Diversity and distribution of molluscs (Gastropoda and Bivalvia) in the seagrass beds at Pulau Gazumbo, Penang, Malaysia

Vian L.W.[1]; Nilamani N.[2]; Sharuiddin S.F.F.[1]; Woo S.P.[2]; Ilias N.[2]; Yasin Z.[2]; Hwai A.T.S.[1,2*]

Received: December 2021 Accepted: February 2022

Abstract

In recent decades, rapid coastal development has threatened the scarce seagrass beds. Therefore, more comprehensive research on the ecosystem of the seagrass beds in Penang is urged. The purpose of this study was to investigate the diversity of molluscs (Gastropoda and Bivalvia) and the effect of sediment characteristics on the distribution of molluscs in the seagrass beds at Pulau Gazumbo, Penang. Field measurement was conducted from September 2020 to March 2021 at six stations. Using the quadrat and transect methods, the molluscs samples were collected by handpicking and scrapping up the surface substrate. A total of 28 species of gastropods from 16 families, 22 genera and 13 species of bivalves from seven families, 10 genera, were recorded in this study. The most dominant mollusc species found were *Cerithium coralium* from Cerithiidae. Although an inconsistent effect of sediment characteristics was recorded, the distinctly high percentage of organic matter content and finer sediments demonstrated an apparent detrimental effect on molluscs, especially bivalves. The results of this study serve as a framework for a proper checklist of molluscs at Pulau Gazumbo. In addition, a more detailed investigation on habitat type, which focuses on certain mollusc species with regards to their feeding behaviours, is recommended for future research.

Keywords: Biodiversity, Molluscs, Seagrass bed, Pulau Gazumbo, Straits of Malacca

1-School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia
2-Centre for Marine & Coastal Studies (CEMACS), Universiti Sains Malaysia, Penang, Malaysia.
*Corresponding author's Email: aileen@usm.my

[DOI: 10.18331/SFS2022.9.1.7]

Introduction

Phylum Mollusca is one of the most diverse groups in the animal kingdom, with eight classes which are Gastropoda, Bivalvia, Cephalopoda, Polyplacophora, Solenogastres, Caudofoveata, Monoplacophora and Scaphopoda (Gosling, 2015). The successful evolution of Mollusca into various shapes and adaptations allows them to colonize almost every ecosystem, from deep water to terrestrial habitat, including seagrass beds.

Seagrasses are submerged marine flowering plants often found in shallow coastal and estuarine water (Short *et al*., 2016). The common presence of seagrasses in shallow water and the interface between ocean and land makes it more vulnerable to disturbances. The accelerating decline of seagrass beds is recorded worldwide due to anthropogenic stressors and climate change (Ontoria *et al*., 2019; Short *et al*., 2011). Inevitably, degradation of seagrass beds and marine water quality have directly impacted on fauna community structure (Githaiga *et al*., 2019), especially the benthic community (Matin *et al*., 2018).

Mollusca is one of the most dominant groups among marine benthic communities (Rueda et al., 2009) and it can be used as bioindicators because of their limited mobility and low tolerance towards environmental disturbances (Wats and Jindal., 2017; Escamilla-Montes *et al*., 2019). In past years, several research on benthic fauna in seagrass beds had been done in Malaysia, especially study on mollusc communities (Tan *et al*., 2007; Zaidi *et al.*, 2008; Zaleha *et al.*, 2009; Long *et al*., 2014; Teh *et al*., 2014; Nooraini *et al.*, 2021). However, the biodiversity of molluscs in Malaysia is still not fully discovered. Moreover, due to anthropogenic impacts, the composition and diversity of molluscs in seagrass beds might be altered.

Despite the importance of seagrasses in maintaining marine biodiversity and providing ecosystem services, the focus of conservation efforts has been concentrated on the more charismatic habitats such as coral reefs, compared to the less known seagrass beds. The unknown states of seagrass habitats from many places reduce the recognition of seagrasses among the public, stakeholders and policy makers, and therefore, limit the conservation resources (Unsworth *et al*., 2019).

More study is urged to deepen our understanding of seagrass ecosystem which helps to develop an appreciation towards seagrass ecosystem and determine effective management strategies in conserving the ecosystem. The aims of this study were to investigate the diversity and composition of molluscs and to study the relationship between the distribution of molluscs with the sediment characteristics in the seagrass beds at Pulau Gazumbo. In this study, only the classes of Gastropoda and Bivalvia from Mollusca were focused and considered.

[DOI: 10.18331/SFS2022.9.1.7]

Materials and methods

Sampling site

This study was conducted at Pulau Gazumbo (5°21′N, 100°19′E), northeast of Penang Island which is located in the northern region of the Straits of Malacca (Fig. 1). The sampling period was from September 2020 to March 2021. A total of six sampling stations was selected in this study where Station A, B, C and D were located at Pulau Gazumbo Besar, while Station E and F were located at Pulau Gazumbo Kecil. The details of sampling station were listed in Table 1. The seagrass species that can be found at Pulau Gazumbo were *Halophila ovalis* Hook (1858), *Halophila spinulosa* Aschers (1875), *Halophila beccarii* den Hartog (1977) and *Halophila ovata* Gaud (1827) (Tan *et al*., 2007).

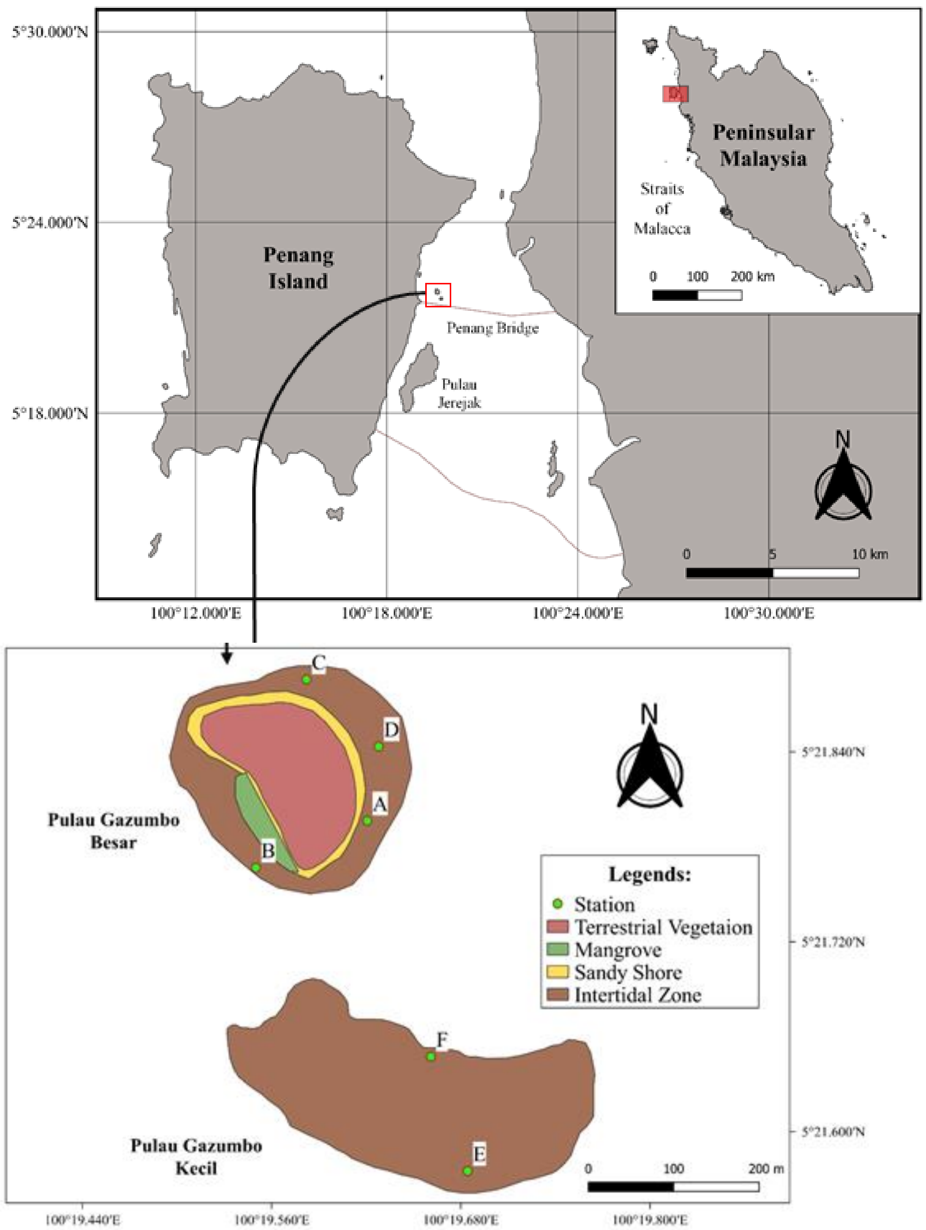

Figure 1: Map showing the location of Pulau Gazumbo Besar and Kecil.

[DOI: 10.18331/SFS2022.9.1.7]

Field sampling method

Sampling was carried out during the lowest spring tide when the seagrass beds were exposed. Quadrat and transect methods were applied, as shown in Figure 2. A total of three transect lines (50 m each) was established parallel to the shoreline according to the intertidal zonation. For each transect line, five replicates of samples were collected by using 0.5 m×0.5 m quadrats. The benthic molluscs found in the quadrants were handpicked and scrapped up from the surface of substrate by using a hand shovel and sieved through a 1 mm mesh sieve. Soil samples were obtained for sediment grains size analysis by using the core method (core measurement: 10 cm in diameter, 15 cm in height) as described in [15]. Following the core, 50 mL falcon tubes were used to collect the soil samples for organic matter content analysis.

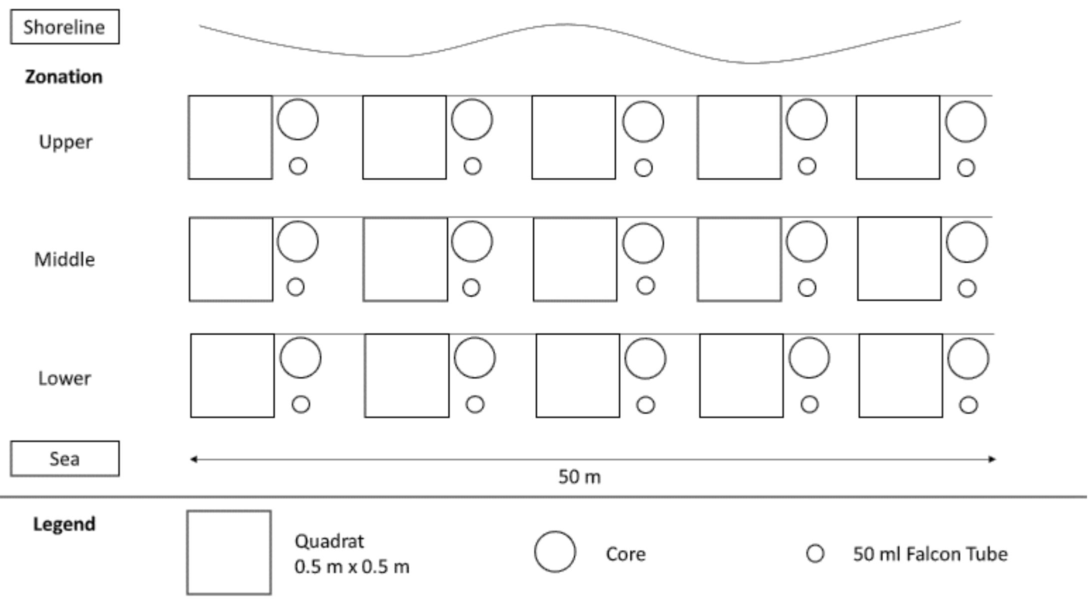

Figure 2: Quadrat and transect methods for sampling at Pulau Gazumbo.

Species identification

Mollusc specimens were identified to the lowest possible taxonomic level by examining the morphological characteristic of the shells. The main identification keys used were from Abbott (Abbott, 991), Carpenter and Niem (Swennen *et al.,* 2001), Lamprell and Healy (Carpenter and Niem, 1998), Swennen *et al*. (Lamprell and Healy, 1998) and database from WoRMS Editorial Board (2021). Photographs of the shell were taken using a digital camera, Nikon D3200 with different standard positioning (Callomon, 2019).

Sediment grain size analysis

The wet sieving method was applied to analyse the composition of sediment particle size. The sieves with a mesh size range of 2 mm, 1 mm, 710 µm, 300 µm, 250 µm, 125 µm and 63 µm were used. The class of sediment particle size was determined according to the Udden-

[DOI: 10.18331/SFS2022.9.1.7]

Wentworth grain size classification scale (Wentworth, 1922).

Organic matter analysis

The loss on ignition (LOI) method was used to measure the organic matter content in sediments by calculating the percentage of the sediment weight loss after ignition (Eqn. 1) (Heiri *et al*., 2001; Howard *et al*., 2014). The soil samples were dried at 105°C, homogenised using mortar and pestle and followed by weighing 10 g of samples into each crucible before the combustion. The soil samples were ignited at 550°C for 4.5 hours in a furnace to remove all the organic matter. The weight of soil samples after ignition was measured after cooling to room temperature:

$$\text{Percentage of loss on ignition, LOI (\%)} = \frac{\mathrm{DW}_{105} - \mathrm{DW}_{550}}{\mathrm{DW}_{105}} \times 100$$

Eqn. 1

Where, DW_{105}=Dry weight of soil sample before ignition at 105°C; DW_{550}=Dry weight of soil sample after ignition at 550°C

Diversity indices

Ecological analysis was performed using PAST software (Paleontological Statistics). Shannon's diversity indices were used to analyse the species diversity (*H'*), species evenness or Pielou's evenness (*J'*) and Margalef's species richness index (D_{mg}).

Statistical analysis

The statistical tests were carried out using SPSS version 27. Kruskal-Wallis H Test was conducted to analyse the abundance of molluscs, diversity indices, soil composition, organic matter content at a 95% confidence level. The statistical difference across stations and intertidal zones was tested. Spearman's Rank-Order Correlation was used to test the presence and strength of the monotonic relationship between the abundance of molluscs and the sediment organic matter content.

Results

Abundance and composition of molluscs

A total of 41 mollusc species from 32 genera of 23 families was identified from 4260 mollusc specimens. Gastropods comprised 16 families, 22 genera and 28 species, while bivalves were categorized into seven families, 10 genera and 13 species. Gastropods comprised 97.00% of all molluscs (183.64±165.47 individuals per m^2 (ind/m^2)) (mean±SD) and only 3.01% was represented by bivalves with the abundance of 5.69±10.47 ind/ m^2. The mean density and composition of molluscs were summarised in Table 2.

[DOI: 10.18331/SFS2022.9.1.7]

Table 2: Composition and mean density (ind/ m2) (mean ± SD) of the gastropods and bivalves at Pulau Gazumbo.

Family	Species	A	B	C	D	E	F	Total
GASTROPODS								
Calyptraeidae	*Calyptraea* sp.1	–	1.60 ± 4.22	2.13 ± 4.24	–	0.53 ± 1.41	0.80 ± 2.24	0.84 ± 2.71
	Calyptraea sp.2	–	0.53 ± 1.41	0.27 ± 1.03	0.27 ± 1.03	–	–	0.18 ± 0.83
	Desmaulus extinctorium	–	–	0.27 ± 1.03	–	–	0.27 ± 1.03	0.09 ± 0.59
	Ergaea walshi	–	–	2.67 ± 4.70	–	0.53 ± 1.41	1.87 ± 4.24	0.84 ± 2.78
Naticidae	*Paratectonatica tigrina*	0.27 ± 1.03	–	–	1.07 ± 1.83	1.60 ± 2.03	–	0.49 ± 1.32
Columbellidae	*Zafra atrata*	3.20 ± 3.76	–	4.27 ± 7.48	0.80 ± 3.10	1.07 ± 2.37	1.07 ± 1.83	1.73 ± 4.02
Melongenidae	*Volegalea cochlidium*	0.27 ± 1.03	–	–	–	–	0.80 ± 1.66	0.18 ± 0.83
Nassariidae	*Nassarius livescens*	0.53 ± 1.41	1.07 ± 2.37	1.60 ± 2.53	0.80 ± 2.24	0.80 ± 2.24	1.60 ± 3.31	1.07 ± 2.38
	Nassarius stolatus	0.53 ± 1.41	–	–	0.80 ± 1.66	5.87 ± 9.43	–	1.20 ± 4.38
	Nassarius jacksonianus	5.87 ± 7.98	6.40 ± 9.17	5.07 ± 10.63	13.07 ± 23.10	13.60 ± 13.16	–	7.33 ± 13.22
	Nassarius sufflatus	0.27 ± 1.03	–	3.47 ± 4.50	0.27 ± 1.03	1.07 ± 2.37	1.87 ± 3.34	1.16 ± 2.76
Pseudomelatomidae	*Ptychobela nodulosa*	–	–	0.27 ± 1.03	–	–	0.27 ± 1.03	0.09 ± 0.59
Muricidae	*Drupella margariticola*	0.53 ± 1.41	–	1.60 ± 6.20	0.27 ± 1.03	–	–	0.40 ± 2.62
	Indothais sp.1	–	–	–	–	1.33 ± 4.19	0.27 ± 1.03	0.27 ± 1.78
	Indothais sp.2	–	0.80 ± 2.24	0.80 ± 1.66	–	2.13 ± 4.98	0.80 ± 2.24	0.76 ± 2.54
	Indothais lacera	–	–	–	0.27 ± 1.03	0.80 ± 2.24	–	0.18 ± 1.02
	Murex occa	–	–	0.53 ± 1.41	0.27 ± 1.03	–	0.53 ± 1.41	0.22 ± 0.92
Cancellariidae	*Scalptia scalariformis*	–	–	1.07 ± 1.83	–	5.60 ± 8.39	1.33 ± 2.47	1.33 ± 4.07
Marginellidae	*Cryptospira ventricosa*	0.27 ± 1.03	0.27 ± 1.03	0.80 ± 1.66	–	–	–	0.22 ± 0.92
Cerithiidae	*Cerithium coralium*	156.27 ± 74.67	67.47 ± 56.67	198.93 ± 176.79	101.07 ± 148.01	82.93 ± 121.71	166.67 ± 151.78	128.89 ± 134.22
	Clypeomorus bifasciata	18.93 ± 35.44	10.67 ± 15.17	21.33 ± 72.15	1.07 ± 3.20	1.07 ± 2.37	2.13 ± 8.26	9.20 ± 33.73
Litiopidae	*Gibborissoia virgata*	85.33 ± 67.13	0.53 ± 1.41	41.60 ± 53.36	16.8 ± 53.35	–	0.53 ± 1.41	24.13 ± 50.82
Haminoeidae	*Haminoea* sp.	–	–	–	0.27 ± 1.03	0.27 ± 1.03	–	0.09 ± 0.59
Neritidae	*Nerita polita*	–	0.27 ± 1.03	0.53 ± 1.41	–	–	–	0.13 ± 0.72
	Smaragdia souverbiana	0.53 ± 1.41	0.27 ± 1.03	6.13 ± 8.12	1.87 ± 2.97	0.27 ± 1.03	0.80 ± 1.66	1.64 ± 4.15
Chilodontaidae	*Euchelus asper*	–	–	0.53 ± 2.07	–	0.27 ± 1.03	–	0.13 ± 0.94
Phasianellidae	*Tricolia* sp.	0.80 ± 1.66	–	1.60 ± 2.95	0.80 ± 3.10	–	–	0.53 ± 1.92
Trochidae	*Conotalopia musiva*	0.27 ± 1.03	–	1.07 ± 2.37	0.27 ± 1.03	0.27 ± 1.03	–	0.31 ± 1.23
BIVALVES								
Arcidae	*Anadara antiquata*	–	1.60 ± 4.22	–	–	–	0.27 ± 1.03	0.31 ± 1.82
	Anadara indica	–	–	–	–	0.53 ± 1.41	0.27 ± 1.03	0.13 ± 0.72
Crassatellidae	*Bathytormus radiatus*	–	–	0.27 ± 1.03	–	–	–	0.04 ± 0.42
Lucinidae	*Cardiolucina* sp.	–	–	–	0.27 ± 1.03	0.27 ± 1.03	–	0.09 ± 0.59

[DOI: 10.18331/SFS2022.9.1.7]

Table 2 (continued):

Family	*Species*	A	B	C	D	E	F	Total
Mytilidae	*Perna viridis*	–	–	–	–	0.8 ± 1.66	–	0.13 ± 0.72
	Arcuatula senhousia	0.53 ± 1.41	–	1.60 ± 2.95	–	–	–	0.36 ± 1.42
	Modiolus philippinarum	1.33 ± 1.95	–	1.60 ± 3.31	–	12.27 ± 17.14	0.53 ± 2.07	2.62 ± 8.27
Corbulidae	*Corbula* sp.	5.33 ± 6.17	–	2.67 ± 6.35	0.53 ± 1.41	0.27 ± 1.03	0.53 ± 1.41	1.56 ± 4.10
Pectinidae	*Chlamys* sp.	–	–	0.27 ± 1.03	–	–	–	0.04 ± 0.42
Veneridae	*Paphia rotundata*	–	–	–	–	0.53 ± 1.41	–	0.09 ± 0.59
	Paphia sp.1	–	–	–	–	0.80 ± 2.24	–	0.13 ± 0.94
	Paphia sp.2	–	–	–	–	0.27 ± 1.03	–	0.04 ± 0.42
	Dosinia sp.	–	–	–	–	0.80 ± 2.24	–	0.13 ± 0.94
TOTAL		281.07 ± 127.06	91.47 ± 63.42	302.93 ± 204.36	140.80 ± 184.89	136.53 ± 123.64	183.20 ± 158.82	189.33 ± 165.47
Species		18	12	27	19	27	20	41
Genus		15	10	24	16	20	17	32
Family		13	8	17	13	16	13	23

*Note: "–" means not present.

Gastropod communities in the seagrass beds at Pulau Gazumbo were numerically dominated by Cerithiidae (72.9%), Litiopidae (12.7%) and Nassariidae (5.7%). Meanwhile, Mytilidae was the most abundant family of bivalves which made up 54.7% of all bivalves found. The most dominant gastropod species recorded was *Cerithium coralium* (128.89±134.22 ind/ m^2), followed by *Gibborissoia virgata* (24.13±50.82 ind/ m^2). Among bivalves, *Modiolus philippinarum* (2.62±8.27 ind/ m^2) and *Corbula* sp. (1.56±4.10 ind/ m^2) were recorded with the highest density. The images of the dominant species were shown in Figure 3.

The highest gastropod density was recorded at Station A and C, while the lowest gastropod abundance was presented at Station B. Meanwhile, Station E had the highest density of bivalves, while station B, D and F were recorded with the lowest density of bivalves. In general, the abundance of molluscs among the intertidal zones did not differ significantly.

Diversity indices

Diversity indices of gastropods and bivalves were presented in Table 3. Station E was the most diverse station with diversity index *(H')* of 0.92±0.54 for gastropods and 0.28±0.44 for bivalves, with species richness (*S*) of 18 and nine, respectively. Meanwhile, Station F had the lowest value of *H'* for gastropods (0.41±0.32) and the second lowest of *H'* for bivalves (0.07±0.27) with S of 16 and four, respectively.

The distribution of gastropods at Station E (Pielou's Evenness, *J'*=0.65±0.29) was the nearest to the state of equilibrium while Station F (*J'*=0.31±0.24) had the most unevenly

[DOI: 10.18331/SFS2022.9.1.7]

distribution of gastropods. On the other hand, low evenness of bivalves was reported at all stations ($J' \leq 0.32 \pm 0.47$).

Figure 3: Dominant gastropod and bivalve species in the seagrass beds at Pulau Gazumbo, (a) *Cerithium coralium*, (b) *Gibborissoia virgata*, (c) *Modiolus philippinarum* and (d) Corbula sp.

Table 3: Species Richness (S), Total number of individuals (N), Diversity Index (H'), Pielou's Evenness (J') and Richness Index (D_{mg}) (mean ± SD) of gastropods and bivalves among stations at Pulau Gazumbo.

Diversity Indices	A	B	C	D	E	F	TOTAL
Gastropods							
S	15	11	22	17	18	16	28
N (ind/ m^2)	273.87 ± 124.11	89.87 ± 63.42	296.53 ± 204.36	140.00 ± 184.89	120.00 ± 123.64	181.60 ± 158.82	183.64 ± 165.47
H'	0.87 ± 0.21	0.65 ± 0.45	0.87 ± 0.41	0.52 ± 0.45	0.92 ± 0.54	0.41 ± 0.32	0.70 ± 0.44
J'	0.60 ± 0.14	0.57 ± 0.28	0.49 ± 0.20	0.40 ± 0.36	0.65 ± 0.29	0.31 ± 0.24	0.50 ± 0.28
D_{mg}	0.89 ± 0.33	0.70 ± 0.50	1.27 ± 0.57	0.70 ± 0.61	1.18 ± 0.77	0.73 ± 0.47	0.91 ± 0.59
Bivalves							
S	3	1	5	2	9	4	13
N	7.20 ± 6.09	1.60 ± 4.22	6.40 ± 8.11	0.80 ± 2.24	16.53 ± 19.06	1.60 ± 4.22	5.69 ± 10.47
H'	0.22 ± 0.33	–	0.19 ± 0.28	0.05 ± 0.18	0.28 ± 0.44	0.07 ± 0.27	0.13 ± 0.29
J'	0.32 ± 0.47	–	0.27 ± 0.41	0.07 ± 0.26	0.27 ± 0.37	0.06 ± 0.24	0.16 ± 0.34
D_{mg}	0.41 ± 0.62	–	0.28 ± 0.46	0.10 ± 0.37	0.39 ± 0.62	0.10 ± 0.37	0.20 ± 0.47

*Note: "–" means not applicable.

[DOI: 10.18331/SFS2022.9.1.7]

Soil particle size composition

Medium sand (≥300 µm) consistently composed the largest part of the soil composition (22.42±4.40% to 59.30±6.00%) throughout all tidal zonation, followed by the very coarse sand (≥1 mm) and coarse sand (≥710 µm). The sediments across intertidal zones at Pulau Gazumbo were poorly sorted and the tendency of having more finer sediments from the upper to lower intertidal zone was observed.

The highest percentage of finer sediment (<250 µm) was recorded along the lower intertidal zone at Station D at 54.57%. Meanwhile, the lowest percentage of finer sediment (<250 µm) was reported along the middle and lower intertidal zones at Station E. Generally, Station E had the lowest average percentage of finer sediment (10.29%), while Station D and F had the highest (39.43% and 44.81%, respectively). Besides, Station E had a distinctly high proportion of coarser sediment (≥710 µm) at 41.36% compared to other stations in which the coarser sediment constituted 21.90% to 30.81% of the sediment.

Soil organic matter content

The mean percentage of organic matter content was showed in Fig. 4. Significant variations in organic matter content among stations were recorded. The highest organic matter content was recorded at Station F (3.80±0.90%), while Station A (1.92±0.48%) and Station E (1.93±0.41%) had the lowest. Even though organic matter content among intertidal zones did not display significant difference from a general view, an apparent peak was reported at the lower intertidal zone at Station D (5.1±0.69%).

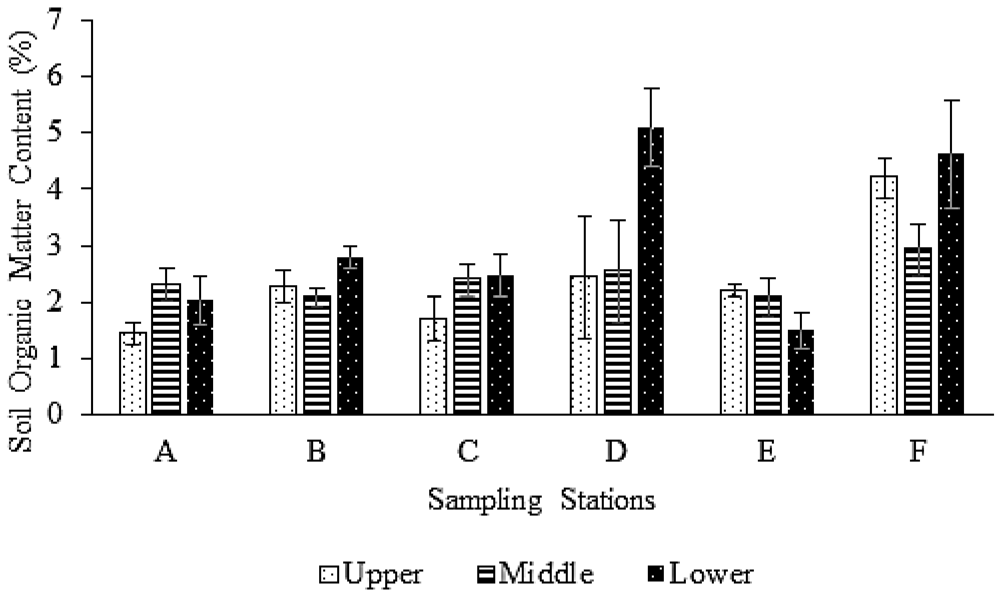

Figure 4: Soil organic matter content among intertidal zones at different stations at Pulau Gazumbo.

[DOI: 10.18331/SFS2022.9.1.7]

Relationship between mollusc abundance and sediment characteristics

Moderate and weak negative correlations were observed between the organic matter content and the abundance of gastropods (r_s=-0.315, p=0.002) and bivalves (r_s=-0.233, p=0.027), respectively. It showed that high organic matter content in soil did not favour the presence of molluscs at Pulau Gazumbo.

A drastically low abundance of gastropods and no bivalves were observed along the lower intertidal zone at Station D which had the highest percentage of finer sediment and organic matter content (5.1±0.69%). Meanwhile, the highest density of bivalves (17±3.76 ind/ m^2) was recorded at Station E which had the highest proportion of coarser sediments (≥710 µm at 41.36%) and low sediment organic matter content (1.93±0.41%). However, non-linear relationships between the variables were recorded besides the stations with distinctly high values of finer sediments and soil organic matter content.

Discussion

Diversity and distribution of molluscs

The prominently low number of bivalves species in this study may be associated with the choice of the sampling method (handpicking and scrapping the surface of substrate) which did not collect infaunal bivalve species. Notably, *C. coralium* had a distinctly high occurrence (68.1%; 129±134.22 ind/ m^2). The high density of Cerithiidae (Creeper snails) at Pulau Gazumbo may be due to its high tolerance towards stresses (dryness and erosion), comparatively high resilience and availability of food in the seagrass bed as it primarily feeds on algal and detritus (Tan *et al*., 2007; Casebolt, 2017; Houbrick, 1974). Moreover, the empty shells occupied by hermit crabs and the drill holes on the shells have highlighted the ecological importance of *C. coralium* as shelter and food source for predatory species such as Muricidae (Tan, 2008).

This study was the first to record the presence of the abundant species, *S. souverbiana* and *G. virgata* at Pulau Gazumbo despite its frequent occurrence at nearly all stations. The lack of documentation on these species may be related with its tiny size (less than 5 mm), shell colour and transparency (green in *S. souverbiana*; white in *G. virgata*) which led to overlook in the previous survey (Tan *et al*., 2017). The diversity of *Nassarius* spp. (Mud whelks) in seagrass beds was also recorded in various studies (Tan *et al.*, 2007; Teh *et al*., 2014; Leopardas *et al.*, 2014). They are scavengers that serve critical functions in balancing the benthic ecosystem as they actively remove the dead matter on the seafloor (Morton, 1995). Their worldwide distribution and abundance in seagrass beds were due to their ability to adjust themselves to handle the osmotic stress and the fluctuation in salinity (Cheung, 1997; Morton, 1990).

Numerous economically important species were found in this study. The molluscs that have been commonly harvested at Pulau Gazumbo are mussels (Mytilidae), ark clams (Arcidae),

[DOI: 10.18331/SFS2022.9.1.7]

scallops (Pectinidae), venus clams (Veneridae), moon snails (Naticidae) and harrowed murex (*Murex occa*) (Carpenter and Niem, 1998). Commercial and recreational shellfishing by the local fishing communities were observed at Pulau Gazumbo. The increasing frequency of non-professional shell gathering activities before the Covid-19 pandemic had brought concern as their shellfishing technique may cause high disturbances in the seagrass communities. Trampling, increased availability of carrion and other physical disruptions due to shellfishing could affect the behaviour and increase the predation risk of molluscs, hence, negatively influence the diversity of mollusc (García-García *et al*., 2015; Garmendia *et al*., 2017).

Comparison between current study and previous survey (Tan *et al*., 2007) showed a shift in species diversity and structure of the mollusc communities at Pulau Gazumbo, indicating the alteration of the seagrass ecosystem in the past 14 years. There is an increase in molluscs density (107 ind/ m^2 to approximately 189 ind/ m^2) and number of mollusc species from 2007 to 2021. However, more study focusing on the relationship between the occurrence of dominant species and environmental factors were required to pinpoint the underlying causes of the alteration in species diversity.

From October 2015 to January 2016, a survey on the mollusc community (Gastropoda and Bivalvia) took place in the seagrass beds at Middle Bank, a sandbank adjacent to Pulau Gazumbo (Nooraini *et al*., 2021). Most of the mollusc species in the study were also found at Pulau Gazumbo. The gastropods species, *C. coralium* was found to be the most abundant species at both study sites with a distinctly high density. However, higher species richness was observed at Pulau Gazumbo (number of identified species=41) as only 12 species of molluscs were identified at Middle Bank. The lower species diversity at Middle Bank may be related to its location near the coastal development and Penang River estuary, which led to higher exposure to intensive anthropogenic disturbances. In addition, less sampling effort in the study at Middle Bank also contributed to the lower number of identified species as only four stations were sampled over the 2 km seagrass bed.

A study documented 18 species from 10 families of macrogastropods in the seagrass meadow of Merambong Shoal, located in the western Johor Straits (Teh *et al*., 2014). Meanwhile, similar studies by Zaidi *et al*. (2008) and Oliver and Glover (1996) at Merambong Shoal also demonstrated seagrass environment as a highly diverse habitat. Pulau Gazumbo (*H'*=0.70±0.44) was less diverse, compared to Merambong Shoal, especially in the bivalve population, which showed a low value in *H'* (0.13±0.29). Even though the total number of mollusc species at Pulau Gazumbo outran Merambong Shoal, a lower value of diversity indices was shown at Pulau Gazumbo. This phenomenon could be the combined effect of the unevenly distributed mollusc population at Pulau Gazumbo, a greater sampling effort covering more sampling areas, and the use of the corer method in the study at Merambong Shoal that allowed the sampling of infaunal burrowing bivalves (Zaidi *et al*., 2008).

Relationship between mollusc abundance and sediment characteristics

Despite the inconsistent effect of sediment condition on mollusc abundance, a detrimental effect of the intensely high percentage of finer sediments and organic matter content was recorded. Moreover, the lowest species diversity was reported at Station D and F, which were recorded as the stations with the highest mean percentage of finer sediments. It exemplified the detrimental effect of the intensely high percentage of finer sediments and organic matter content when it passed the threshold for the survival of molluscs at Pulau Gazumbo.

Studies by Zaleha et al. (2009) and Bell and Sherman (1980) reasoned that the less compactness in the coarser sediments offered more space for inhabitation. Therefore, a higher abundance of benthic fauna can be found in the area. However, contrary findings for the assumption were reported (Callaway et al., 2014; Ampili and Sreedhar, 2016). Callaway et al. (2014) have proposed a positive correlation between finer sediment and the occurrence of cockles, and the contribution of sediment movement in determining the distribution pattern of bivalves. The research also stressed the choosing of sediment types based on the burrowing ability of bivalves and the abundance of food.

In addition, the observation forecasted the severity of habitat destruction on the species diversity if sedimentation seriously impacts Pulau Gazumbo in future. The effect was discovered to be more severe on the bivalve population as most of the bivalves found at Pulau Gazumbo were epifaunal and unable to move freely. The coastal development, proximity of Pulau Gazumbo to urbanised areas, land reclamation projects and the construction work along the inland coastline makes the Pulau Gazumbo more susceptible to human disturbances. With a general investigation on mollusc abundance in this study, the result did demonstrate the effect of sediment characteristic on the mollusc abundance to a certain degree, but the inconsistency of the effect prevents a confident conclusion to be made.

Conclusion

Results of this study can be used as a framework for a more updated checklist and proper taxonomy database of molluscs at Pulau Gazumbo, Penang. However, the limitations on the mollusc species identification, lack of a comprehensive taxonomy database in the region and insufficient knowledge in the identifier's malacology could potentially undermine this study's significance. Under- or overestimation of species diversity can occur as some mollusc species cannot be easily distinguished due to the interspecifically similar shell characteristics (Ran *et al*., 2020; Tan and Sigurdsson, 1996; Oliver and Glover, 1996; Collin, 2003). Furthermore, molluscs within the same species may display diverse shell characteristics and shell colouration at different growing stages and living environments, contributing to misidentification as distinct species (Ran *et al*., 2020; Tan and Sigurdsson, 1996; Oliver and Glover, 1996; Collin, 2003; Kumar *et al.*, 2017). To improve the accuracy in species identification, studies suggested the combined effort of morphological characteristics, DNA barcoding and molecular clarification on the uncertain specimens (Ran *et al*., 2020; Tan and Sigurdsson, 1996; Oliver and Glover, 1996; Collin, 2003; Kumar *et al.*, 2017; Glover *et al*., 2016).

This study demonstrated the detrimental effect of distinctly high organic matter content and percentage of finer sediments on the presence of molluscs. The molluscs, especially bivalves, could hardly survive at Pulau Gazumbo, if habitat destruction becomes more severe in the future. Moreover, the high number of mollusc species in this study also suggested the importance of Pulau Gazumbo as a biodiversity hotspot in the Straits of Malacca. Continuous documentation of diversity is essential as we need a comprehensive database to understand the extent of biodiversity, and therefore, influence the management system's design towards a sustainable direction. For further research, we recommend a more detailed investigation on sediment characteristics that focuses on specific species regarding their feeding guilds in order to justify the effect of habitat type on the mollusc abundance.

Acknowledgements

Authors would like to thank School of Biological Sciences, Universiti Sains Malaysia (USM), researchers and postgraduates of Centre for Marine and Coastal Studies (CEMACS) for providing facilities and kind help during field sampling. This finding was aligned with the United Nations' Sustainable Development Goal 14 (SDG 14): Life below water to provide information for the formulation of a sustainable coastal management in Penang. This work was funded by Penang Institute under project code, R212/21 USAINS. Special thanks to Penang State Government and YB Phee Boon Poh, the Penang State Exco for Welfare and the Environment for supporting this study.

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