Tropical intertidal gastropods: insights on diversity, abundance, distribution and shell morphometrics of Pulau Bidong, Malaysia

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Abstract. The intertidal zone or littoral zone is the part of the ocean that is underwater during high tide and exposed during low tide. The intertidal ecosystem is continually under pressure from both humans and the natural elements of waves and tidal shifts. The organisms that reside here must be able to tolerate extreme changes to physicochemical factors such as light, temperature, water movement, salinity and oxygen. Gastropods from phylum Mollusca are highly resistant and adaptable to extreme changes in the environment. This study investigates the diversity, abundance, and distribution of tropical intertidal gastropods in different areas. Also, it examines how shell morphometrics and biomass affect these factors. Sampling was done in Pantai Pasir Cina (PPC) and Pantai Pasir Pengkalan (PPP) at Pulau Bidong, Malaysia in August 2018. Transect lines of 60 m × 10 m were laid out perpendicular to the shore. Six quadrats of 1 m^2 were placed at three tidal zonation's: high, mid, and low tide. A total of 1326 individual gastropods represented by eight families (Littorinidae, Muricidae, Planaxidae, Siphonariidae, Neritidae, Nacillidae, Patellidae and Trochidae) were recorded, along with five subclasses namely Ceanogastropoda, Heterobranchia, Neritimorpha, Patellogastropoda and Vetigastropoda. A total number of 19 species were recorded from both study sites. The Shannon diversity index, *H'* showed that at the intertidal zones at both locations the diversity was less than two, indicating low diversity. In contrast, Simpson's index, *D* at all intertidal zones at both sites had values of almost one, indicating a high level of dominance. This pattern is also seen for evenness indices such as *J'* and *Ep'* where all values are close to one, which indicates complete evenness for all tidal zones. The diversity t-test revealed significant differences between the sites of PPC and PPP, t (1192.5) = -4.9652, $p < 0.05$. The SHE analysis of the two sites showed a lognormal pattern. Community structures of intertidal zones at PPC and PPP are between 'more equally' and 'very equally' and fall under the 'good' or the 'very good' categories. Although it is the baseline, a future study on spatial heterogeneity and temporal variability are needed to provide more comprehensive knowledge of malacofauna communities and their ecological importance.
Key Words: shallow, waves, Gastropoda, diversity t-test, SHE analysis.

Introduction. The intertidal zone or littoral zone is the shallowest part of the ocean and can be underwater or exposed to the air depending on the tide. This area feels the full force of nature and is continuously pounded by waves and currents. Tidal shifts are caused by the gravitational effects of the sun and moon. According to Miller & Spoolman (2015), coastal areas usually have at least six hours of rising and falling tides, which vary according to the magnitude and frequency. Magnitude refers to the amount of gravitational pull and the position of earth, moon and sun. There are two types of tidal fluctuation which are spring tides and neap tides. Spring tides usually occur during full or new moons when the sun, moon and earth are aligned in such a way that it causes drastic fluctuations to the tides (Kvale 2006). Whereas neap tides occur when the sun and moon are positioned in a way that creates minimum tidal disruption, usually during the first and third quarters of the moon (Kvale 2006). The nature of tidal cycles is also highly dependent on the location, and a place can be classed as either semidiurnal or diurnal. Semidiurnal tide cycles are where there are two low tides and two high tides in a day, while locations with diurnal cycles only have one low and high tide per day. The South China Sea and the Gulf of Mexico both have diurnal tide cycles due to their geographical position (Molles 2016). Tidal differences can drastically affect ecosystems because during high tide all areas are underwater whereas during low tide they are exposed.

The landscape in the intertidal zone is commonly composed of boulders, pebbles, cobbles, blocks, rock platforms, and tide pools (Londoño-Cruz et al 2014). These structures create vertical zonation that allows the intertidal zone to be divided into at least five zones which are the supratidal fringe, high, middle, low, and subtidal. The supratidal fringe or splash zone is hugely exposed and spends the least amount of time covered by water, while the lower area is usually always inundated and has the least exposure to the atmosphere (Molles 2016). Because of this zonation, abiotic factors such as light, temperature, water movement, salinity, and oxygen vary tremendously across the different zones.

Organisms that live in this ecosystem must adapt successfully to tolerate the physio-chemical changes that tidal factors cause. One example is gastropods which belong to the second most abundant phylum Mollusca. Gastropods have a single shell made of calcium carbonate that protects their soft-bodies. The operculum is a secreted plate made of calcareous or corneous that is located at the end of its foot. It tightly closes and plugs the shell aperture by coiling its soft body into the shell to avoid predators or environmental threats (Xu et al 2018). This intelligent adaptation allows gastropods to thrive in hostile environments like the intertidal zone, where low tide temperatures can exceed 52°C on tropical rocky shores like Brunei Darussalam (Marshall et al 2013). Organisms that live in the low tide zone have a greater tolerance to high temperatures and desiccation (Knox 2001). Given these unique characteristics demonstrated by gastropods, this study examines the diversity, abundance, and distribution of gastropods in the different zones. Secondly, it looks at the morphometric and biomass of tropical intertidal gastropods in Pulau Bidong, Malaysia. This study is the first of its kind, and to date, there is little research on tropical intertidal gastropods in a Malaysian context. Previous work that did focus on Malaysia was limited in geographical scope and investigated shallow water ecosystems like coral reefs rather than the intertidal zone. Therefore, this study contributes to the current literature by investigating intertidal ecosystems, specifically Pulau Bidong, and how they are affected by tidal systems.

Material and Method

Study sites. This study was conducted on the 12th to 18th August 2018 at two locations in Pulau Bidong, Terengganu (Figure 1). The sites were Pantai Pasir Cina (N 05°37'20.5'' E 103° 03'26.2'') and Pantai Pasir Pengkalan (N 05°36'45.7'' E 103°03'32.4'').

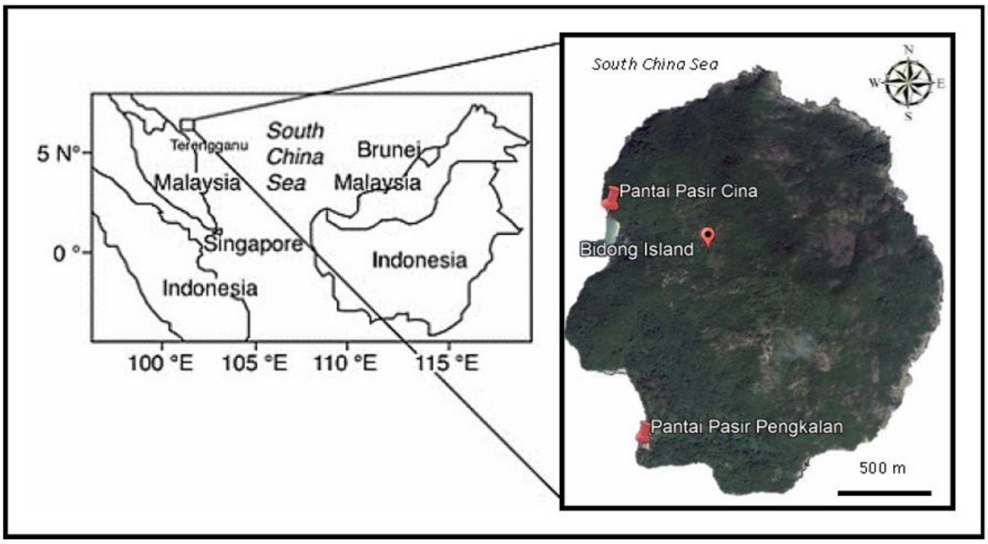

Figure 1. A map of study sites, Pantai Pasir Cina and Pantai Pasir Pengkalan at Pulau Bidong, Terengganu, Malaysia (East Peninsular Malaysia).

Both areas are moderately sheltered by vegetation. However, some areas are exposed to direct sunlight during the daytime. The rocks at the high tide zone appeared to be mostly bare without any encrusting algae in contrast to those in the mid and low tide zones. In Pantai Pasir Cina, the intertidal area is not accessible to the public because it is part of Universiti Malaysia Terengganu Marine Station (UMT MaReSt), and visitation is restricted for research purposes only. In comparison, Pantai Pasir Pengkalan is located next to a jetty which the public can visit. The area also has the Pulau Bidong museum that is dedicated to the history of how in the 1970s the island was used as a refuge for the Vietnamese seeking shelter from the war (Figure 2).

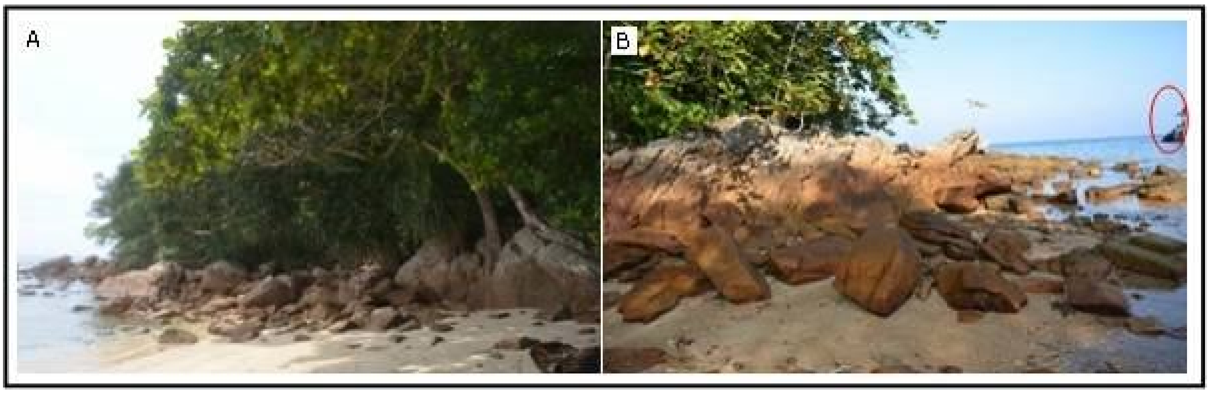

Figure 2. (A) The intertidal zone of Pantai Pasir Cina that is sheltered by vegetation, and (B) the intertidal zone of Pantai Pasir Pengkalan that is located next to the jetty (red circle) of Pulau Bidong museum.

Sampling method and gastropod identification. A transect with a length of 60 m and a width of with 10 m was established perpendicular to the shore at both study sites. Then, three sub-transects were created within it for replication. Next, six quadrats of 1 m^2 were placed according to the random number generator to acquire quantitative data and avoid bias. The gastropod samples were collected from the high and low tide zones (Long et al 2014). Pictures were taken, and the number of individuals was recorded in each quadrat. During the fieldwork, pressure on biodiversity was reduced by avoiding the collection of large quantities of samples. Generally, the identification of the species was made during the fieldwork, then 10-15 individuals were selected randomly and put into a labelled zip lock bag and brought to the laboratory for further identification and morphometrics measurement. All samples were placed in a freezer (±4°C) before removed for analysis. The gastropod shells were cleaned with tap water and a brush to make identification more straightforward and to remove algal film or other encrustations. The gastropods were identified based on shape, colour, size and ornamentation of the shell. Also, taxonomic identification keys by Abbot & Dance (1982), Abbot (1991), Tan & Chou (2000), Long (2010), Long & Ramli (2010), and Baharuddin & Marshall (2014) were also referred to during the process. The WoRMS website (World Register of Marine Species, www.marinespecies.org) and MolluscaBase (www.molluscabase.org) were used to verify the names of species at the lowest taxonomic level possible.

Shell morphometrics and photograph. Shell length, shell width, aperture length and aperture width were measured using Vernier callipers of ±0.01 mm accuracy (Figure 3). The photos were taken with a Canon DSLR camera. Next, to determine the dry weight, pieces of tinfoil were cut to a size that was large enough to enclose the gastropod, then they were numbered and weighed with an electronic scale. Then, the gastropods in the tin foil were reweighed and placed in the oven on a steel tray to dry at 65°C for 72 hours (3 days). All gastropods were then reweighed on the third, fourth and fifth days to monitor changes of weight and to obtain the constant whole-body dry weight (Baharuddin 2010).

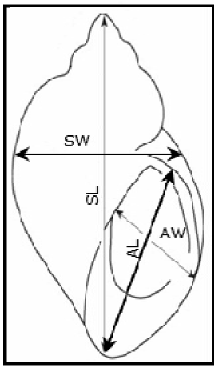

Figure 3. The shell morphometrics of the gastropods: shell length (SL), shell width (SW), aperture length (AL), and aperture width (AW).

Data analysis

Ecological indices. The species diversity of the marine gastropods was calculated using the Shannon Index:

$$H' = -\sum_{i=1}^{s} Pi \log Pi$$

In the above, H' is the value of the Shannon diversity index, Pi is the proportion of the species, logPi represents the natural logarithm of Pi, and s represents the number of species in the community. The Shannon diversity index is classified into three levels: low (H' < 2), moderate (2 < H' < 4), and high (H' > 4) (Odum & Barret 2004).

The Simpson Index (*D*), also known as dominance index, was used to determine the weight and abundance of the most common species. It also measured the probability that two individuals randomly selected from the sample belonged to the same species. This index ranges from 0 (low biodiversity) to almost 1 (high diversity).

$$D = 1\text{-}\Sigma\ (Pi)\ 2$$

The richness index was used following the Margalef Index (*Ma*) and the Menhinick Index (*Me*), according to Hammer et al (2001), as below:

$$Ma = (s\text{-}1)/\ln N$$

$$Me = s/\sqrt{n}$$

Where s equals the number of distinct species represented in the sample, N equals the total number of individual organisms in the sample. The Margalef index indicates the number of species in a sample or the abundance of the species per unit area (Ludwig & Reynolds 1988). Both indices were strongly influenced by the sampling effort.

The evenness index was measured using the Evenness Index (*J'*) and Equitability (*Ep*). Homogeneity and the pattern distribution of species in the sample area were observed (Hammer et al 2001), as below:

$$J' = H'/H'\ max$$

$$Ep = H'/\ln\ (S)$$

Where H' = Shannon diversity index and S = number of species. In the above, the value of 1 represents complete evenness, while 0 represents no evenness. Moreover, the evenness index can also be used to describe community conditions in a particular ecosystem by following Krebs (1972). The author also explained such categories are reflective of the wealth of each species. For example, values close to 1 represents that the individual species are relatively similar, while values closer to 0 indicate more variation in species (Table 1).

Table 1

The evenness criteria following Krebs (1972)

E value	*Condition of community structures*	*Category*
> 0.81	Very equally	Very good
0.61-0.80	More equally	Good
0.41-0.60	Equally	Medium
0.21-0.40	Fairly equally	Poor
< 0.2	Not equally	Very poor

Frequency of incidence (*FoI*) was calculated using the below equation:

$$FoI = \text{Ni.St} / \text{N.St} \times 100\%$$

For this equation, Ni.St is the total number of locations where the species i was found and N.St is the total number of sampling locations (Muchlisin & Azizah 2009; Rahmawati et al 2015).

The diversity t-test was also performed which compared Shannon diversities in two samples of abundance data with the assumption that both provide similar sampling conditions. Data were arranged following two columns of abundance data and taxa down the rows as described by Poole (1974).

SHE analysis was also performed to examine the relationship between S (species richness), H (information-the Shannon-Wiener diversity index) and E (evenness as measures using the Shannon-Wiener evenness index, or known as Pielou, J) in the samples (Seaby & Henderson 2006). SHE analysis is used for identifying ecotones which is a region where different ecological communities integrate. Common locations where ecotones are found are marshes, riverbanks, and the edges of lakes (Hayek & Buzas 1997). There are three types of output and data conforms as log-normal, log-series or MacArthur's broken stick model (Seaby & Henderson 2006). The authors also confirmed that such analysis is useful in testing 'goodness-of-fit' for these models. All analyses were performed using PAST – Paleontological Statistics version 3.23.

Results. A total of 1326 individual gastropods represented by eight families (Littorinidae, Muricidae, Planaxidae, Siphonariidaee, Neritidae, Nacillidae, Patellidae and Trochidae), and five subclasses namely Ceanogastropoda, Heterobranchia, Neritimorpha, Patellogastropoda and Vetigastropoda with total number of 19 species were recorded at both study sites in Pulau Bidong (Table 2 and Figure 5). The highest number of species was documented in the low tide zone in Pantai Pasir Pengkalan (PPP), where 11 species were found compared to nine in Pantai Pasir Cina (PPC). *Echinolittorina mallacana* was the most abundant species with a total of 345 individuals from both sites. The second was *Planaxis sulcatus* with 260 individuals, while *Cellana radiata* and *Patelloida* sp. had the least with four and three individuals respectively. The low tide zone contained more species than the middle and high tide zones (PPC: low tide > mid tide < low tide; and PPC: low tide > mid tide > low tide). The total number of individuals was the lowest at the middle tide zone with 154 individuals in PPC and 188 individuals in PPP. Frequency of Incidence (*FoI*) contributed by *Echinolittorina malaccana,* and *Nodilittorina pyramidalis* were 83% each, which shows these species thrive in all zones and have the highest percentage. The second highest contribution with 67% belonged to *Planaxis sulcatus*, which are generally found at mid and high tide zones (Figure 5, Table 2).

Cellana enneagona is the longest for shell length with 29.2 mm compared to other species. *Echinolittorina malaccana* and *Nodilittorina pyramidalis* recorded the shortest shell length in comparison with a range of 4-10 mm for both species. Neritidae and Siphonariidae families at PPC had shorter shell lengths compared to PPP with differences of at least 7-12 mm for Neritidae, and 8 mm for Siphonariidae. This pattern is the same for shell width and dry weight of Neritidae and Siphonariidae. In contrast, species from Littorinidae (*Echinolittorina malaccana*), Muricidae (*Tenguella musiva*), Planaxidae (*Planaxis sulcatus*) and Trochidae (*Monodonta labio*) had longer shells in PPC than in PPP.

For all these species the differences of shell length between PPC and PPP were in the range of 6-13 mm. This same pattern applies to shell width, aperture length and dry weight. *Littoraria strigata* (Littorinidae) was the lightest with a dry weight of 0.11 g compared to other species, while *Nerita undata* was the heaviest of dry weight with an average of 5.25 g in PPC and 5.59 g in PPP (Table 3).

The Shannon diversity index, *H'* showed that at all intertidal zones at both sites the diversity was less than two, indicating low diversity. In contrast, Simpson's index, *D* at all intertidal zones for both sites had values of almost one and indicated high dominance. This pattern is seen for evenness indices *J'* and *Ep'* where all values are approximately one; meaning complete evenness for all tidal zones at both sites. These values of uniformity showed that the condition of community structures is between 'more equal' and 'very equal', with a categorisation of 'good' to 'very good' (Krebs 1972). However, in terms of relative abundance, the Margalef (*Ma*) and Menhinick (*Me*) indices show that in the low tide zone, the abundance of species per unit area is higher than the mid and high tide zones. This result is reinforced by the number of species found in the low tide zones. There were nine species in PPC and 11 species in PPP, the sites contributed 264 individuals and 227 individuals respectively, and were the highest in terms of the number of different species and the abundance (Tables 3 and 4). Further investigation was done using the diversity t-test that revealed significant differences between sites of PPC and PPP, t (1192.5) = -4.9652, $p < 0.05$ (Table 5).

SHE analysis of two sites showed a lognormal pattern with the two diversity indices, the richness (S) and Shannon index (H'), which had the same increasing trend line. While the evenness index (E) line showed a reversing downward trend line. This figure showed that by increasing the sample number, the richness and diversity would rise to the maximum rate (about 3), and the evenness of species will be less. Reaching maximum diversity will happen swiftly at these sites because of the line head which started at 675 (the number of sample size, $\log_{10}$ = 2.8) and finished at 1275 (the number of sample size, $\log_{10}$ = 3.1) (Figure 4).

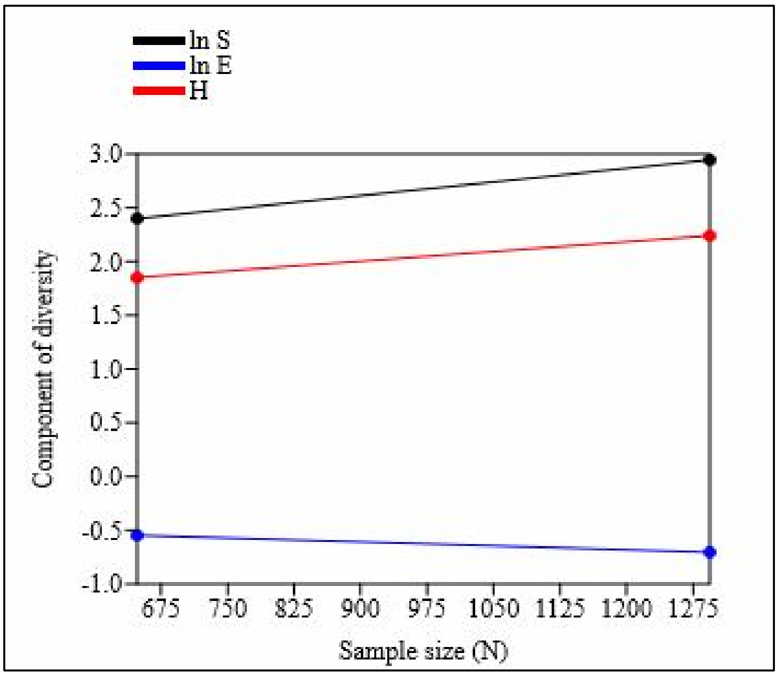

Figure 4. The SHE analysis of Pantai Pasir Cina (PPC) and Pantai Pasir Pengkalan (PPP) that showed a lognormal pattern.

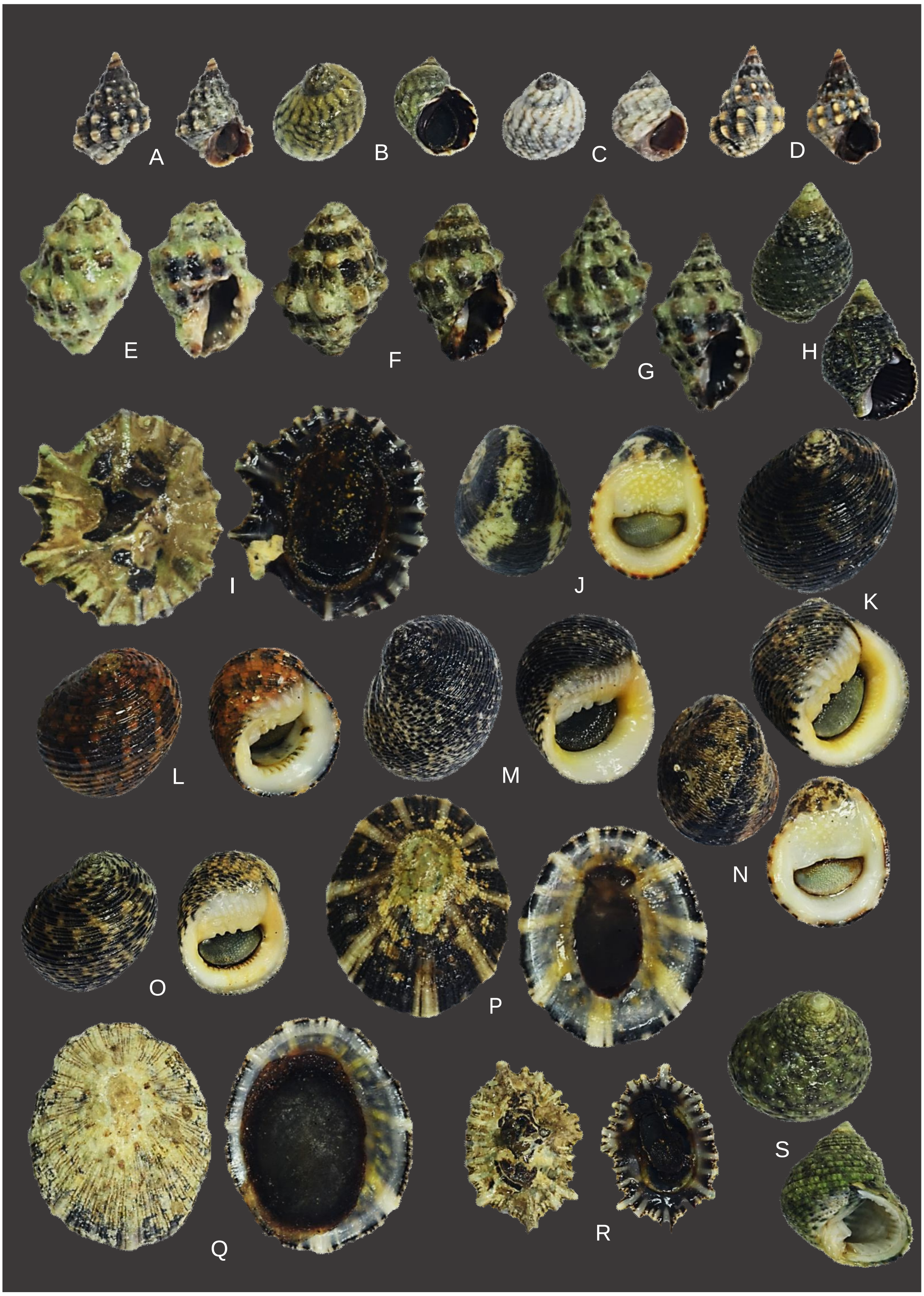

Figure 5. Apertural and abapertural view of marine gastropods of Pulau Bidong. (A) *Echinolittorina malaccana,* 7 mm; (B) *Littoraria intermedia,* 6 mm; (C) *Littoraria strigata,* 7 mm; (D) *Nodilittorina pyramidalis,* 7 mm; (E) *Morula striata,* 16 mm; (F) *Tenguella marginalba,* 14 mm; (G) *Tenguella musiva,* 16 mm; (H) *Planaxis sulcatus,* 10 mm; (I) *Siphonaria atra,* 26 mm; (J) *Nerita albicilla,* 14 mm; (K) *Nerita balteata,* 25 mm; (L) *Nerita chamaeleon,* 22 mm; (M) *Nerita striata,* 23 mm; (N) *Nerita plicata,* 20 mm; (O) *Nerita undata*, 22 mm; (P) *Cellana radiata,* 32 mm; (Q) *Cellana enneagona,* 31 mm; (R) *Patelloida* sp., 21 mm; (S) *Monodonta labio,* 21 mm. Number in parenthesis indicates shell length (mm).

Table 2

The abundance of marine gastropods in Pantai Pasir Cina (PPC) and Pantai Pasir Pengkalan (PPP) according to subclass, family and species at intertidal zonation

Subclass	*Family*	*Species*	*Study sites*		*Total (n)*	*Zonation*						*FoI (%)*
			PPC	*PPP*		*PPC*			*PPP*			
			No. of individual (n)			*H*	*M*	*L*	*H*	*M*	*L*	
Caenogastropoda	Littorinidae	*Echinolittorina malaccana* (Philippi, 1847)	130	215	345	75	-	55	84	36	95	83
Caenogastropoda	Littorinidae	*Littoraria intermedia* (Philippi, 1846)	-	25	25	-	-	-	-	25	-	17
Caenogastropoda	Littorinidae	*Littoraria strigata* (Philippi, 1846)	-	50	50	-	-	-	50	-	-	17
Caenogastropoda	Littorinidae	*Nodilittorina pyramidalis* (Quoy & Gaimard, 1833)	185	35	220	77	40	68	21	14	-	83
Caenogastropoda	Muricidae	*Morula striata* (Pease, 1868)	-	33	33	-	-	-	-	-	33	17
Caenogastropoda	Muricidae	*Tenguella marginalba* (Blainville, 1832)	-	26	26	-	-	-	-	-	26	17
Caenogastropoda	Muricidae	*Tenguella musiva* (Kiener, 1835)	92	8	100	54	-	38	-	-	8	50
Caenogastropoda	Planaxidae	*Planaxis sulcatus* (Born, 1778)	140	120	260	44	96	-	52	68	-	67
Heterobranchia	Siphonariidaee	*Siphonaria atra* Quoy & Gaimard, 1833	2	6	8	-	-	2	6	-	-	33
Neritimorpha	Neritidae	*Nerita albicilla* Linnaeus, 1758	-	8	8	-	-	-	-	5	3	33
Neritimorpha	Neritidae	*Nerita balteata* Reeve, 1855	9	11	20	9	-	-	-	8	3	50
Neritimorpha	Neritidae	*Nerita chamaeleon* Linnaeus, 1758	18	24	42	-	-	18	-	-	24	33
Neritimorpha	Neritidae	*Nerita striata* Burrow, 1815	23	-	23	8	-	15	-	-	-	33
Neritimorpha	Neritidae	*Nerita plicata* Linnaeus, 1758	18	17	35	-	18	-	11	-	6	50
Neritimorpha	Neritidae	*Nerita undata* Linnaeus, 1758	26	14	40	-	-	26	-	-	14	33
Patellogastropoda	Nacillidae	*Cellana radiata* (Born, 1778)	-	4	4	-	-	-	-	1	3	33
Patellogastropoda	Nacillidae	*Cellana enneagona* (Reeve, 1854)	4	2	6	-	-	4	2	-	-	33
Patellogastropoda	Patellidae	*Patelloida* sp.	-	3	3	-	-	-	-	3	-	17
Vetigastropoda	Trochidae	*Monodonta labio* (Linnaeus, 1758)	38	40	78	-	-	38	-	28	12	50
Total of individual (s)			685	641	1326	267	154	264	226	188	227	
Total species			12	18	19	6	3	9	7	9	11	

L = lower tide, M = middle tide, and H = high tide;
The total number of individual (n) and Frequency of Incidence (*FoI*) contributed by each species;
"–" indicates absent.

Table 3

Shell morphometrics: shell length (SL; mm), shell width (SW; mm), aperture length (AL; mm), aperture width (AW; mm) and dry weight (g) of marine gastropods following species and sample size (n) in Pantai Pasir Cina (PPC) and Pantai Pasir Pengkalan (PPP). Mean with standard deviations, S.D (mm)

Species	*Shell morphometrics*									
	SL ± S.D (n)		*SW ± S.D*		*AL ± S.D*		*AW ± S.D*		*Dry weight ± S.D*	
	PPC	*PPP*	*PPC*	*PPP*	*PPC*	*PPT*	*PPC*	*PPP*	*PPC*	*PPP*
Echinolittorina malaccana	9.1±0.7 (12)	5.4±1.2 (36)	5.4±0.8	4.0±1.2	3.7±0.6	3.6±1.0	2.9±0.5	2.6±0.9	0.63±0.13	0.27±0.05
Littoraria intermedia	-	5.7±1.0 (15)	-	3.4±0.5	-	2.5±0.5	-	1.8±0.6	-	0.65±1.52
Littorraria strigata	-	7.4±0.4 (6)	-	5.8±0.5	-	4.8±0.6	-	3.9±0.3	-	0.15±0.04
Nodilittorina pyramidalis	6.5±1.1 (26)	5.1±0.8 (15)	5.5±1.0	1.9±0.9	4.4±1.1	1.3±0.4	3.5±1.0	0.6±0.1	0.52±0.12	0.23±0.03
Morula striata	-	16.5±0.7 (2)	-	13.0±1.4	-	8.5±0.7	-	6.5±0.7	-	1.11±0.07
Tenguella marginalba	-	14.3±1.3 (4)	-	12.6±0.8	-	6.4±1.9	-	4.9±1.9	-	1.12±0.14
Tenguella musiva	16.5±1.8 (8)	12.0±1.8 (4)	9.7±3.1	6.8±0.6	8.7±3.1	4.3±1.0	7.5±3.3	3.4±1.2	1.55±0.64	3.63±0.92
Planaxis sulcatus	16.0±1.6 (18)	7.8±3.4 (23)	3.8±2.5	2.9±2.0	5.9±2.3	2.9±2.0	4.8±2.1	2.0±1.8	1.41±0.24	0.23±0.06
Siphonaria atra	22.2±3.6 (2)	25.8±0.6 (2)	9.9±0.1	21.8±0.8	19.3±2.6	22.9±1.0	6.0±0.3	19.2±0.8	1.76±0.15	1.68±0.10
Nerita albicilla	-	12.9±1.5 (4)	-	11.4±1.7	-	6.6±1.9	-	4.7±1.0	-	1.14±0.60
Nerita balteata	17.2±2.2 (3)	20.9±7.0 (4)	7.2±0.4	12.3±7.4	9.5±6.9	7.4±4.9	5.1±0.7	4.5±2.8	1.47±0.16	4.34±0.91
Nerita chamaeleon	21.0±1.6 (2)	28.0±2.1 (2)	18.0±0.9	18.0±0.6	16.3±0.7	12.8±1.3	15.2±0.6	9.2±0.7	3.92±0.51	2.81±0.23
Nerita striata	19.2±3.5 (10)	-	14.7±1.4	-	8.4±2.9	-	6.0±2.7	-	2.47±1.04	-
Nerita plicata	10.0±0.4 (4)	22.7±4.3 (2)	8.4±0.8	19.6±2.5	6.9±0.5	17.1±4.0	5.5±0.2	14.3±3.4	0.45±0.06	5.82±0.68
Nerita undata	23.0±3.6 (8)	25.4±1.4 (6)	18.3±2.9	18.6±0.9	13.6±2.8	12.0±0.5	11.3±2.2	6.8±1.2	5.25±2.27	5.59±0.59
Cellana radiata	-	32.6±2.1 (4)	-	15.3±1.5	-	26.8±4.3	-	12.3±2.0	-	1.29±0.47
Cellana enneagona	29.2±1.7 (4)	-	16.2±1.0	-	27.0±1.1	-	13.9±0.9	-	0.81±0.12	-
Patteloida sp.	-	15.0±0.9 (2)	-	8.5±1.0	-	13.3±0.8	-	6.6±1.7	-	1.08±0.07
Monodonta labio	21.9±1.2 (5)	17.7±2.7 (9)	15.8±1.1	13.7±4.7	8.9±1.1	11.4±5.2	5.8±0.7	9.8±5.3	3.86±0.41	1.62±0.62

Table 4

Ecological indices of marine gastropods in Pantai Pasir Cina (PPC) and Pantai Pasir Pengkalan (PPP) following intertidal zones at high, mid and low tide

Zonation	*Ecological indices*											
	H'		*D*		*Ma*		*Me*		*J'*		*Ep'*	
	PPC	PPP	PPC	PPP	PPC	PPP	PPC	PPP	PPC	PPP	PPC	PPP
High tide	1.555	1.546	0.768	0.748	0.895	1.107	0.367	0.466	0.789	0.670	0.868	0.794
Mid tide	0.896	1.754	0.530	0.784	0.397	1.528	0.242	0.656	0.816	0.642	0.815	0.798
Low tide	1.909	1.843	0.831	0.770	1.435	1.843	0.554	0.730	0.750	0.574	0.869	0.769

Table 5
Diversity t-test using Shannon diversities of Pantai Pasir Cina dan Pantai Pasir Pengkalan

Site	*H'*	Variance	t	df	*p*
PPC	1.957	0.001	-4.9652	1192.500	7.9E-07*
PPP	2.221	0.0018			

* Indicates significant difference with 95% confidence limit (α: 0.05).

Discussion. The genus *Echinolittorina* (formerly Nodilittorina) is the largest genus in the family Littorinidae (Reid 2007). *Echinolittorina* includes 60 recognised species, which makes up nearly half of the gastropod species found in the Indo-West Pacific region (Reid 2007; Reid et al 2012). *Echinolittorina* are among the most common and most abundant macrofauna found in the upper eulittoral and supralittoral zones of rocky shore habitats (Williams & Reid 2004). *Echinolittorina malaccana* (Philippi, 1847; formerly known as *Nodilittorina trochoides*, see Gould 1859) are found from 30°15'N latitude to approximately 5°00'N. This area includes Zhejiang China in the north and Indonesia in the South (Reid 2007).

Most littorinids are oceanic or continental in characteristics (Reid 1984; Reid et al 2012), and their habitat is seasonal (Marshall & McQuaid 2010). They exhibit behavioural isolation that allows them to withstand more than 50 days of continuous exposure to the air by withdrawing into their shells (Marshall et al 2015). These factors could explain the large numbers found in this study (345 individuals), and that they had the highest frequency of incidence (*FoI*) with 83%.

The second highest species found was *Planaxis sulcatus* that recorded 260 individuals residing in the mid and high tide zones at both sites. *P. sulcatus* is also known as clusterwinks and are gastropods that cluster together on the rocky intertidal shore and sea walls during low tide (Houbrick 1987; Tan & Low 2014). Their distribution is widespread in the Indo-West Pacific, although literature by Houbrick (1987) suggested there are at least two separate sibling species that co-exist in the Indian and Pacific Oceans. However, Tan & Low (2014) noted gaps in the evidence relating to this theory. The species are herbivores that graze on microalgae found on top of the rocky substrate (Tan & Low 2014). Other literature by Rao & Sundaram (1972) suggested they also consume marine macroalgal species such as *Chaetomorpha*, *Enteromorpha compressa* as well as organic detritus.

At Pantai Pasir Cina (PPC), species such as *Echinolittorina malaccana, Tenguella musiva*, *Palanaxis sulcatus* and *Monodonta labio* have a longer shell length than those at Pantai Pasir Pengkalan (PPP), probably due to the high-spired shells that give them protection from the rough conditions created by waves. Furthermore, the cone-shaped high-spired shells help them to survive high temperatures (Vermeij 1973) and increase their resistance to desiccation (Chapman 1997). Due to these factors, such species clump together, often on top of each other to reduce the effects of the heat. They are mostly dormant, and the shell is very dry (pers. obs.). *Echinolittorina malaccana* is known for its ability to depress metabolism and reserve energy during rest periods to maximise energy for survival in the littoral zone (Marshall et al 2011).

Gastropods from the family Neritidae at PPP had longer shell lengths compared to those at PPC. The difference in shell length could be because the jetty acts as a breakwater at PPP and protects the gastropods. While at PPC waves pound the area, and the gastropods are more exposed. This provides an ideal place for Neritidae to live comfortably at low tide zone. However, a study by Tan & Clements (2008) in Singapore found that this family were more common in the middle and upper intertidal zones. Neritids ability to attach themselves to stone allows them to survive the threat of waves and predators (Dharma 2005).

Moreover, these edible prosobranch snails are herbivores that feed on thin films of blue-green algae, diatoms, and detritus that cover the rocks (Kulkarni & Jaiswar 2000). They also have high biomass compared to other families with at least 0.4-7 g of dry weight. This is also supported by Kulkarni & Jaiswar study (2000) who mentioned that

Neritidae is the main contributor of biomass for the intertidal region of the tropics and subtropics like the Mumbai coastline on the west coast of India.

Following Shannon's index, *H'* low diversity was recorded at both study sites and all tidal zones. This result needs to be interpreted cautiously because Simpson's index, *D* indicated high dominance. The same pattern was seen in the evenness indices, *J'* and *Ep'* which meant complete evenness for all tidal zones and sites. Further investigation using SHE analysis found the same pattern where richness (S) and Shannon index (*H'*) lines steadily increased, and the evenness index (E) decreased with the increase in sample number. The richness and species will rise to a maximum rate (about 3), which the Shannon index, *H'* considers to be moderately diverse. The ecological data value of the Shannon-Wiener diversity index is generally between 1.5 and 3.5 and rarely exceeds 4.0 (May 1975). The diversity data from both of the tested sites conformed to these guidelines.

Furthermore, Wilhm & Dorris (1966) categorised the Shannon index, *H'* regarding the pollution factor. Where 1 indicates severe pollution, a value between 1 and 3 indicates moderate pollution, and a value exceeding 3 indicates no pollution. In this study, both sites were moderately polluted, although using a higher number of samples could lead to them being classed as non-polluted. It is important to note that PPC is not accessible to the general public. Therefore, human activities and impacts are minimised because the area is managed by UMT MaReST.

The evidence demonstrates that community structures of intertidal zones at PPC and PPP are between the categories of 'more equal' and 'very equal', and they fall under the 'good' and 'very good' categories. This result indicates that if a community has many species of a similar type, then it also has a high level of diversity. This theory is supported by the fact that where five subclasses were found, eight families and 19 species were recorded at both sites. Furthermore, there was a significant difference in terms of Shannon diversity, *H'* between PPC and PPP. Purnama et al (2011) mentioned that high diversity means the community has maximum complexity in terms of interaction among species. He also explained that high interaction allows energy transfer, competition, predation and niche separation to occur. In contrast, if a community has a low number of species, then these become dominant, and it leads to reduced diversity. In this study, the results show that at both sites there is a balance in the ecosystem of the intertidal zones.

Monitoring and evaluation programs should be recommended to UMT MaReST so that efforts can be made to maintain these ecosystems and protect their 'good' and 'very good' categorisation. Protection could ensure anthropogenic activities are minimised, although the area still faces exposure to other threats like sea-level rises, tropical storms, and global warming.

Conclusions. This study is crucial in providing information on gastropods that live in the intertidal zones of Pantai Pasir Cina and Pantai Pasir Pengkalan in the South China Sea. Although diversity was low, high dominance of certain species was found at both sites. Future research should focus on spatial heterogeneity and temporal variability in more depth to provide knowledge of malacofauna communities and their ecological importance.

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