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Original Article

Species composition, richness, and distribution of molluscs from intertidal areas at Penang Island, Malaysia

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Abstract

A fundamental baseline study for integrated coastal management of tropical intertidal areas was conducted. The present study describes the species composition and distribution of molluscs in the intertidal areas of Penang Island. Five selected sites, that comprised Teluk Aling, Pulau Betong, Jelutong, Teluk Kumbar, and Batu Feringghi, were sampled based on a stratified random design from May 2015 to January 2016. High in species diversity (H' = 1.21±0.22) and species evenness (J' = 0.92±0.10) were recorded at Teluk Kumbar. Meanwhile, Pulau Betong was high in species richness (S = 6.60±6.47). The intertidal area of Teluk Aling, that was characterized by fine sand, favored the abundance of *Umbonium vestiarium* and thus had the highest total abundance of 2,535 individuals/m^3. *Zeuxis* sp. and *Diplodonta asperoides* were the most common species found at all sites except in Batu Feringghi. Environmental parameters, such as soil temperature, soil salinity, organic matter and sediment type, were significantly different among the five sites (ANOVA, P<0.05). The sites which were heavily impacted by anthropogenic activities had very low species diversity, for example Jelutong, and there was an absence of molluscs at Batu Feringghi throughout the study period.

Keywords: species composition, gastropods, bivalves, intertidal, Penang Island

1. Introduction

An intertidal area consists of various habitats that support many living organisms (Menge *et al.*, 1986; Omar *et al.*, 2011; Terlizzi *et al.*, 2002). Organisms living in an intertidal area are inherently tolerant to a wide range of natural conditions. This zone is harsh and is characterized by extreme changes in salinity, desiccation, temperature, currents, and predators. Hence, many organisms possess special adaptation features to overcome these challenges. For instance, mussels avoid desiccation by closing their shell tightly to retain moisture (Senechal-Brown & Dean, 1997).

Intertidal shorelines can be divided into three zones: upper intertidal, middle intertidal, and lower intertidal. In the upper intertidal, only the most resilient species can survive since the conditions are similar to that of terrestrial areas. The middle intertidal is occasionally submerged by the tides and is associated with more competition for space and a greater number of predators. The lower intertidal zone remains submerged most of the time and is populated by diverse communities, including members of all the major phyla (Senechal-Brown & Dean, 1997; Spring, 2002). Sessile and mobile molluscs are an essential element of natural intertidal assemblages.

The intertidal mollusc plays a significant role in terms of providing food sources to aquatic animals, migratory birds, and humans. They form a key link in the food chain and have a high socioeconomic value for coastal fisheries.

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Moreover, they function in marine ecosystems through nutrient cycling and energy flow. In addition, the intertidal zone also serves as a recreational spot for tourism. Thus, molluscs are identified as an important biological indicator in marine and estuarine environments. Since they have the ability to assess water quality and ecological risk assessments, the mollusc population is greatly affected by changes in the physicochemical characteristics (Garg *et al.,* 2009; Sharma *et al.*, 2013; Udayantha & Munasinghe, 2009;). Unfortunately, the population of the intertidal mollusc seems to have declined due to changes in water conditions resulting from human activities, pollution levels, and climate change (Deepananda & Macusi, 2013; Omar *et al.,* 2011).

This alarming trend is a cause of concern, particularly in developing tropical regions such as those observed in Malaysia. At the present, the majority of coastal zones in Malaysia have been reclaimed for urban development, and more proposals of reclamation/coastal development have been designated as part of the future plans for Malaysia. Therefore, this baseline study is essential to assess ecosystem degradation. Data that comprises the current status of molluscs in the intertidal region, specifically in an area exposed to rapid development, is crucial for future sustainable management policies of intertidal areas. This study aimed to identify the species composition and spatial distribution of intertidal mollusc communities at Penang Island, Malaysia.

2. Materials and Methods

Penang Island is a metropolitan island with an area of approximately 293 km^2 and is situated on the north-west side of Peninsular Malaysia. The average annual rainfall is 2,989 mm with an average annual temperature of 26 ºC.

The selection of sites was based on the different development/disturbances occurring in the area (Figure 1). Teluk Aling (TA) (N 5°28.0780" E 100° 12.009") is located on the northwest coast of the island and is a part of Penang National Park gazetted in 2003 under the National Park Act of 1980. TA is considered the least disturbed area from human activities with a very gradual extensive intertidal area. Meanwhile, Batu Feringghi (BF) (N 05°28.4560" E 100° 14.811") is heavily impacted by tourist activities. Jelutong (JT) (N 05°22.8820" E 100° 19.090"), previously a mangrove area, is now part of a reclaimed area. At the southern part is Teluk Kumbar (TK) (N 05°16.9110" E 100° 12.721") with a sandy intertidal area and small fishing communities. Pulau Betong (PB) (N 05°18.5370" E 100° 11.619") is on the southwest corner of Penang Island and is characterized by a muddy intertidal area with mangrove trees.

Sampling of molluscs was done at the upper, middle, and lower intertidal areas using the stratified random sampling method proposed by Flores-Garza *et al.* (2011) and Deepananda and Udayantha (2013). The samples were collected from each study site with a total of five replicates sampled from each zonation. The sampling number was generated from the Research Randomizer software.

On the intertidal shore, a core with a volume of $V = \pi r^2 h$ (0.003117 m^3) with dimensions of 0.21 m (diameter) and 0.09 m (depth) was placed vertically on the substrate to collect the samples. Five quadrat frames (1x1 m) were randomly placed at each zone and a total of five core samples were taken from each zonation. Hence, 15 samples were obtained from each study site as outlined by Chapman (2005). *In situ* environmental parameters such as soil temperature were recorded using Fisher Scientific™ Traceable™ Digital Waterproof Thermometer. Meanwhile, the soil pH and soil salinity were measured using STARTER 300 Portable pH Meter (Ohaus, USA) and refractometer (ATAGO-USA), respectively.

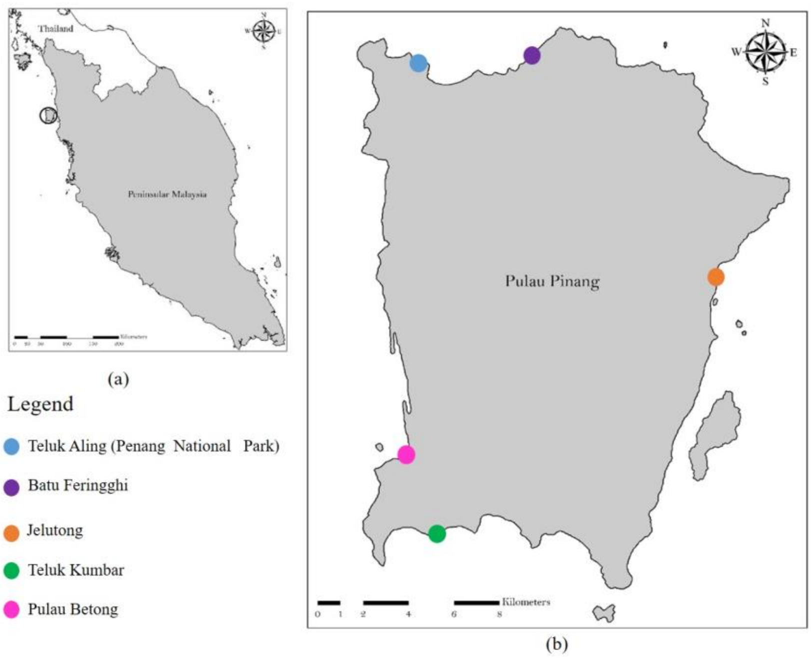

Figure 1. Detailed map of the study site (a) Penang, (b) study localities of Teluk Aling (TA), Batu Feringghi (BF), Jelutong (JT), Teluk Kumbar (TK) and Pulau Betong (PB).

In the laboratory, approximately 100 g of sediments were taken for particle size analysis carried out by the dry sand sieving method (Brown & McLaachlan, 1990; Holme & McIntyre, 1971; McBride, 1971). Organic matter analysis was done based on the direct gravimetric method suggested by Bale and Kenny (2005). The mollusc samples were sieved using a 500 µm sieve and the retained samples were put back into a new plastic bag and preserved with a mixed solution of (10% formalin and Rose Bengal) that was diluted with seawater. The abundance of molluscs was measured as the number of individuals found per sample in the community. The mean abundance of the species was calculated by dividing the number of individuals found throughout the sampling period with the five sampling months and the three zones.

Identification of the molluscs was based on previous studies by Beesley *et al.* (1998), Hosseinzadeh *et al.* (2001), Kira (1965), Okutani (2000). In addition, the international checklists of species (World Register of Marine Species, WoRMS) were used to catalogue species correctly.

Shannon-Wiener diversity index was performed to determine the value of taxon richness (Shannon-Wiener index: $H' = -\Sigma\, pi\ ln\ pi$, where pi is the proportion of individuals found in species i). The estimation of $pi = ni/N$, where ni is the number of individuals in species i and N is the total number of individuals in the community, was outlined by Shannon and Weaver (1949). The evenness index was measured using Pielou's (1977) equation [$J' = H'/\ln S$], where H' = Shannon-Wiener diversity index and S = total number of species. The PERMANOVA test was done on mollusc assemblages using PRIMER version 7 to detect any differences in mollusc assemblages among these groups, while two-way ANOVA was done on environmental parameters, i.e. soil temperature, soil pH, soil salinity, organic matter and particle size. Pearson's correlation was performed to find the correlations between environmental data with intertidal mollusc assemblages.

3. Results

A total of 375 sediment samples containing molluscs were collected in the intertidal zone of several sites of Penang Island from May 2015 to January 2016. From these samples, 5,096 individuals/m^3 were sorted of which 460 individuals/m^3 were identified as bivalves and 4,636 individuals/m^3 were recognized as gastropods. They were classified into 2 classes, 12 orders, 22 families, 25 genera, and 30 species (Figure 2). The family Trochidae recorded the highest and most diverse number of gastropods, while the family Mytilidae recorded the highest number of bivalves.

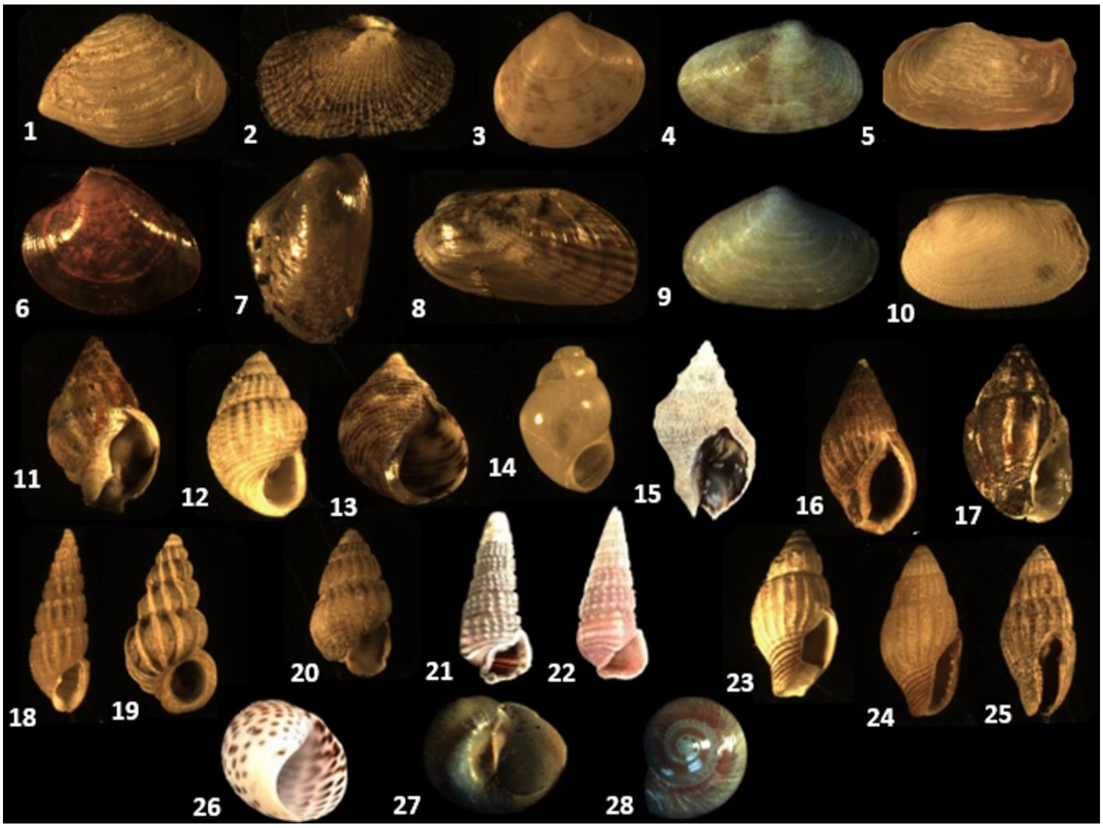

Figure 2. The Bivalvia and Gastropoda sampled from the study site: 1) *Anisocorbula* sp.; 2) *Barbatia fusca*; 3) *Diplodonta asperoides*; 4) *Donax cuneatus;* 5) *Laternula* sp.; 6) *Meretrix meretrix*; 7) *Modiolus* sp.; 8) *Musculista senhousia*; 9) *Nitidotellina* sp.; 10) *Solecurtus* sp.; 11) *Alectrion* sp.; 12) *Alvania* sp.; 13) *Littorina scabra*; 14) *Stenothyra* sp.; 15) *Euchelus* sp.; 16) *Zeuxis* sp.; 17) *Zeuxis olivaceus*; 18) *Rissoina* sp.; 19) *Epitonium pulchellum*; 20) *Pusia* sp.; 21) *Cerithidea cingulata*; 22) *Cerithidea* sp.; 23) *Zafra pumila*; 24) *Zafra* sp.; 25) *Zafra minuscula*; 26) *Natica tigrina*; 27) *Natica* sp.; 28) *Umbonium vestiarium.* Scale bar=1 cm. (Species with no photos taken: *Mya* sp. and *Polinices mammatus*).

The species composition and distribution of molluscs along the intertidal areas are shown in Table 1. The TA intertidal area was the least disturbed area which recorded the highest species abundance with 2535 individuals/m^3 and a mean abundance of 169 individuals/m^3. The species identified were *Umbonium vestiarium, Diplodonta asperoides, Donax cuneatus, Natica tigrina, Polinices mammatus, Zeuxis* sp., and *Meretrix meretrix*. *U. vestiarium* dominated the area and represented 94% of the total species abundance (Figure 3).

PB with an extensive mudflat exhibited the second highest abundance with 1,696 individuals/m^3 with a mean abundance of 113 individuals/m^3. There were 19 taxonomic groups that were comprised of *Diplodonta asperoides, Meretrix meretrix, Solecurtus* sp., *Barbatia fusca, Anisocorbula* sp., *Laternula* sp., *Musculista senhousia*, *Modiolus* sp., *Zeuxis* sp., *Zeuxis olivaceus*, *Alectrion* sp., *Natica* sp., *Cerithidea* sp., *Cerithidea cingulata*, *Zafra* sp., *Stenothyra* sp., *Pusia* sp., *Euchelus* sp., and *Epitonium pulchellum* (Figure 2). *C. cingulata* was the dominant species that represented 77% of the total abundance followed by *M. senhousia* (8%), *Cerithidea* sp. and *Laternula* sp. (3%), and other species (9%) (Figure 3).

Table 1. Distribution of intertidal mollusc (number of individuals/m^3) collected at intertidal area (lower zone, middle zone and upper zone) at the five study sites during study period.

Species	Teluk Aling (TA)			Pulau Betong (PB)			Jelutong (JT)			Teluk Kumbar (TK)			Batu Feringghi (BF)		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Diplodonta asperoides	0	44	3	3	0	0	2	0	0	28	6	2	0	0	0
Meretrix meretrix	0	2	0	17	16	0	0	0	0	0	2	0	0	0	0
Zeuxis sp.	8	0	0	9	14	21	55	0	0	8	0	0	0	0	0
Umbonium vestiarium	1300	939	136	0	0	0	0	0	0	0	0	0	0	0	0
Donax cuneatus	0	0	66	0	0	0	0	0	0	0	2	6	0	0	0
Natica tigrina	32	2	2	0	0	0	0	0	0	2	0	0	0	0	0
Polinices mammatus	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solecurtus sp.	0	0	0	2	0	0	0	0	0	3	0	0	0	0	0
Barbatia fusca	0	0	0	0	3	0	0	0	0	2	0	0	0	0	0
Anisocorbula sp.	0	0	0	25	6	0	8	0	0	2	0	0	0	0	0
Laternula sp.	0	0	0	52	2	0	0	0	0	0	0	0	0	0	0
Musculista senhousia	0	0	0	139	2	2	0	0	0	0	0	0	0	0	0
Modiolus sp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Stenothyra sp.	0	0	0	3	0	0	602	0	0	25	0	0	0	0	0
Zafra sp.	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0
Cerithidea cingulata	0	0	0	13	116	1184	65	0	0	0	0	0	0	0	0
Zeuxis olivaceus	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Cerithidea sp.	0	0	0	3	2	41	0	0	0	0	0	0	0	0	0
Pusia sp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Alectrion sp.	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Euchelus sp.	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Epitonium pulchellum	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Natica sp.	0	0	0	0	0	8	0	0	0	0	2	0	0	0	0
Rissoina sp.	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
Nitidotellina sp.	0	0	0	0	0	0	3	6	0	0	2	0	0	0	0
Mya sp.	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Alvania sp.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
Zafra pumila	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Littorina scabra	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Zafra minuscula	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Total no. of species	4	4	4	16	8	6	7	1	0	10	7	3	0	0	0
Total no. of individuals	1341	987	207	279	161	1256	743	6	0	90	16	10	0	0	0

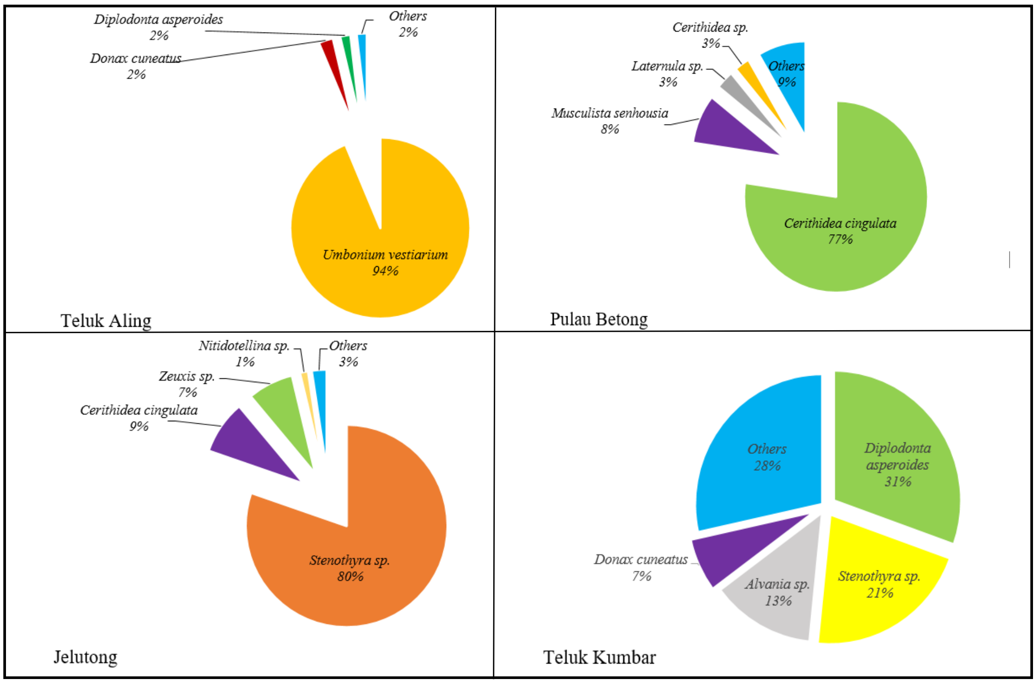

Figure 3. Relative abundance of the most frequently sampled species at Teluk Aling, Pulau Betong, Jelutong, and Teluk Kumbar.

A total of 7 intertidal molluscs, i.e. *Diplodonta asperoides*, *Anisocorbula* sp., *Stenothyra* sp., *Cerithidea cingulata*, *Zeuxis* sp., *Rissoina* sp., and *Nitidotellina* sp. were found at JT. JT, which is considered as one of the highly disturbed areas due to land reclamation, recorded a total abundance of 749 individuals/m^3 with a mean abundance of 50 individuals/m^3. *Stenothyra* sp. was the dominant species (80%), followed by *C. cingulata* (9%), *Zeuxis* sp. (7%), *Nitidotellina* sp. (1%), and other species (3%) (Figure 3).

TK with a sandy beach had a total abundance of 116 individuals/m^3 with a mean abundance of 8 individuals/m^3. There were 17 species, namely *Diplodonta asperoides*, *Solecurtus* sp., *Barbatia fusca*, *Anisocorbula* sp., *Meretrix meretrix*, *Mya* sp., *Alvania* sp., *Zafra* sp. *Zafra pumila*, *Zafra minuscula*, *Stenothyra* sp., *Littorina scabra*, *Zeuxis* sp., *Nitidotellina* sp., *Donax cuneatus*, *Natica* sp., and *Natica tigrina*. Apparently, the BF intertidal area is highly exposed and heavily impacted by human activities since it is the most popular tourist beach. During the study period, no living molluscs were recorded in the BF intertidal area (Table 1). Broken shells were found at the lower intertidal zone, but most of these shells were empty.

Table 2 shows the mean species richness (S), Shannon-Wiener index (*H'*), and evenness index (*J'*) at each study site. TK recorded the highest value of *H'* and *J'* with mean values of 1.21±0.22 and 0.92±0.10, respectively. However, the highest species richness (mean value 6.60±6.47) was recorded at PB. The recorded mean values of *H'* and *J'* at PB were 0.72±0.59 and 0.42±0.17, respectively. At TA the mean values were *H'* = 0.34±0.28 and *J'* = 0.29±0.18 and at JT the mean values were *H'* = 0.14±0.31 and *J'* = 0.08±0.17. Based on the PERMANOVA test, there were significant differences between mollusc assemblages with site and zonation (P=0.001) (Table 3).

Table 2. Mean species richness (S), Shannon-Wiener index (*H'*) and evenness index (*J'*) of mollusc species recorded in all site (TA=Teluk Aling, PB=Pulau Betong, JT=Jelutong, TK=Teluk Kumbar).

Site	S	*H'*	*J'*
TA	3.20±0.84	0.34±0.28	0.29±0.18
PB	6.60±6.47	0.72±0.59	0.42±0.17
JT	1.80±2.39	0.14±0.31	0.08±0.17
TK	4.20±2.17	1.21±0.22	0.92±0.10

Table 3. Summary of results from permutational analysis of variance (PERMANOVA) on mollusc assemblages with different sources of variation, i.e. site, zonation, and month for all sites (TA=Teluk Aling, PB=Pulau Betong, JT=Jelutong, TK=Teluk Kumbar, BF=Batu Feringghi).

Source of variation	df	MS	Pseudo-F	P (perm)
Site (Si)	4	118640.00	116.53	0.001
Zonation (Zo)	2	6096.20	5.99	0.001
Month (Mo)	4	6318.40	6.21	0.001
Si x Zo	8	6558.70	6.44	0.001
Si x Mo	16	4169.50	4.09	0.001
Zo x Mo	8	4531.70	4.45	0.001
Si x Zo x Mo	32	2562.80	2.52	0.001
Residual	300	1018.10		
Total	374			

Note: Significant at P=0.001.

A particle size analysis revealed that most of the intertidal shores at the studied sites were comprised of coarse sand and a mixture of coarse and medium sand (1000 µm and 630 µm), except for TA (Figure 4). The upper intertidal zone of TA was composed of coarse sand and a mixture of coarse and medium sand while the lower and middle intertidal zones were comprised of fine and very fine sand. Generally, the lower zone of the intertidal area exhibited higher organic matter content (2.41±0.29%) compared to the middle zone (2.09±0.72%) and upper zone (1.73±0.80%) (Table 5). The mean soil salinity was higher at the lower zone (30 ppt) and decreased from the middle (16 ppt) to the lower zone (8 ppt). Soil pH and temperature indicated slight fluctuations within the intertidal zone that were 5.91-7.16 and 28.86-31.4 ºC, respectively (Table 4). Environmental parameters, i.e. soil temperature, soil salinity, organic matter, and sediment type, were significantly different among the five sites (ANOVA, P<0.05).

A Pearson correlation analysis of the environmental data with intertidal mollusc assemblages revealed that the *Donax cuneatus* (bivalve) was strongly correlated (r>0.9) with a mixture of coarse and medium sand but negatively correlated with very fine sand (r=–0.998). The *Meretrix meretrix* (bivalve) *and Zafra minuscula* (gastropod) were positively correlated (r>0.9) with a mixture of coarse and medium sand (630 µm). However, *Certhidea cingulata* (gastropod), *Cerithidea* sp. (gastropod) *Epitonium pulchellum* (gastropod), and *Natica* sp. (gastropod) were negatively correlated (r>–0.9) with a mixture of coarse and medium sand. Only *Zafra pumila* (gastropod) had a strong positive correlation with soil salinity (r>0.9) while *Zeuxis* sp. was negatively correlated with soil salinity (<10 ppt). The *Anisocorbula* sp. (bivalve) had a strong correlation (r=1.0) with fine sand (250 µm) (Table 6).

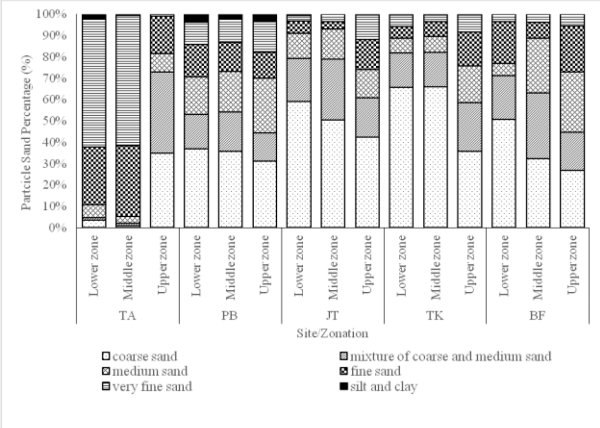

Figure 4. Particle size composition (%) throughout the sampling period from May 2015 to January 2016 at Teluk Aling (TA), Pulau Betong (PB), Jelutong (JT), Teluk Kumbar (TK), and Batu Feringghi (BF).

4. Discussion

The present study describes the species diversity, richness, and evenness of molluscs in intertidal region of Penang Island. TK recorded the highest species diversity which was derived from the number of different species that were represented in a community that was incorporated with the evenness of the species abundance. Meanwhile, the highest species richness was discovered in PB due to the higher number of species found. In addition, TA recorded the highest species abundance (number of individuals per species) due to the occurrence of a high density of *Umbonium vestiarium*.

Table 4. List of overall environmental parameters (soil temperature, soil pH, soil salinity) at all sites.

ID	Study site	Abbreviation	Soil temperature (◦C)			Soil pH			Soil salinity (ppt)		
			Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
1	Teluk Aling	TA	30.99	30.89	31.4	6.31	6.43	6.65	33	26	17
2	Pulau Betong	PB	30.98	30.78	30.59	6.27	6.17	5.98	32	22	10
3	Jelutong	JT	30.28	29.63	28.86	6.25	6.13	6.15	25	12	3
4	Teluk Kumbar	TK	30.97	31.25	30.79	7.16	7.27	7.14	25	14	7
5	Batu Feringghi	BF	31.18	30.22	29.54	6.26	6.21	5.91	32	5	3
Mean (SD)			30.88 (0.35)	30.55 (0.64)	30.24 (1.02)	6.45 (0.40)	6.44 (0.48)	6.37 (0.52)	30 (4)	16 (8)	8 (6)

Table 5. Results of overall organic matter (%) and sediment characteristics at all sites.

ID	Study site	Abbreviation	Organic matter (%)			Sediment type		
			Lower	Middle	Upper	Sediment description	Dominant	Subdominant
1	Teluk Aling	TA	2.12	1.53	1.15	Very fine sand	Very fine sand	Medium sand
2	Pulau Betong	PB	2.63	3.33	3.14	Firm coarse sand	Medium sand	Silt and clay
3	Jelutong	JT	2.74	2.08	1.41	Firm coarse sand	Medium sand	Fine sand
4	Teluk Kumbar	TK	2.46	1.83	1.49	Firm coarse sand	Medium sand	Fine sand
5	Batu Feringghi	BF	2.11	1.67	1.47	Firm coarse sand	Medium sand	Fine sand
Mean (SD)			2.41 (0.29)	2.09 (0.72)	1.73 (0.80)			

Table 6. Correlation of the environmental parameters with intertidal molluscs.

Intertidal molluscs	Environmental parameter correlations					
	Soil pH	Soil salinity	Coarse sand	Mixture of coarse and medium sand	Fine sand	Very fine sand
Umbonium vestiarium	**r = -0.999***	r = 0.985	r = -0.929	r = -0.949	r = 0.878	r = 0.976
Donax cuneatus	r = 0.944	r = -0.896	r = 0.996	**r = 0.999***	r = -0.978	**r = -0.998***
Zeuxis sp.	r = -0.995	**r = -0.999***	r = -0.982	r = -0.908	r = -0.937	r = 0.835
Meretrix meretrix	r = 0.966	r = 0.923	r = 0.852	**r = 0.997***	r = 0.755	r = -0.975
Zafra pumila	r = 0.099	**r = 0.998***	r = 0.836	r = -0.874	r = -0.913	r = -0.373
Zafra minuscula	r = -0.619	r = -0.803	**r = -1.0****	**r = 0.998***	r = 0.989	r = 0.814
Cerithidea cingulata	r = -0.965	r = -0.921	r = -0.849	**r = -0.998***	r = -0.751	r = 0.976
Cerithidea sp.	r = -0.927	r = -0.867	r = -0.780	**r = -0.999***	r = -0.667	r = 0.995
Epitonium pulchellum	r = -0.941	r = -0.886	r=-0.804	**r = -1.0****	r = -0.696	r = 0.990
Natica sp.	r = -0.941	r = -0.886	r=-0.804	**r = -1.0****	r = -0.696	r = 0.990
Anisocorbula sp.	r = 0.888	r = 0.942	r = 0.983	r = 0.688	**r = 1.0***	r = -0.572

*Significant at P<0.05
**Significant at P<0.001

The TK site was considered to have fewer anthropogenic effects and a minimal amount of inshore fishing. This condition was linked to several aspects such as ecological niche, nutrient availability, environmental pressure, and site patterns (Hensgen *et al.,* 2014). In this study, a high population of *U. vestiarium* was found in a clean beach which had the characteristic of fine sand (Kalyanasundaram *et al.,* 1975; Ong & Krishnan, 1995). *U. vestiarium* can be classified as a site-specific organism that can be found only at habitable sites on a gently sloping beach. This finding is in accordance with the findings of the particle size at TA by Arularasan and Kasinathan (2007) that showed this gastropod preferred fine and very fine substrates. Another factor that contributed to their survival in TA was probably the moderate wave energy and a sand grain size of 0.31-0.20 mm that was preferred by *U. vestiarium* (Sivadas *et al.,* 2012).

Intensive commercial fishing and cage culture activities at PB showed a decreasing trend in the abundance of mollusc assemblages. However, a high abundance of *Cerithidea cingulata* was found at PB and JT probably due to the similarity in their physical conditions. The presence of a muddy substrate attributed to this abundance of cerithiid gastropods (El-Sorogy *et al.,* 2016). The only gastropod that was found at JT in a high abundance was *Stenothyra* sp. during the first month of sampling and was absent during the next sampling period.

During the study period, no live species of molluscs were found at the BF site. BF serves as a recreation and tourist spot with a high density of visitors every year. Trampling effects contribute to the destruction of the environment through sand compaction. Compact sand loses the ability to retain water and oxygen which results in the desiccation and hypoxic conditions for living organisms along the sandy shore. Sewage and detergents that are discharged from the nearby premises undoubtedly disturb the living organisms in the intertidal area. Those anthropogenic activities induce stress on the community structure which leads to a reduction in species diversity and an increase in the dominance of stress-tolerant species (Linton and Warner, 2003).

Environmental parameters, such as pH (Garg *et al.,* 2009) and temperature (Joubert *et al.,* 2014), did not show any effect on mollusc distribution in this study. Even though some findings highlighted temperature as one of the factors contributing to intertidal mollusc distribution (Rueda & Salas, 2008; Sharma *et al.,* 2013), temperature was meaningless in this study. Molluscs that live in the sand are more immune to the influence of salinity and temperature differences because they can burrow deeper into the sand.

The high organic matter content found close to the shoreline possibly influenced the mollusc diversity which led to a large number of species, such as deposit feeders (bivalves), i.e. *M. senhousia* and *Anisocorbula* sp., which are usually buried in the sediment, whereas *Z. olivaceus* and *Zafra* sp. are detritus decomposers (gastropods) that play a role in degrading energy rich compounds of soil organic matter.

Z. pumila was positively correlated with soil salinity and was found in TK, which preferred a salinity range of 20-25 ppt. It is postulated that this salinity level is the most ideal and is an optimum range for these gastropods because this species requires warm, saline water to thrive well but somehow there is too little information regarding the physical tolerance of this species (Humfrey, 1975). The high content of coarse and medium sand particles provide a greater availability of food as it is synonymous with a high-energy habitat because of the current and wave action activity (Levinton, 1972). Meanwhile, *Anisocorbula* sp., which highly dominated the lower and middle intertidal zones of PB, JT, and TK, showed a positive correlation with fine sand (250 µm). Fine sand was identified as subdominant sediment type at these three sites. According to Velasco and Navarro (2002), habitats with a high content of fine sediments indicated a high level of organic matter. Furthermore, this gastropod prefers fine particle size because the finer sediment allows high water retention (Okutani, 2000).

The differences in species richness at the five sites may be due to the variation in the nature of the habitats and other factors affecting the diversity, such as anthropogenic activities around the study sites. Competition for food and space had a lower impact on the distribution of organisms, but it was certainly believed that the biotic interactions and physical conditions have superior effects towards mollusc distribution in these environments (Wilson, 1991). Without proper planning and management, anthropogenic disturbances from land reclamation, tourism, commercial fishing, and aquaculture could lead to erosion of mollusc biodiversity. Hence, we have deduced that the low diversity of intertidal molluscs was due to the increase in disturbances at the study sites.

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