Marine gastropods (Gastropoda; Mollusca) diversity and distribution on intertidal rocky shores of Terengganu, Peninsular Malaysia

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Abstract. Rocky shores are considered heterogenous environments due to their composition and structure. Therefore, they support numerous habitats of flora and fauna. Organisms found on rocky shores are facing intense physicochemical conditions during tidal changes from upper to lower intertidal zones. Gastropoda, or snails, belonging to the phylum Mollusca, have colonized highly contrasting habitats with single taxonomic orders represented in marine, freshwater, and terrestrial domains. To date, there is no documented evidence on the diversity of molluscan fauna found by intertidal rocky shores along the South China Sea in Peninsular Malaysia. This study determines the diversity and distribution of gastropods present along two intertidal rocky shores, Tanjung Jara and Teluk Bidara, in Dungun District, Terengganu, between November 2016 and February 2017. A total of five subclasses of gastropods (Caenogastropoda, Heterobranchia, Neritimorpha, Patellogastropoda and Vetigastropoda) belonging to nine families and 28 species were found from upper to lower intertidal zones. On Tanjung Jara, the upper zone was recorded to have the highest diversity and evenness indices (Shannon-Wiener diversity index: H' = 0.702±0.213, and Pielou's evenness index: J' = 0.303±0.075) compared to the lower and middle zones. Planaxidae and Muricidae were the most predominant species found in all intertidal zones. In contrast, the lower zone in Teluk Bidara was recorded to have the highest diversity and evenness indices (Shannon-Wiener diversity index: H' = 0.414±0.082, and Pielou's evenness index: J' = 0.269±0.028) compared to the upper and middle zones. Littorinidae and Neritidae species were predominant here. Although the diversity and evenness indices (H' and J') of marine gastropods in both study sites were categorised as low, several selected species were found to be high in abundance. This study contributes to a complete checklist on macroinvertebrates of the South China Sea.
Key Words: intertidal zones, South China Sea, snails, evenness, abundance.

Introduction. A rocky shore is an intertidal area located at the shoreline between low and high tides and is made up of mainly solid rocks (Miller 2004; Coughlan & Crowe 2009). Depending on the slope and elevation, coasts that have steep gradients are known as cliffs or exposed rocky shores that are pounded by waves (Miller 2004; Cruz et al 2014). Rocky shores can be divided into tidal ranges with three zones: supratidal, intertidal, and subtidal. Supratidal, or the splash zone, can be identified from the upper region that is covered during extremely high tides or spring tides (0.7 m, chart datum, CD) and is shaped by breaking waves (Knox 2001). The intertidal zone is a transition zone, known as vertical zonation, and can be divided into three subzones set by different biological and physical factors: upper, middle, and lower (Ellis 2003). Finally, the subtidal zone is partially submerged and never exposed to the atmosphere (Knox 2001). During the highest tides, all three intertidal subzones are submerged, and the low tide zone is only exposed during the lowest tides (Molles 2016). Rocky shores are considered heterogenous environments (Araújo et al 2005) due to their composition (substrate such as cobbles, boulders, pebbles, blocks, and rock platforms) and structure (slope and gradient). Therefore, they support numerous habitats for flora and fauna (Cruz et al 2014). This in turn influences the distribution and abundance of rocky shore communities along the gradient (Archambault & Bourget 1996; Pandey & Thiruchitrambalam 2018).

Organisms found on rocky shores are facing intense physicochemical conditions during tidal changes from upper to lower intertidal zones. This includes regular exposure to air during low tide as well as differences in environmental parameters such as temperature, salinity, pH, and oxygen that occur perpendicular to the shore (Smith 2013; Chappuis et al 2014; Marshall et al 2013). Other factors such as exposure to wind and breaking waves, desiccation from sunlight, irradiance, high salinity, and predation by terrestrial animals (Smith 2013) are among the threats for organisms that live in this ecosystem. Despite these challenges, resilient and resistant organisms such as algae, lichens, barnacles, and molluscs are commonly found in such environments (Moyse & Smith 1963; Coughlan & Crowe 2009).

Gastropoda, or snails (Class Gastropoda), belongs to phylum Mollusca. It is the second largest phylum after Arthropoda (insects), estimated at 80,000–100,000 described species (Strong et al 2008; Pechenik 2016). From an ecological perspective, snails have colonized highly contrasting habitats, with single taxonomic orders being represented in marine, freshwater, and terrestrial domains (Dayrat et al 2011; Webb 2012). Gastropods are algal feeders, detritivores, and deposit feeders (Houbrick 1984; Plaziat 1984). They are soft bodied animals, covered by single coiled and calcareous shells varying in size, shape, and color. Gastropods are economically important as a source of protein, decorations, dye, and medicines (Haszprunar & Wanninger 2012; Garza et al 2012; Ahmad et al 2018). In addition, these organisms are crucial in the marine food chain as part of the natural diet of fishes and birds.

A large survey on marine mollusc diversity and abundance on the East and West Coasts of Peninsular Malaysia was first done by Purchon from 1973 to 1974 (Morris & Purchon 1981; Purchon & Purchon 1981; Way & Purchon 1981). The survey collected 301 species from Class Gastropoda and all vouchers were deposited at the British Natural History Museum in London. Since then, scientific studies on tropical rocky shores are scarce, although a handful of studies were completed in Malaysia by Aziz et al (2001), Kee Alfian et al (2005), Tan et al (2007), Wong et al (2008), and Siti-Balkhis et al (2014). These studies covered limited geographical ranges and ecosystems, such as the intertidal areas of islands and coral reefs. To date, there is no documented evidence on the diversity of molluscan fauna in the intertidal zones of the South China Sea in Peninsular Malaysia. Therefore, the present study's objective was to identify marine gastropods on intertidal rocky shores and to determine and compare the richness, abundance, diversity (Shannon-Wiener index), and evenness (Pielou index) of gastropods in intertidal zones along the coastline of Terengganu.

Material and Method

Study sites. This study was conducted at Teluk Bidara and Tanjung Jara, which are situated in the middle coastline of Terengganu located to the north of the Dungun district (Figure 1). It is about 90–115 km from Kuala Nerus, Terengganu, along the East Coast of Malaysia. The two study sites are Tanjung Jara (04°48.886˙N, 103°25.487˙E) and Teluk Bidara (04°46.848˙N, 103°26.136˙E). Tanjung Jara is well-known as a favorite tourist spot due to sandy beaches facing the South China Sea (Figure 2A). It is full of solid rocks, boulders, and fine sands and is exposed to an open area that is subjected to monsoonal effects annually. Tanjong Jara Resort, a five-star hotel located nearby this area, has made some areas restricted and not accessible by the public. In contrast, Teluk Bidara is close to fisherman villages. Activities such as making fish crisps and fishing can be seen there. This site is covered due to the presence of Pulau Tenggol, compared to the open area in Tanjung Jara (Figure 2A, B). In addition, most fishermen park their boats around the area. Teluk Bidara has a vertical elevation that shapes a small cave and the substrate is composed of solid rocks and coarse sand (Figure 2B).

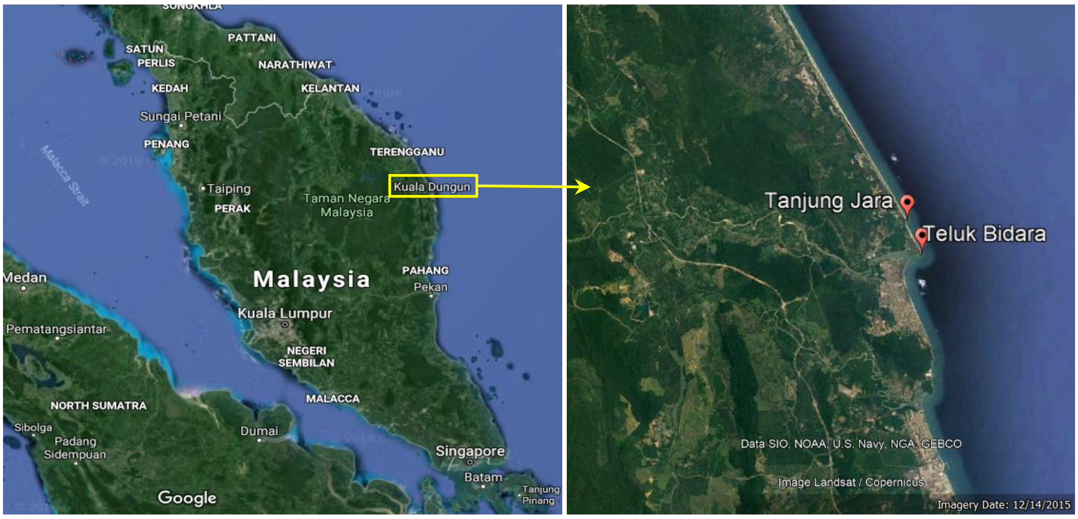

Figure 1. Map of study sites which are Tanjung Jara and Teluk Bidara located at the Dungun district, Terengganu, Peninsular Malaysia. Source: Google Earth 2015.

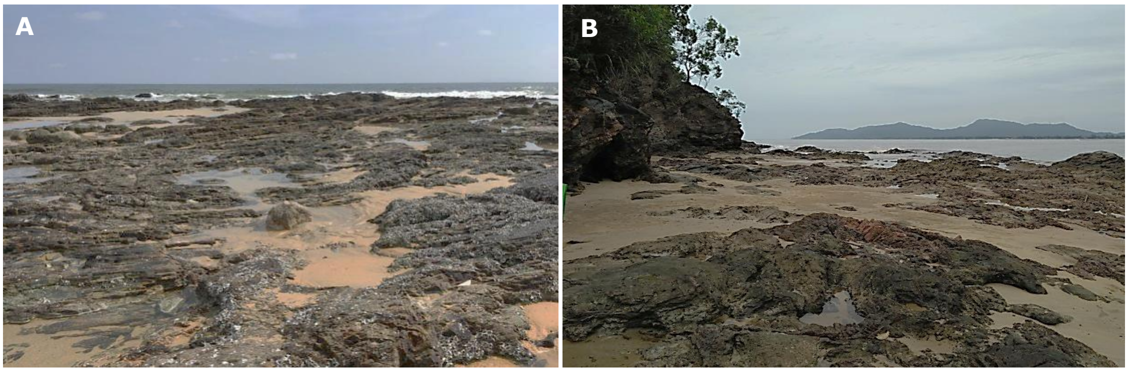

Figure 2. Landscape differences of intertidal rocky shore of Tanjung Jara (A) and Teluk Bidara (B). Vertical elevation of hill that shape a small cave in surrounding of Teluk Bidara has made this area covered compared to an exposed and open sea at Tanjung Jara.

Sampling procedures. Sampling was carried out from November 2016 and February 2017 during spring low tide (0.5 m chart datum, CD: 9 AM to 12 PM). The geographical locations of the study sites were recorded using a hand-held GPS (60CSx Garmin). The intertidal area was divided into three traditional zones: upper, middle, and lower intertidal shores. At each study site, a transect of 40 m length and 10 m width was laid perpendicular to the shore and samples were collected from high tide to low tide marks (Long et al 2014). For quantitative data, six quadrats of 1 m^2 were placed randomly (English et al 1997) following random number generator. Rocks, crevices, and holes were searched for gastropods. Rocks that were hand lifted or overturned during the search procedure were returned to reduce disturbance towards the ecosystem (Chapman & Underwood 1996). From each quadrat, the number of individuals was counted and recorded. Photos from each quadrat were captured. In the field, collection of organisms in large quantities was avoided to not put stress on the biodiversity. Therefore, maximum effort for species identification was carried out at the site. Only representatives of gastropods (10-15 individuals) per species and unidentified species were handpicked, put into labeled plastic bags, and brought back to the laboratory.

Species identification. Gastropods were cleaned using a brush and washed with tap water to remove algal film, other encrustations, and debris. Identification of gastropods was based on morphological characteristics such as shape, color, and shell characteristics. Snails were identified to the lowest possible taxonomic level using taxonomic identification keys of Abbott & Dance (1982), Abbott (1991), Long & Ramli (2010), Baharuddin & Marshall (2014), and Tan & Chou (2000). The validity of species names was also reviewed from the World Register of Marine Species (WoRMS) database. Shell morphometrics such as shell length and shell width were measured using vernier calipers with ±0.01 mm accuracy. For each species, photographs were taken using a Nikon D7000 DSLR camera. All voucher specimens were fixed and preserved in 70% ethanol. All specimens were deposited at the South China Sea Repository and Reference Centre of the Institute of Oceanography and Environment in Malaysia University Terengganu.

Data analysis. The density of marine gastropods was determined as number of individuals/m^2.

Diversity was calculated using Shannon-Wiener index (H'):

$$H' = -\sum_{i=1}^{S} p_i \log p_i$$

In the above, H' is the value of the Shannon-Wiener diversity index, P_i is the proportion of the i^{th} species, $\log_e$ represents the natural logarithm of Pi, and s represents the number of species in the community. The Shannon-Wiener diversity index is classified into three levels: low (H'<2); moderate (2<H'<4); and high (H'>4) (Odum & Barret 2004).

The species evenness index was calculated using Pielou's evenness index, written as:

$$J' = H' / H'_{max}$$

In the above equation, H' is the Shannon-Wiener diversity index and H'_{max} is the natural logarithm of species richness. Species evenness ranges from zero to one, with zero signifying no evenness, and one a complete evenness.

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

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

For this equation, N*i*.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).

Results. A total of five subclasses of marine gastropods (Caenogastropoda, Heterobranchia, Neritimorpha, Patellogastropoda and Vetigastropoda), belonging to nine families and 28 species, were found from upper to lower intertidal zones in Tanjung Jara and Teluk Bidara (Figure 3 & Table 1). In total, 12 species can be found in Teluk Bidara and 18 species can be found in Tanjung Jara (Table 1). However, two species, *Echinolittorina vidua* (Littorinidae) and *Nerita chamaeleon* (Neritidae), can be found at both study sites (Frequency of Incidence, FoI = 100%). These species have shell lengths of 5.61±0.63 mm (n=12) and 19.43±0.76 mm (n=4), respectively (Table 1 & Table 2). Out of the 6,844 individuals/m^2 collected from both study sites, *Planaxis sulcatus* (Planaxidae) comprised of 2,086 individuals/m^2 (average shell length, 13.83±0.68 mm) in Tanjung Jara (Table 1). 2,864 individuals/m^2 of *Clithon oualaniense* (average shell length, 4.22±0.63 mm) can be found at Teluk Bidara (Table 2). Among the fewest individuals, with only one individual found, was *Littoraria undulata* (Littorinidae) and *Clithon pulchellum* (Neritidae) at Teluk Bidara. These have shell lengths of 10.33 mm and 8.23 mm, respectively (Table 1 & Table 2).

In Tanjung Jara, the upper zone was recorded to have the highest diversity and evenness indices (Shannon-Wiener diversity index: H' = 0.702±0.213; Pielou's evenness index: J' = 0.303±0.075) compared to the lower and middle zones (Table 3). Planaxidae (*Planaxis sulcatus*) and Muricidae (*Indothais rufotincta*, *Reishia bitubercularis*, *Semiricinula fusca*, *Tenguella musiva* and *Thais* sp.) were the most predominant species found at the upper, middle, and lower zones with high abundance (Table 1). In contrast, the lower zone in Teluk Bidara recorded the highest diversity and evenness indices (Shannon-Wiener diversity index: H' = 0.414±0.082; Pielou's index: J' = 0.269±0.028) compared to the upper and middle zones (Table 3). Littorinidae (*Echinolittorina malaccana*, *Echinolittorina vidua* and *Littoraria strigata*) and Neritidae (*Clithon faba*, *Clithon oualaniense* and *Nerita chamaeleon*) were predominant here (Table 1).

Figure 3. Apertural and abapertural of marine gastropods of Tanjung Jara and Teluk Bidara. (1) *Batillaria* sp., 17 mm; (2) *Batillaria sordida*, 9 mm; (3) *Batillaria zonalis*, 12 mm; (4) *Echinolittorina malaccana*, 5 mm; (5) *Echinolittorina vidua*, 6 mm; (6) *Littoraria strigata*, 6 mm; (7) *Littoraria undulata*, 10 mm; (8) *Thais* sp., 16 mm; (9) *Indothais rufotincta*, 9 mm; (10) *Reishia bitubercularis*, 16 mm; (11) *Semiricinula fusca*, 15 mm; (12) *Tenguella musiva*, 13 mm; (13) *Planaxis sulcatus*, 14 mm; (14) *Pirenella cingulata*, 14 mm; (15) *Siphonaria atra*, 5 mm; (16) *Siphonaria guamensis*, 3 mm; (17) *Monodonta labio*, 23 mm; (18) *Siphonaria hispida*, 3 mm; (19) *Siphonaria* sp., 12 mm; (20) *Nerita albicilla*, 20 mm; (21) *Nerita chamaeleon*, 19 mm; (22) *Clithon oualaniense*, 4 mm; (23) *Clithon faba*, 5 mm; (24) *Clithon pulchellum*, 8 mm; (25) *Cellana enneagona*, 5 mm; (26) *Cellana radiata*, 4 mm; (27) *Patelloida saccharina*, 4 mm, and (28) *Patelloida* sp., 4 mm. Measurements indicates shell length (mm).

Table 1

Abundance of marine gastropods according to subclass, family and species between study sites

Subclass	*Family*	*Species*	*Study site / Ind./m²*		*∑ Ind.*	*FoI (%)*
			TB	*TJ*		
Caenogastropoda	Batillariidae	*Batillaria* sp.	-	7	7	50
		Batillaria sordida (Gmelin, 1791)	41	-	41	50
		Batillaria zonalis (Bruguière, 1792)	13	-	1	50
	Littorinidae	*Echinolittorina malaccana* (Philippi, 1847)	213	-	213	50
		Echinolittorina vidua (Gould, 1859)	6	6	12	100
		Littoraria strigata (Philippi, 1846)	600	-	600	50
		Littoraria undulata (Gray, 1839)	1	-	1	50
	Muricidae	*Indothais rufotincta* (K. S. Tan & Sigurdsson, 1996)	-	3	3	50
		Reishia bitubercularis (Lamarck, 1822)	-	187	187	50
		Semiricinula fusca (Küster, 1862)	-	87	87	50
		Tenguella musiva (Kiener, 1835)	-	136	136	50
		Thais sp.	-	57	57	50
	Planaxidae	*Planaxis sulcatus* (Born, 1778)	-	2086	2086	50
	Potamididae	*Pirenella cingulata* (Gmelin, 1791)	282	-	282	50
Heterobranchia	Siphonariidae	*Siphonaria atra* Quoy & Gaimard, 1833	-	6	6	50
		Siphonaria guamensis Quoy & Gaimard, 1833	-	47	47	50
		Siphonaria hispida Hubendick, 1946	-	3	3	50
		Siphonaria sp.	48	-	48	50
Neritimorpha	Neritidae	*Clithon faba* (G. B. Sowerby I, 1836)	21	-	21	50
		Clithon oualaniense (Lesson, 1831)	2864	-	2864	50
		Clithon pulchellum (Récluz, 1843)	1	-	1	50
		Nerita albicilla Linnaeus, 1758	-	9	9	50
		Nerita chamaeleon Linnaeus, 1758	4	83	87	100
Patellogastropoda	Nacellidae	*Cellana enneagona* (Reeve, 1854)	-	10	10	50
		Cellana radiata (Born, 1778)	-	3	3	50
		Patelloida saccharina (Linnaeus, 1758)	-	11	11	50
		Patelloida sp.	-	7	7	50
Vetigastropoda	Trochidae	*Monodonta labio* (Linnaeus, 1758)	-	2	2	50
Total individuals			4094	2750	6844	-
Total species			12	18	-	-

Total number of individuals (∑ Ind.) and Frequency of Incidence (FoI) are presented. TB: Teluk Bidara, and TJ: Tanjung Jara.

Table 2
Mean shell length, mm (S.L.) and shell width, mm (S.W.) with standard deviations (s.d.) of sample sizes (n = 1-60) for each species collected at both study sites: Teluk Bidara and Tanjung Jara

Subclass	*Family*	*Species*	*S.L. ± s.d. (n)*	*S.W. ± s.d. (n)*
Caenogastropoda	Batillariidae	*Batillaria* sp.	17.12±2.80 (7)	9.13±1.59 (7)
		Batillaria sordida	9.13±3.52 (30)	4.13±1.04 (30)
		Batillaria zonalis	11.92±1.51 (13)	4.22±0.51 (13)
	Littorinidae	*Echinolittorina malaccana*	4.93±0.13 (60)	3.04±0.21 (60)
		Echinolittorina vidua	5.61±0.63 (12)	3.73±0.42 (12)
		Littoraria strigata	5.92±2.32 (60)	3.64±1.24 (60)
		Littoraria undulata	10.33 (1)	5.04 (1)
	Muricidae	*Indothais rufotincta*	9.36±3.03 (3)	5.91±1.78 (3)
		Reishia bitubercularis	16.09±8.11 (60)	13.08±0.95 (60)
		Semiricinula fusca	14.99±1.17 (60)	9.39±0.85 (60)
		Tenguella musiva	12.63±1.22 (60)	7.86±0.95 (60)
		Thais sp.	15.53±0.81 (50)	10.03±0.80 (50)
	Planaxidae	*Planaxis sulcatus*	13.83±0.68 (60)	8.16±0.59 (60)
	Potamididae	*Pirenella cingulata*	13.83±3.03 (60)	5.22±1.01 (60)
Heterobranchia	Siphonariidae	*Siphonaria atra*	5.11±0.26 (6)	18.06±0.35 (6)
		Siphonaria guamensis	2.92±0.56 (45)	7.34±1.90 (45)
		Siphonaria hispida	2.65±0.13 (3)	7.06±1.65 (3)
		Siphonaria sp.	12.03±2.64 (30)	8.73±2.24 (30)
Neritimorpha	Neritidae	*Clithon faba*	5.13±1.24 (21)	4.02±1.01 (21)
		Clithon oualaniense	4.22±0.63 (60)	3.63±0.21 (60)
		Clithon pulchellum	8.23 (1)	6.91 (1)
		Nerita albicilla	19.82±1.99 (9)	16.43±1.45 (9)
		Nerita chamaeleon	19.43±0.76 (4)	20.67±1.38 (4)
Patellogastropoda	Nacellidae	*Cellana enneagona*	5.34±1.83 (19)	20.45±3.65 (19)
		Cellana radiata	4.34±0.65 (3)	17.24±0.03 (3)
		Patelloida saccharina	3.89±0.83 (11)	12.35±4.59 (11)
		Patelloida sp.	3.78±0.20 (7)	13.18±1.53 (7)
Vetigastropoda	Trochidae	*Monodonta labio*	22.83 ± 0.35 (2)	22.12±1.48 (2)

Table 3

The Shannon-Wiener diversity index (H') and species evenness index (J') of marine gastropods between intertidal zonation and study sites

Zonation	Indices			
	Shannon-Wiener (H')		*Species evenness (J')*	
	Study sites			
	TB	*TJ*	*TB*	*TJ*
Upper	0.245±0.218	0.702±0.213	0.149±0.093	0.303±0.075
Middle	0.226±0.236	0.327±0.288	0.116±0.098	0.165±0.130
Lower	0.414±0.082	0.271±0.266	0.269±0.028	0.174±0.125

TB: Teluk Bidara; TJ: Tanjung Jara.

Discussion. Littorinidae (*Echinolittorina vidua*) and Neritidae (*Nerita chamaeleon*) were found at both study sites. According to Abbot (1991), Neritidae and Littorinidae are classified as herbivore grazers and are the most common family to be found across wide ecological zones. Feeding groups of herbivores are a decisive factor in species spatial distributions within tropical rocky shore ecosystems (Cruz-Motta 2007). In Tanjung Jara, *Planaxis sulcatus* (Planaxidae) was the most abundant compared to other species found. This species is categorized as herbivore grazers. A study by Rao & Sundaram (1972) along the Indian coasts found that prosobranch gastropods such as Planaxidae (*Planaxis sulcatus*) and Nacellidae (*Cellana radiata*) feed on marine green algal species such as *Chaetomorpha* and *Enteromorpha compressa* and organic detritus.

In comparison, *Clithon oualaniense* (Neritidae) was the most abundant in Teluk Bidara. In Singapore, this species is listed as nationally vulnerable by Davison et al (2008) in the second edition of the Singapore Red Data Book. Moreover, in the marine food chain, *Clithon oualaniense* is found in the gut contents of at least six fish species: *Tetraodon nigroviridis* (spotted green puffer), *Chelanodon patoca* (milk spotted puffer), *Ambassis interrupta* (longspined perchlet), *Vespicula trachinoides* (goblinfish), *Monodactylus argentus* (silver moony), and *Lethirinus lentjan* (pink ear emperor) (Kadir et al 2017). The landscape of Teluk Bidara is mostly covered plus a small cave and could provide a sheltered habitat for fish. Juvenile fish were found in tide pools and villagers were seen to do recreational fishing around the site (personal observations).

Predatory gastropods, such as Muricidae, were found in all zones with a high density in Tanjung Jara. This could be related to its shell morphology and sculptural patterns that highlight their evolutionary importance (Merle & Houart 2004; Kumbhar & Rivonker 2012). Muricids, better known as murex snails or rock snails, are shown to inhabit a wide distribution of coastal and marine habitats (Radwin & D’Atillio 1976; Apte 1998; Tsuchiya 2000; Mills et al 2007). Moreover, Muricidae such as *Indothais rufotincta*, *Reishia bitubercularis*, *Semiricinula fusca*, *Tenguella musiva* and *Thais* sp. have slender shells and high spires that may help them to minimize the effects of strong waves during high tide and water loss during low tide. Most muricids are seen to aggregate and clump by rock crevices and gaps. This behavior is to ensure water conservation and moisture during a dry period at low tide. This could prevent malfunction of the marine gastropods’ body systems such as respiration, excretion, and digestion (Zhang et al 2016). Such characteristics aid these marine gastropods to be resilient and thrive in challenging ecosystems.

Differences in landscape at both study sites may explain the composition of marine gastropods, although the diversity and evenness indices (H’ and J’) in both study sites were categorized as low, based on Odum a& Barret (2004). A study by Gonzalez et al (2004) found that at exposed shores, a greater stability of malacology communities can be seen as its dominant community. This could be the case in Tanjung Jara, which recorded 18 species (dominant families: Muricidae and Planaxidae) compared to 12 species in Teluk Bidara (dominant families: Littorinidae, Potamididae and Neritidae). Moreover, the low scores in the indices could be underestimating total diversity, because this study was carried out by only two researchers at a time. Therefore, greater effort during sampling, including the duration of study, could contribute towards a more comprehensive result. Nevertheless, the findings show that several selected species were found to be high in abundance.

Conclusions. This study was the first attempt made in surveying marine gastropods at intertidal rocky shores along the East Coast of Peninsular Malaysia. Although it is preliminary, it could provide a baseline study on the mollusc class gastropoda. There is a need for further surveying and monitoring of key benthic taxa, such as algae, crustaceans, molluscs, and polychaetes in this underappreciated ecosystem to derive a better understanding of its importance. This study contributes to a complete checklist on macroinvertebrates of the South China Sea.

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