species can burrow deeply (Morton 1984) and live semi-infaunally in soft sediments (Ingole et al 2002). They feed on algae and detritus through filtering during immersion at the settling stage (Elvira & Jumawan 2017). Adult clams usually occupy the landward side and are most abundant during high tides, while juvenile clams are found in areas with low-medium tides and when algae are available (Clemente & Ingole 2011; Idris et al 2017).

The availability of natural food in the water column corresponds with physiological processes that trigger growth in these species (Sahin et al 2006), leading to a direct relationship between the condition index (CI) and gonadal somatic index (Clemente & Ingole 2009; Rahim et al 2012). Usually, the CI in bivalves is related to the spawning season (Clemente & Ingole 2009; Yang et al 2011; Celik et al 2012). As such, mature *G. coaxans* can spawn throughout the year when natural environmental conditions are optimal (Clemente & Ingole 2009; Idris et al 2017). Globally, mangrove ecosystems are experiencing changes in function caused by reduced mangrove forest area, land use change, sedimentation, and illegal logging (Redjeki et al 2020). Particularly in Southeast Asia, the mangrove forests have been lost due to the conversion of forests into aquaculture ponds and rice plantations during last decades (Friess et al 2019; Bryan-Brown et al 2020). These environmental changes impacted the population structure of benthic organisms, especially *Geloina* and other economically important species (Wijaya et al 2010; Redjeki et al 2020). In the Philippines, the distribution and composition of *G.*

erosa are also altered by human activities (Elvira & Jumawan 2017). Currently, in Southeast Asian countries especially in Vietnam, studies on the population structure and biomass of mangrove clams in relation to fluctuations of environmental factors is still limited. In this study, water environmental parameters and key data on biomass, density, and condition index of *G. coaxans* were collected throughout the year in U Minh Thuong zones, An Giang Province, on the southwest coast of Vietnam to obtain information about the pattern of *G. coaxans* population. The results support a better understanding of the developmental dynamics of *G. coaxans* populations in relation to the environment in their habitat. Furthermore, the research findings can provide useful information for sustainable resource management or for developing plans to culture this valuable Bivalvia species.

Material and Method

Site description and study duration. This study was carried out in the coastal mangrove sites of Hoa Chanh, U Minh Thuong National Park, An Giang Province, in the southern region of Vietnam, for a period of 12 months from January to December 2020. Six sites were selected with the estimated total area of each site being $\approx 100 \text{ m}^2$ (Figure 1). The rationale for selecting the sampling sites is the abundance of *G. coaxans*, estimated based on the interviews applied to the inhabitants and to the preliminary field surveys. Some sites had densely populated mangrove forests. The sites were near areas with aquaculture practices. The common vegetation observed at the studied sites included *Nypa* palm, *Nypa fruticans*, and *Rhizophora* spp. The waters of the Cai-Lon River, its canals, and the Cai-Be River were turbid in the study area.

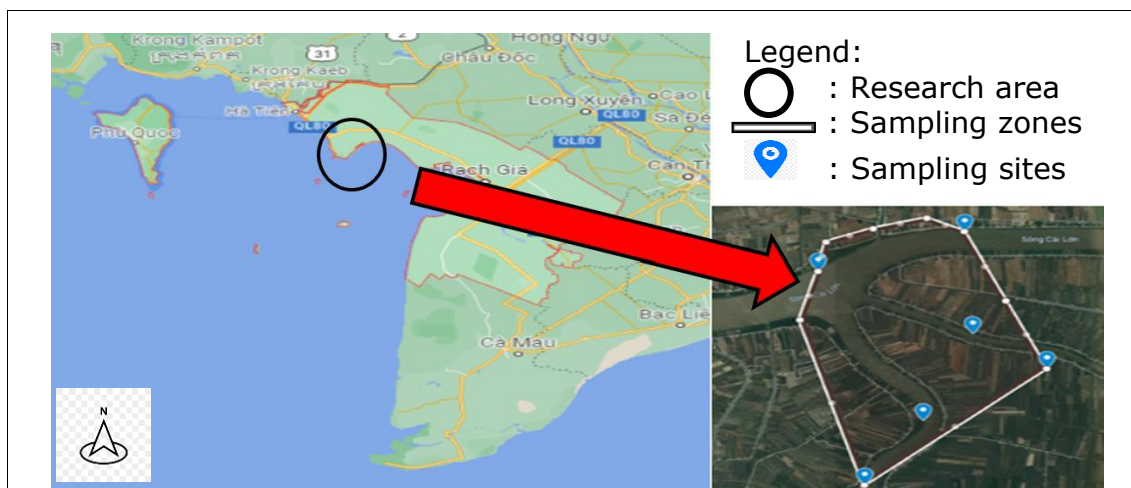


Figure 1. Sampling sites in U Minh Thuong National Park, An Giang Province, Vietnam

Sampling methods. Monthly random sampling was conducted at 6 sites ($\approx 100 \text{ m}^2$), and the collected data were also analyzed by comparing dry (January, February, March, April, November, and December) and rainy months (May, June, July, August, September, and October). The following water quality parameters were measured at each site: pH and temperature using a HANNA Instruments pH tester (HI98127, Romania), and salinity using a master refractometer (Atago, Japan). Water samples were also collected in bottles and stored under cool conditions for laboratory analysis of nitrite and alkalinity using HANNA Instruments handheld colorimeters (HANNA HI83303, Romania). Sediment samples were collected using plastic bags at a depth of 15 cm at each site and placed in a cooler box. A total of 3,387 samples of *G. coaxans* were collected at six sampling sites (without tides) using a rake or by hand, at a depth of 5 to 15 cm and placed on a steel sieve for washing, in order to remove mud. All samples were then transported to Can Tho University for analysis. Sediment pH was analyzed following the method described by Boyd (1998), while total organic matter (TOM) was determined using volume ratio and gravity methods (AOAC 2000).

Population structure and size of individuals. Upon arrival at the laboratory, all clams were washed to remove mud and measured for length, width, height, and total body weight. Of these, 30 *G. coaxans* from each site were randomly selected during each sampling period and opened to analyze flesh for sex determination and condition index. Shell lengths of *G. coaxans* were measured using a Vernier caliper, while weights were measured using an analytical balance. All values were recorded. *G. coaxans*'s gender was determined based on the color of gonads among the 30 clams randomly selected at each site during the sampling period. The sex ratio is a measure of the potential for recruitment or continuation and also helps to determine if the organisms are hermaphrodites in a population setting. When fresh, female gonads are black in color and male gonads are cream-white (Clemente & Ingole 2009).

Average biomass of mangrove clams was calculated within a sampling area of $\approx 100 \text{ m}^2$. Each sampling area was divided into 5 plots with fixed locations for all sampling times. All clams (3,387 individuals) collected in these plots were counted, weighed, and their total biomass was calculated according to Roddick et al (2011):

$$\text{Biomass} = (\text{Weight of total individuals (g)}) / 100 \text{ m}^2$$

G. coaxans collected at each site were counted and averaged. Population density, which is defined as the number of individuals per unit area, was calculated according to Ferliana et al (2017):

$$\text{Density} = (\text{Number of individuals}) / 100 \text{ m}^2$$

During each sampling period, flesh from 30 randomly selected clams were collected and dried in an oven at a temperature of 60°C for 36-48 hours before being weighed for condition index calculations. The condition index (CI) was determined according to Walne & Mann (1975):

$$\text{CI (\%)} = 100 \times (\text{Dry weight of meat (g)}) / (\text{Dry weight of shell (g)})$$

Data analysis. Data were entered into MS Excel and separated by months, sites, and season. Data were then analyzed using the Statistical Package for Social Sciences (SPSS) version 22. One-way analysis of variance (ANOVA) was performed. Significant differences ($p < 0.05$) among means were determined using Duncan's multiple range test (DMRT). Pearson correlation analysis was performed to measure linear correlations among environmental parameters and condition index.

Results

Environmental conditions

Variations in salinity during the sampling period. Variations in salinity were recorded throughout the sampling period. The mean water salinity was high in the first three months of the rainy season (May, June, and July). The trend also showed an increase in salinity during the dry season, likely due to saline water intrusion into the river. Salinity peaked in June (14‰) and was lowest in December (0.4‰) (Figure 2).

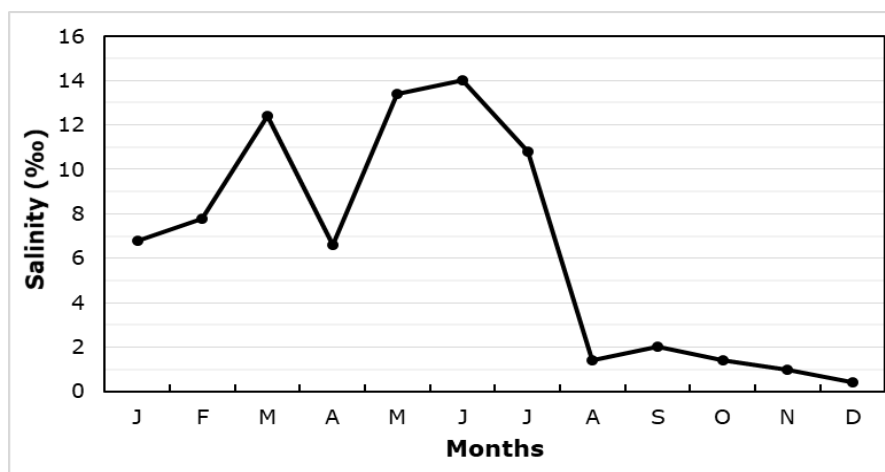


Figure 2. Variations in salinity during sampling period.

Variations in total organic matter (TOM) during the study period. Total organic matter (TOM) varied from 4.6 to 7.5% (Figure 3). TOM was high in May and November during the onset of the rainy and dry seasons, respectively. The lowest TOM levels were observed at the end of both seasons: the end of the dry season (April) and towards the end of the rainy season (October).

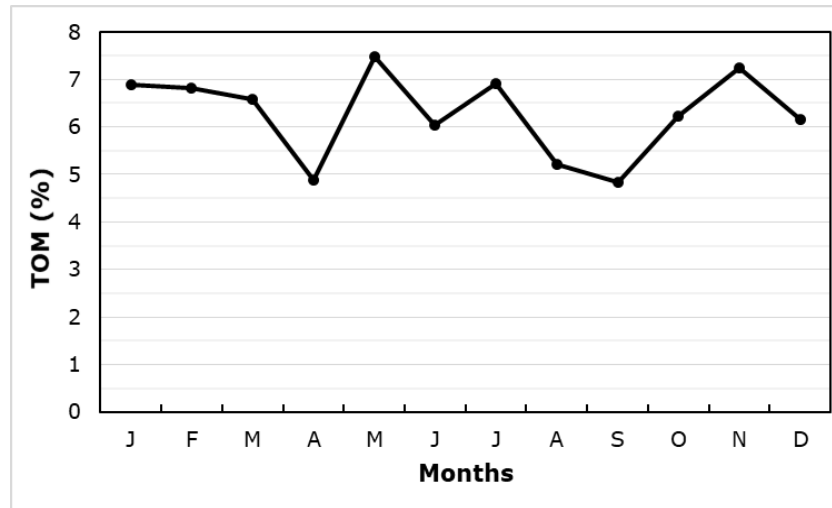


Figure 3. Variations in total organic matter (TOM) during the sampling period.

Variations in pH in the sediment and water during the sampling period. Sediment pH showed continuously fluctuation during sampling period, especially in rainy season, due to the loading and the decomposition of organic matters from the surrounding rivers and canal systems (Figure 4). In terms of water pH, May and November recorded the highest values, coinciding with the onset of both seasons (Figure 5). The lowest values were recorded in April (at the end of the dry season) and July (at the peak of the rainy season). This could be due to variations in photosynthetic activity and heavy rainfall. However, the mean values of water pH remained within an acceptable range.

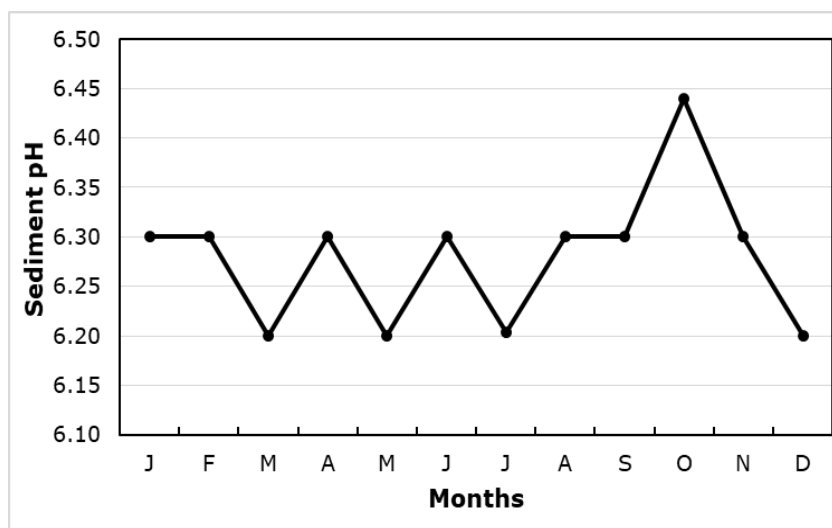


Figure 4. Changes in the sediment pH during the sampling period.

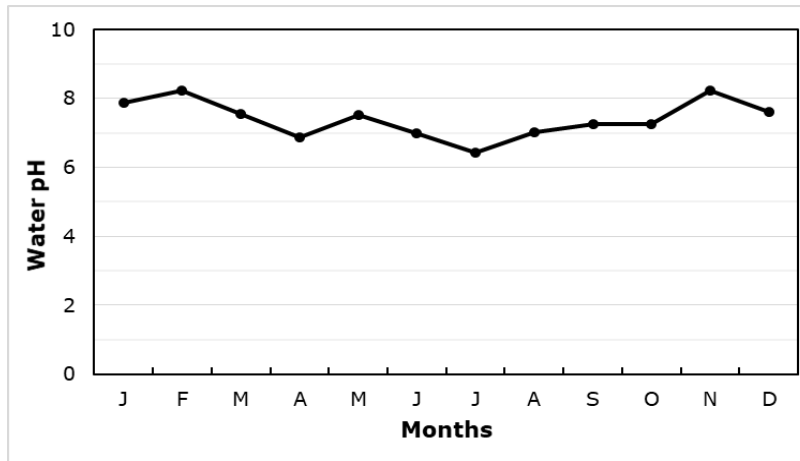


Figure 5. Changes in the water pH during the sampling period.

Variations in temperature during the sampling period. Generally, variations (in sites and months) in average water temperature (Figure 6) throughout the study period could be attributed to solar radiation and air temperatures.

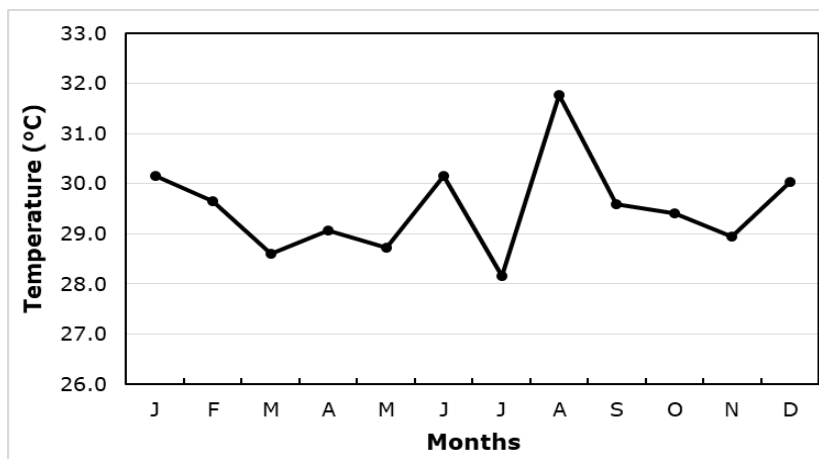


Figure 6. Variations in the measured temperature during the sampling period.

Variations in alkalinity during the study period. The reported mean alkalinity values were also within the optimal range, with higher values observed in the rainy season compared to the dry season, likely due to the influence of rainfall. April (at the end of the dry season) and January (in the middle of the dry season) recorded the highest and lowest mean values, respectively (Figure 7).

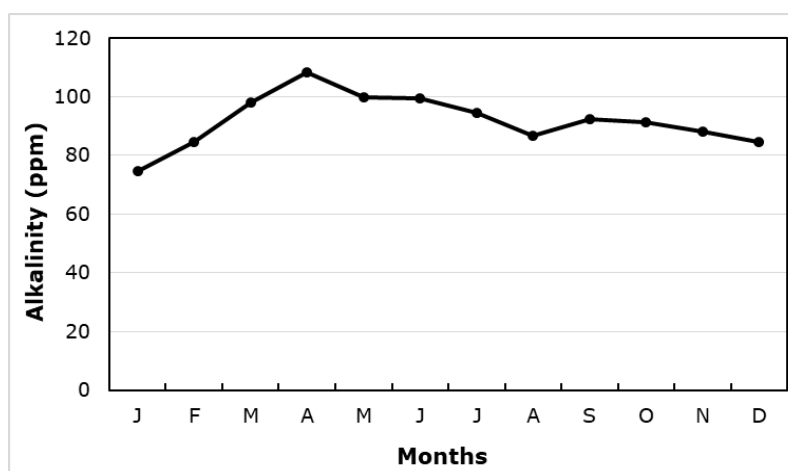


Figure 7. Variations in the measured alkalinity during the sampling period.

Variations in nitrite concentrations during the sampling period. The average nitrite concentrations were higher in the rainy season, peaking in June and July, and lower in the dry season, likely due to the cumulative effect of runoff (Figure 8).

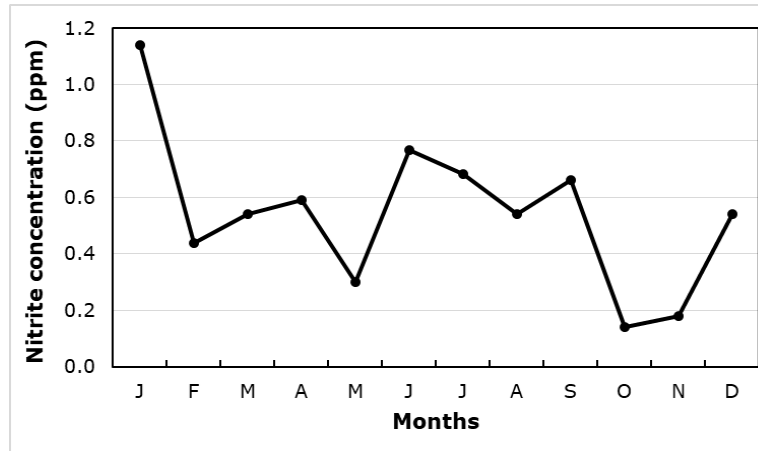


Figure 8. Changes in the nitrite concentrations during the sampling period.

Clam population patterns

Shell length and weight frequency distribution. The majority of the clams were in the classes of 41 to 50 mm in length and 21 to 30 g in weight (Figure 9 and Figure 10), respectively, which were categorized as small. This study also found that the minimum and maximum lengths were 4.3 mm and 72.9 mm, respectively, with corresponding weights of 0.03 g and 98.4 g, respectively. The average length and weight were 43.79 mm and 24.60 g, respectively.

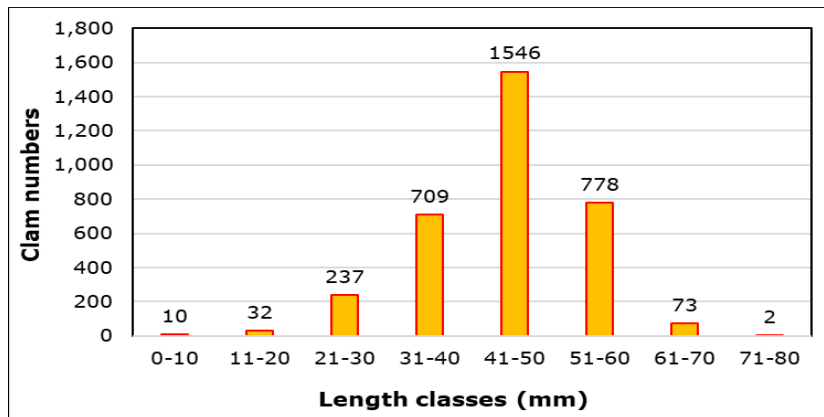


Figure 9. Length frequency of the collected *Geloina coaxans* during the sampling period.

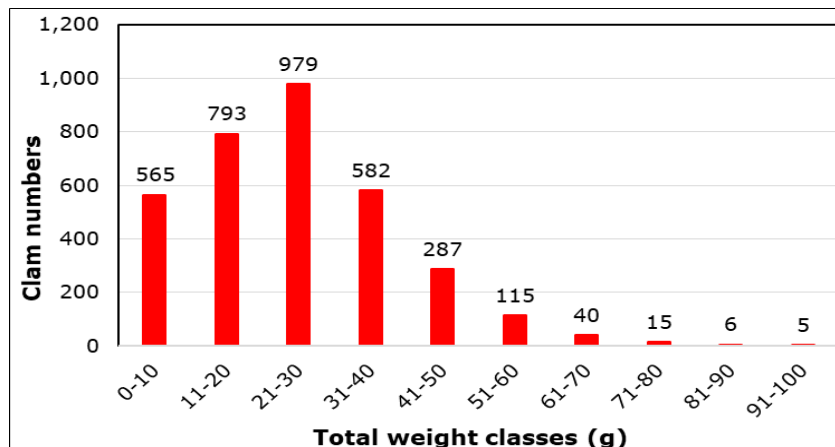


Figure 10. Weight frequency of the collected *Geloina coaxans* during the sampling period.

Biomass and density of *G. coaxans* during the sampling period. Significant differences in biomass and density of *G. coaxans* were observed among sampling months ($p < 0.05$). The mean density and biomass in this study ranged from 0.8 to 2.1 $\text{kg } 100^{-1} \text{ m}^{-2}$ and from 38.4 to 83.6 individuals 100^{-1} m^{-2} , respectively (Figure 11 and Figure 12).

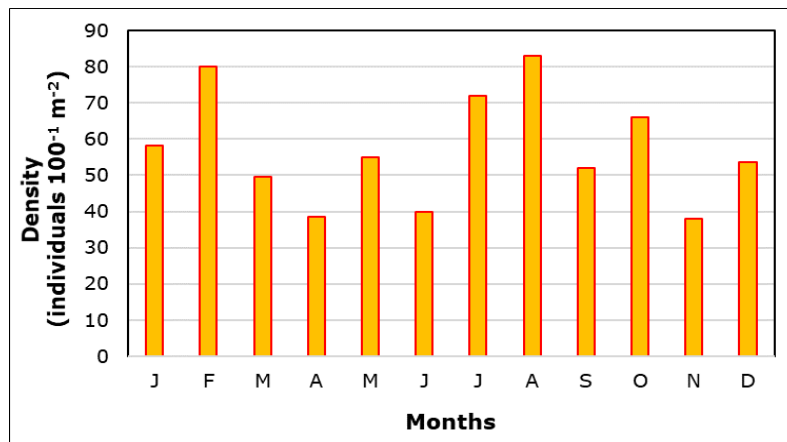


Figure 11. Variations in the average density of *Geloina coaxans* during sampling months.

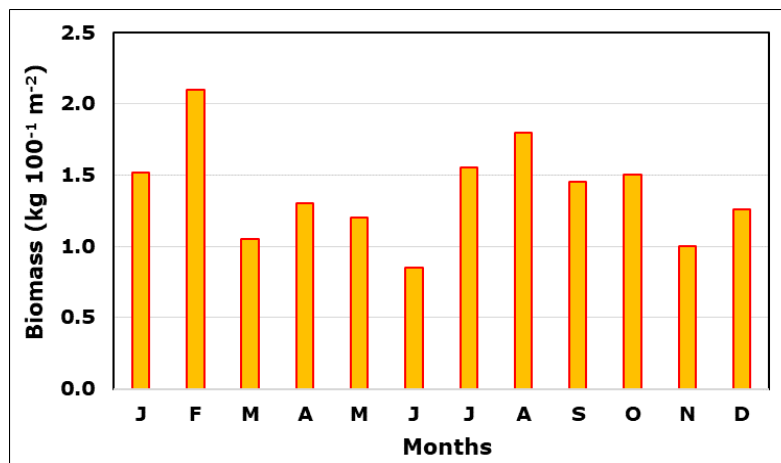


Figure 12. Variations in biomass of *Geloina coaxans* collected during sampling months.

Variations in the condition index of *G. coaxans*. Significant differences in the clam condition index (CI) ($p < 0.05$) were observed among sampling times (Figure 13). The average CI showed high variations throughout the year, with a peak in May, which could be related to the gametogenesis of clams in the studied area.

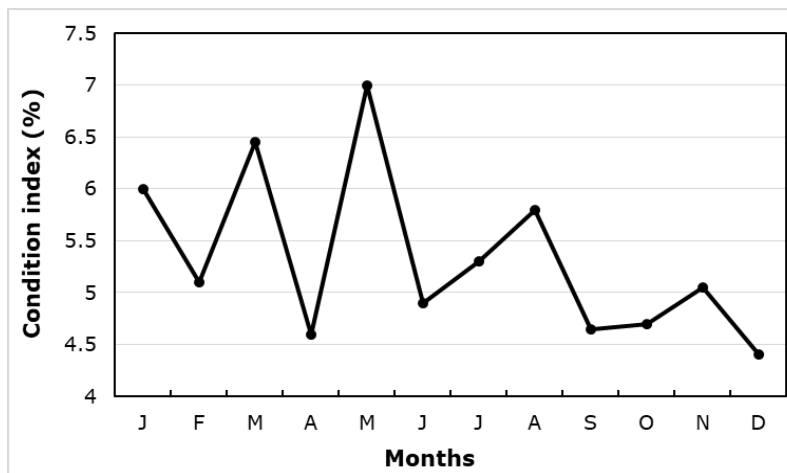


Figure 13. Variations in the mean condition index of clams during the sampling period.

Pearson's correlation between CI and environmental parameters. Data in Table 1 show that CI had a moderate correlation with salinity ($r=0.6$) and also TOM ($r=0.5$).

Table 1

Pearson's correlation among the environmental parameters and the condition index of *Geloina coaxans*

Parameters	CI	Temp.	Salinity	Water pH	Alkalinity	Nitrite	TOM
CI	1						
Temperature	-0.1	1					
Salinity	0.6	-0.4	1				
Water pH	0.1	0	-0.2	1			
Alkalinity	0	-0.5	0.5	-0.6	1		
Nitrite	0	0.3	0.3	-0.2	-0.3	1	
TOM	0.5	-0.5	0.4	0.5	-0.3	-0.2	1

Discussion. The mean water salinity showed clear seasonal variation, with the highest level recorded in June and the lowest in December. This fluctuation could be associated with increased river volume and flow rate after the rainy season in the Mekong Delta, which may have led to decreased salinity. These findings are in accordance with the hypothesis that *Polymesoda (Geloina) erosa* is a euryhaline species (Boominathan et al 2014) and has adapted to salinity fluctuations. Other studies have also reported that the water salinity tolerance for mud clams ranges from 7 to 22‰ (Modassir 2000), 13–32‰ (Irwani & Suryono 2006), and 5–7‰ (Widianingsih et al 2020). Recently, Ngo et al (2023) reported that the best weight and size growth of juvenile *G. coaxans* were recorded at salinity values of 5‰ and 10‰ and were significantly higher than at values of 1‰ and 15‰.

Results from this study showed that TOM exhibited distinct seasonal fluctuations, showing higher values during the transition between the rainy and dry seasons. The observed TOM levels (4.6–7.5%) were lower compared to those reported by Ngo et al (2019b) in mangrove sediments of another site (9.8–16.4%). Variations in TOM could be due to varying concentrations in runoff from the rivers that supplied sediments and the decomposition of bottom sediments. Azlan et al (2012) indicated that heavy rains can detach organic matter from the soil. In contrast, Haryono et al (2021) argued that the average content of TOM in 100 g of sediment was lower (3.72%) during high tide and higher (5.86%) during low tide in the tidal zone. The variations observed in both sediment and water pH indicate stable and suitable environmental conditions for clam survival. As pointed out by Ramadhan (2020), a substrate with a pH of 5.35–6.40 is conducive for *Geloina* species, which align with the range recorded in this study. Silva & Barros (2001) stated that a pH of 6.7–7.2 is optimal for bivalves. Moreover, Wen (2009) observed that a pH greater than 10.5 completely disrupts the buffer system. The temperature pattern observed in this study reflects the natural influence of solar radiation and ambient air temperature on water conditions. Boyd (1990) also noted this relationship in aquatic systems. Moreover, the observed temperature range for the mangrove clam habitat was between 27.0–30.3°C (Irwani & Suryono 2006), which is similar to the findings of the present study.

In this study, the seasonal variations in alkalinity suggest that rainfall plays a major role in influencing alkalinity levels. These findings are in agreement with Boyd (1998), who stated that an alkalinity of 50–150 ppm is moderate, while values exceeding 300 ppm are very high. The seasonal fluctuations in nitrite concentrations indicate that rainfall and runoff play key roles in influencing nitrogen dynamics in the water. However, the present study reported higher nitrite values compared to other studies. For instance, Venkatesan et al (2015) stated that a NO_2^- content of 0.001–0.004 ppm is within the normal range, and 0.025 ppm is sub-optimal for short-neck clams. Ngo et al (2019a) also found that a NO_2^- concentration of 0.2 ppm was acceptable, but higher levels could be toxic for clam larval development. The size distribution of clam *G. coaxans* observed in this study indicates that most individuals were in the smaller size class. According to

Hamdan et al (2019), *Geloina* species with a length less than 50 mm were considered small, those from 50 to 70 mm were medium, and those above 70 mm were large. The maximum length result in this study is in agreement with Poutiers (1998), who stated that a maximum length of 70.0 mm is common in the wild. In contrast to the averages observed in the present study, Elvira & Jumawan (2017) found a mean length of 40.75 mm and a mean weight of 76.43 g for *P. erosa*. The difference in mean weight could be due to the higher body weight range (5.33 g to 168.53 g) recorded in their study compared to the present study. The variations observed in biomass and density of this species throughout the sampling months can be explained by several ecological and environmental factors reported in previous studies. According to Dolorosa & Dangan-Galon (2014), the population of *P. erosa* can vary between regions and even between patches of mangroves, possibly influenced by environmental conditions and harvesting. Additionally, biomass and density could be influenced by factors such as favorable sediment pH, presence of TOM, competition for space around roots (Morton 1976), carrying capacity, water quality (Tanyaros & Tongnunui 2011), predation (Connell 1961), settlement effect (Morton 1976), substrate type for attachment at a younger stage (Clemente & Ingole 2011), and deep burrowing behavior (Lebata 2000).

The fluctuation pattern of the condition index of *G. coaxans* observed in this study is consistent with previous findings on the reproductive cycle and energy allocation in bivalves. Duisan et al (2021) found that gonads represent 59% of the total weight of soft tissues in bivalves. The gonad of mussel *Mytilus trossulus* also contains protein and fat that increase during gametogenesis and decrease after spawning (Wołowicz et al 2006). Moreover, previous studies have also stated that CI is related to the spawning season of bivalves (Clemente & Ingole 2009; Yang et al 2011; Celik et al 2012). For instance, Clemente & Ingole (2009) reported variations in CI from 1.9 to 4.7, with low values during the spawning period of *P. erosa*. This indicates a loss of tissue weight due to the release of gametes (Sahin et al 2006).

The observed correlations between CI and environmental parameters indicate that both salinity and TOM play an important role in influencing the physiological condition of *G. coaxans*. These findings suggest that the availability of TOM may have increased the total weight of *G. coaxans*, while salinity might have triggered spawning activities. As pointed out by Clemente & Ingole (2009), salinity changes after heavy rainfall may act as a cue for spawning in *P. erosa*. Similarly, Morton (1976) stated that variations in water pH, temperature, and salinity play a vital role in the feeding responses of *G. proxima*, ultimately decreasing the condition index. According to Guntur et al (2019), the environmental parameters such as dissolved oxygen also closely related to the richness and diversity index of bivalve populations in the tidal area of East Java, Indonesia.

Conclusions. The measured environmental conditions varied throughout the months, with notable variations in water salinity as it dropped from 14 to 0.4‰ during the rainy season. Sediment pH remained relatively consistent around 6.3, and together with TOM, both provided a suitable habitat for *G. coaxans*. The estimated average clam biomass ranged from 0.8 to 2.1 kg 100⁻¹ m⁻², and the density ranged from 38.4 to 83.6 individuals 100⁻¹ m⁻². The condition index was high in May, with an average of 7.02%, and all *G. coaxans* were considered healthy, with a condition index above the standard value of 4%. Further studies should focus on characterizing the habitat and investigating the interaction between the condition index and the gonadal somatic index of *G. coaxans*.

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Conflict of interest. The authors declare that there is no conflict of interest.

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