Coral-grazing gastropods diversity in shallow reefs, Pulau Redang Marine Park, Terengganu, Malaysia

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Abstract. The global deterioration of coral reefs has prompted research to comprehend the various impacts on coral's organisms as well as the interactions between reefs and their natural predators, coral grazing marine gastropods. However, the status of marine gastropods on Pulau Redang Marine Park is lacking. The study assessed marine gastropod diversity and shell morphometrics as indicators of the coral reef health ecosystem. SCUBA divers laid out a coral belt transect line of 50 m x 10 m at five sites. 177 individuals from four species of two families (Turbinidae and Muricidae; subclasses Vetigastropoda and Caenogastropoda) were collected at other locations. The highest number of individuals belonged to *Drupella rugosa* with 112 individuals, and the lowest number was *Astralium rhodostomum*. For the studied of marine snails, the Shannon index of diversity was H'=0.9 (<2) and the Simpson index of dominance was D=0.5 (<1). In addition, a high evenness, J', and equitability Ep were recorded at the sites of Pulau Redang. In terms of morphometrics, *A. rhodostomum* had the highest value of shell length (28.49±7.06 mm) and shell width (26.63±5.21 mm). No gastropods were found in Chagar Hutang and Mak Simpan due to coral destruction caused by the cyclonic Pabuk storm in early January 2019. Although it is a baseline, future research should also focus on parameters such as seawater temperature and coral bleaching towards effects on corallivorous gastropods and interaction between gastropods species.

Key Words: marine gastropods, recovery, islands, diversity test, morphometrics.

Introduction. Tropical coral reefs are diverse ecosystems that are home to around 830,000 marine species identified by scientists (Fisher et al 2015). Millions of people rely on this complex ecosystem for their livelihoods, cultures, and food production (Eddy et al 2018). The benefits provided by coral reefs can be categorized into two types: provisioning services, which include fisheries, cultural recreation, and tourism (Brander et al 2007), and regulating services, such as coastal protection, which have been extensively researched by scientists (Ferrario et al 2014). Coral reefs are not only beautiful ecosystems, but they also play a crucial role as biological engineers and keystone species. They create and maintain ideal conditions for the survival of a diverse range of animals and plants in the shallow coastal ecosystem (Gillis et al 2014).

Peninsular Malaysia is located on the Sunda Shelf and within the coral triangle region, the world's center of marine biodiversity with 627 species of corals recorded (Veron et al 2015). Malaysia's coral reefs are relatively shallow, and the climate is influenced by the monsoonal wind system, namely the northeast monsoon (Nov-Feb) and southwest monsoon (June-September) (Akhir 2012). Approximately 500 scleractinian coral species are distributed over 4,006 km^2 (Praveena et al 2012). Branching *Acropora* and massive *Porites* contribute with the highest percentage to the coral reef communities in Malaysia's marine ecosystem (Safuan et al 2020). Anthropogenic activities, such as destructive fishing, coral mining (Caras & Pasternak 2009), natural disturbances (e.g., extreme weather events), sedimentation (Fabricius et al 2005), and corallivory, pose threats to coral reef ecosystems (Rice et al 2019) and have caused destruction to coral reef communities on the East Coast islands of Peninsular Malaysia. Over 160 coral predators, or corallivores, are known to prey on coral reefs (Rotjan & Lewis 2008). These range from facultative consumers such as species from the Scaridae (parrotfish) (Turner 2020) and Cidaridae (sea urchins) (Glynn 2004) families to obligate predators such as those from the Chaetodontidae (butterflyfish) (Feary et al 2018), Acanthasteridae (crown-of-thorns starfish) (Pratchett et al 2017), and Muricidae (gastropods) families (Gautrand et al 2023).

Ectoparasitic corallivorous gastropods are organisms that cause significant damage to coral community, affecting its dynamics in different directions and at various densities (Mumby 2009). Their feeding behavior leads to a reduction in coral cover, which disrupts the ecosystem (Bruckner et al 2017). Corallivorous snails feed on coral reef soft tissue, which seriously hinders coral recovery (Kaullysing et al 2016). The first outbreak of corallivorous gastropods from the family Muricidae, specifically genus *Drupella*, was first recorded in the early 1980s in the coral reefs of Southern Japan (Moyer et al 1982). Since then, scientists have become increasingly aware of this issue because excessive density of corallivorous gastropods have a negative impact on coral cover (Bessey et al 2018). Previous studies indicate that most corallivorous gastropods primarily feed on scleractinian corals with small polyps, such as *Acropora*, *Montipora*, and *Pocillopora* (Al-Horani et al 2011). Among these, branching *Acropora* is the most preferred genus due to its complex coral structures and design. It provides a larger surface area, sufficient amount of living tissue to feed on, and a place to hide from predators, ocean currents, and waves (Bessey et al 2018). After removing the soft tissue, *Drupella* corallivorous snails usually lay their egg capsules on the bare coral's skeleton (Scott et al 2017). However, observations of the early life stages of snails are still minimal due to their cryptic behavior and small capsule size (Sam et al 2016). Corallivorous gastropods exhibit clustering behavior at different scales, ranging from a few individuals to three million individuals per square kilometer (Cumming 2009). This leads to population outbreaks that significantly impact the coral reef ecosystem (Schoepf et al 2010).

This study conducted a thorough analysis of the diversity, abundance, and shell characteristics of coral-grazing gastropod in Pulau Redang Marine Park, Malaysia. It serves as a valuable resource to enhance our understanding of mollusks, particularly corallivorous gastropods, in Malaysia. Additionally, it addresses knowledge gaps related to the potential threats these gastropods pose to the marine park.

Material and Method

Description of the study sites. The study was undertaken within Pulau Redang Marine Park (PRMP), situated approximately 24 nautical miles away from the Terengganu mainland. According to the Marine Park Malaysia Order of 1994, the waters encircling several islands in the archipelago were officially designated as part of PRMP (Mamat et al 2013). PRMP's eastern coast boasts white sandy beaches, while its western coast is characterized by rocky terrain adorned with diverse forest types (Mamat et al 2013). For this study, five distinct sites were meticulously chosen: Chagar Hutang (CH) to the north, Terumbu Kili (TK) to the south, Pulau Lima (PL) to the east, Pulau Kerengga Besar (KB) to the southeast, and Pasir Mak Simpan (MS) to the west (Figure 1). Sampling activities were carried out across these sites from the 16th to the 18th of July 2020.

Sampling method. Scuba divers conducted surveys along a 50 x 10 m transect within coral areas situated at depths ranging from 8 m to 12 m at each designated sampling site. Marine gastropods inhabiting these coral areas, specifically *Acropora* and *Pocillopora* colonies, were systematically collected along each transect, adhering to the protocols outlined by McClanahan (1997) and a preliminary survey. These methods were suitably adjusted to align with the unique characteristics of the study area. To document the presence or absence of both marine gastropods and their coral prey species, a series of underwater photographs were taken. The gastropods observed at the sites were meticulously gathered using extended forceps to ensure minimal disturbance to the coral colonies. Subsequently, these collected gastropods were placed within labelled plastic bags and stored within an ice chest. Before undergoing further morphometric analysis, they were then transferred to a freezer set at a temperature of 4°C.

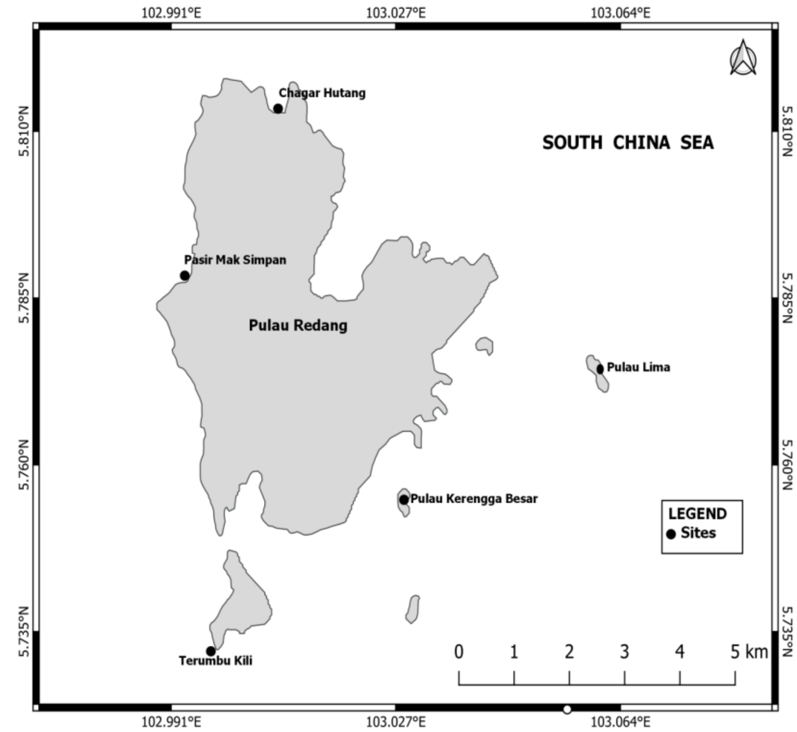

Figure 1. Map of study sites; Chagar Hutang, Terumbu Kili, Pulau Lima, Pulau Kerengga Besar and Mak Simpan at Pulau Redang, Terengganu, Malaysia.

Gastropod identification and shell morphometrics. To elucidate the authentic external morphology, the shells of each gastropod were meticulously cleansed to eliminate any extraneous sand and attached symbionts. Species identification was pursued with the aid of available literature's identification keys and online resources, including World Register of Marine Species-WoRMS, Molluscabase and Hardy's Internet Guide to Marine Gastropods, along with key references by Wells et al (2021) and Abbott et al (1991). Quantitative shell morphometrics, encompassing measurements of shell length (mm) and width (mm), were obtained using an electronic vernier calliper with precision to two decimal places. Subsequently, each gastropod's wet weight was ascertained utilizing an electronic balance, with due attention to the instrument's brand and origin. For the determination of dry weight, gastropods were positioned on pre-weighed aluminium foil sheets of suitable dimensions, which were then weighed again employing an electronic balance. The samples were subsequently subjected to a drying process within an oven set at 65°C for approximately five days to determine the dry weight (g). To ensure consistency, the dry weight was recorded on day 3, 4, and 5. Following the drying process, the gastropods were transferred to labelled crucible jars. An ash oven was utilized to combust the gastropods at 450°C for a duration of 4 hours, after which they were allowed to cool. Subsequent to cooling, the gastropods were carefully removed from the crucible jars, and the shells were gently tapped to eliminate residual ash. The individual's ash-free dry weight (g) was subsequently gauged using an electronic balance. The Condition Index (CI) was calculated as the ratio of dry flesh weight (g) to dry shell weight (g).

Data analysis. Statistical analysis was conducted to evaluate the species diversity and richness within the studied area. The Shannon index was employed for calculating species diversity, which can be represented as:

$$H' = -\sum_{i=1}^{s} pi\ lnpi$$

Where:
H' - the value of the Shannon diversity index;
Pi=ni/N - the proportion of the (i) th species;
ni - the number of individuals within the species;
N - the total number of individuals across all species within the samples.

An increase in the index value signifies a rise in diversity. The Shannon index is categorized into three levels: low (H'<2), moderate (2<H'<4), and high (H'>4) (Odum & Barret 2004).

The Simpson index, often used to quantify habitat biodiversity, assesses the likelihood of randomly selecting two individuals belonging to different species from an infinitely large community (Simpson 1949). The Simpson diversity index (*D*) is calculated as follows:

$$D=1-\sum(Pi)^2$$

When (D) reaches 1, it signifies high diversity, while a value of 0 signifies low biodiversity.

The Margalef index (Ma) and the Menhinck index (Me) were applied to determine species and abundance, as outlined by Hammer et al (2001):

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

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

Where:
s - the number of distinct species within the sample;
N - the total count of individual organisms.

The Margalef index indicates the number of species per specified area or unit. The Margalef and Menhinick indices are significantly influenced by the sampling effort and provide valuable insights into biological diversity (Magurran 2021).

The organism species evenness was assessed using the Evenness index (J’) and Equitability index (Ep). The homogeneity or pattern distribution of species was determined as follows:

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

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

Where:
H' - the Shannon diversity index;
S - the number of species.

A value of 1 indicates complete evenness, whereas a value of 0 suggests no evenness. The analyses were executed using PAST (Paleontological Statistics version 32.3.3). Additionally, the Frequency of Incidence (FoI) was estimated following the methodology outlined by Rahmawati et al (2015), employing the equation:

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

Where:
Ni.St - the total number of locations or study sites;
N.St - the count of sampling locations.

Results. A total of 177 individual marine gastropods, encompassing four distinct species, were collected from three different locations on Pulau Redang: Pulau Kerengga Besar (KB), Pulau Lima (PL), and Terumbu Kili (TK). These gastropods belong to two subclasses, Vetigastropoda and Caenogastropoda, representing two families, Turbinidae and Muricidae. Among the four species, namely *Astralium rhodostomum, Drupella rugosa, Morula spinosa*, and *Tenguella marginalba*, all were recorded in PL, while KB and TK had three species each, excluding *A. rhodostomum* (Figure 2, Table 1). *D. rugosa* accounted for the highest number of individuals, with a count of 112 collected from the three sites (KB, PL, and TK). The second most prevalent species was *T. marginalba* with 43 individuals, whereas *M. spinosa* and *A. rhodostomum* were represented by 12 and 10 individuals, respectively (Table 1, Figure 2). TK and KB exhibited a greater total number of individuals, with 94 and 51 respectively, as compared to PL, where the total count was lowest at 32 individuals. The Frequency of Incidence (FoI) was mainly contributed by *D. rugosa*, *M. spinosa,* and *T. marginalba,* collectively accounting for 60% of occurrences across all three sites. Conversely, *A. rhodostomum* had the lowest FoI at 20%, exclusively found in PL (Table 1). Notably, no gastropods were found at the other two study sites, Chagar Hutang and Pasir Mak Simpan.

Despite being the least common species on Pulau Redang, *A. rhodostomum* (Turbinidae) exhibited the longest and widest shell dimensions, with an average shell length of 29 mm and width of 26 mm. In contrast, *M. spinosa* (Muricidae) displayed the shortest and narrowest shells, with an average length and width of 16 mm and 11 mm, respectively (Table 2). This trend is reflected in the wet and dry weight as well, where *A. rhodostomum* had the heaviest average wet and dry weights at 10 g and 9 g, while *M. spinosa* were the lightest, at 1 g and 0.9 g (Table 2). The Condition Index remained similar across all recorded species, ranging from 1.07 to 1.12 (Table 2).

The Shannon diversity index (H') revealed low diversity at PL, KB, and TK, with values of 1.237, 0.724, and 0.845, respectively. This pattern was consistent with the Simpson index, which exhibited values below one for all study sites, indicating low dominance. However, considering relative abundance, the Margalef (*Ma*) and Menhinick (*Me*) indices were higher in PL (Ma=0.866, Me=0.707) and KB (Ma=1.007, Me=0.687), followed by TK (Ma=0.440, Me=0.309) (Table 3). In terms of evenness and equitability, both PL and TK demonstrated values closest to one, indicating high homogeneity (PL: J’=0.861, Ep=0.892; TK: J’=0.776, Ep=0.769). In contrast, KB exhibited lower values (J’=0.413, Ep=0.450), suggesting a more naturally varied distribution.

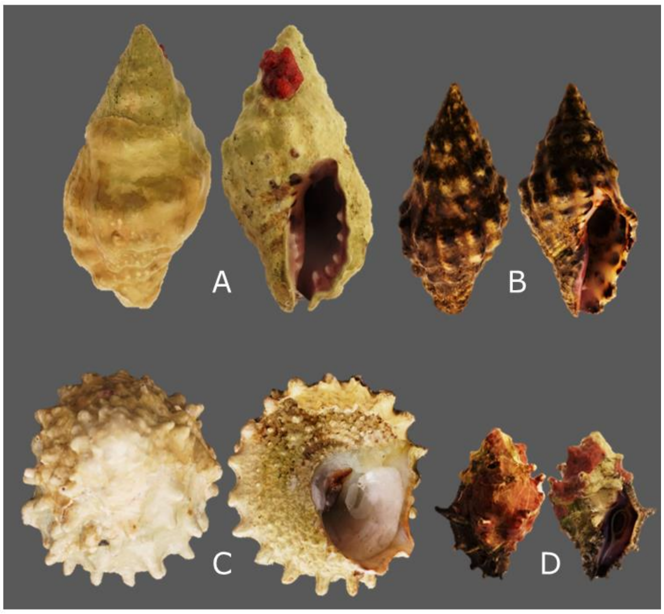

Figure 2. Apertural and abapertural view of corallivorous gastropods at Pulau Redang. (A) *Drupella rugosa,* 30 mm; (B) *Tenguella marginalba*, 24 mm; (C) *Astralium rhodostomum*, 22 mm; (D) *Morula spinosa*, 15 mm.

Table 1
Abundance of corallivorous gastropods found in all different sites according to subclasses according to subclass, family and species in Pulau Redang

Subclass	Family	Species	Sites						FoI (%)
			KB	PL	TK	CH	MS	Total ind.(n)	
			No. of individuals						
Vetigastropoda	Turbinidae	*Astralium rhodostomum*	-	10	-	-	-	10	20
Caenogastropoda	Muricidae	*Drupella rugosa*	41	14	57	-	-	112	60
		Morula spinosa	1	5	6	-	-	12	60
		Tenguella marginalba	9	3	31	-	-	43	60
Total individual(s)			51	32	94	-	-	177	
Total species			3	4	3	-	-	5	

KB=Pulau Kerengga Besar, PL=Pulau Lima, TK=Terumbu Kili, CH=Chagar Hutang, MS=Mak Simpan. The total number of individuals (n) and Frequency of Incidence (*FoI*) contributed by each species;'- 'indicates absence.

Table 2
Shell morphometrics; shell length (mm), shell width (mm), aperture length (mm), aperture width (mm), wet weight (g), dry weight (g) and Condition Index of corallivorous gastropods following species and sample size (n)

Species	Shell		Weight		Condition index
	Length ± s.d. (n)	Width ± s.d. (n)	Wet weight ± s.d (n)	Dry weight ± s.d (n)	
Astralium rhodostomum	28.49±7.06 (10)	25.63±5.21 (10)	10.11±6.66 (10)	9.23±6.14 (10)	1.10±0.06 (10)
Drupella rugosa	28.00±2.25 (81)	15.09±1.31 (81)	3.81±0.84 (81)	3.71±0.73 (81)	1.12±0.19 (81)
Morula spinosa	15.15±4.14 (12)	10.99±3.64 (12)	1.03±0.61 (12)	0.93±0.56 (12)	1.07±0.03 (12)
Tenguella marginalba	17.09± 6.59 (43)	9.80±3.77 (43)	1.12±1.22 (43)	1.08±1.17 (43)	1.10±0.06 (43)

Table 3
Ecological indices of corallivorous gastropods in Pulau Kerengga Besar (KB), Pulau Lima (PL) and Terumbu Kili (TK)

Sites	Indices					
	Shannon	Simpson	Margalef	Menhinick	Evenness	Equitability
	H'	D	Ma	Me	J'	Ep
KB	0.724	0.372	1.007	0.687	0.413	0.450
PL	1.237	0.680	0.866	0.707	0.861	0.892
TK	0.845	0.520	0.440	0.309	0.776	0.769

Discussion. The study identified *D. rugosa* as the most abundant species, with a total of 112 individuals collected, constituting a significant proportion of the overall sample. This species is known for its widespread distribution and its frequent presence on shallow reefs (Cumming 2009). However, a study conducted in 2016 documented a considerably higher count of 401 individuals across similar study sites on Pulau Redang Marine Park, including Chagar Hutang (CH) and Mak Simpan (MK) (Baharuddin et al 2017). The recent decline in the abundance of *D. rugosa* observed in this study, accounting for nearly a quarter reduction, signifies a noteworthy shift from the 2016 record. Malaysia, positioned below the 50° latitude and proximate to the equator, is generally safeguarded from direct tropical storms (Gray 1868). This is attributed to the weak Coriolis force near the equator, which impedes the rotation of air masses (Gray 1968; Chang et al 2003; Zuki & Lupo 2008). Nevertheless, an exception occurred in early January 2019 when the Pabuk storm emerged in the South China Sea and the Malaysian Peninsula, imparting a post-effect impact on Terengganu (Shariful et al 2020; Mohamad Basir et al 2022). Tropical storms are recognized as one of the most formidable physical disruptors to coral reefs (Lugo-Fernández et al 2004; Hongo 2018). The intense winds generated by storms like Pabuk inflict extensive damage on coral reefs, including the breakage of branching corals, dislodgment and removal of large colonies, and sediment deposition, culminating in coral mortality (Beeden et al 2015; Safuan et al 2020). This scenario has particularly impacted *D. rugosa,* which predominantly preys on branching corals. The observed decline in their numbers is a likely consequence of the depletion of food and shelter resources following the disturbance caused by the Pabuk tropical storm on the coral reef ecosystem. In addition, the aftermath of such disasters can trigger intraspecific competition among *D. rugosa* adults for limited resources. In this context, the dominance of adult individuals over available food and space sources may lead to increased mortality among juveniles and intermediates. It is notable that *D. rugosa* typically deposits its egg capsules on exposed coral skeletons (Sam et al 2017). However, the impact of the disaster has likely disrupted this reproductive behavior, as the altered environment resulting from the storm may not be conducive for adult *D. rugosa* to carry out this process during their spawning months. With their habitat severely compromised, a study conducted by Saponari et al (2021) echoes this concern, suggesting that the reduction in coral reef presence coupled with heightened competition from algae could result in limited space for egg deposition. Consequently, this disturbance-driven reduction in reproductive success could contribute to the observed decline in the population of *D. rugosa.*

T. marginalba, the second most prevalent species encountered on Pulau Redang, exhibited its highest population at Terumbu Kili (TK), amounting to 31 individuals. This species stands out due to its distinctive characteristics, particularly its high-spired shells that offer protection against adverse conditions (Baharuddin et al 2019). *T. marginalba* is often observed along rocky edges and within crevices (Coulson et al 2011). Its presence spans intertidal zones and various depths within tropical and subtropical oceans, encompassing environments such as coral reefs (Cahyadi et al 2021). The distribution of this genus is notably influenced by factors including wave exposure, the abundance of competitors, and the availability of food resources (Coulson et al 2011). *T. marginalba* is recognized as a carnivorous gastropod, preying on barnacles, limpets, and oysters (Wright et al 2018). This predation behavior aligns with its membership in the Muricidae family, indicating adaptation to its prey consumption capacity.

M. spinosa, on the other hand, predominantly feeds on carrion, polychaetes, and small mollusks, similarly to the dietary preferences of other muricid gastropod species (Barco et al 2010). While the initial documentation of *M. spinosa* feeding on coral reefs originated from Japan, this species is more commonly regarded as a coral scavenger than a corallivore due to its feeding habits (Yokochi 2004). While *M. spinosa* does exist within Pulau Redang, its population and distribution do not solely rely on the coral reef community (Moerland et al 2016). This stems from the fact that the species does not exclusively rely on coral reef consumption, showcasing an ability to exploit alternative prey sources (Titlyanov & Titlyanova 2009). *M. spinosa* are recognized as carnivorous gastropods inhabiting the surfaces of coral reefs, where they also prey on small herbivorous gastropods (Soekendarsi 2019). *Morula* genus frequently engaged in feeding behaviors that involve drilling into sedentary or semi-mobile prey with the prey size often smaller than the predator (Taylor 1976).

A. rhodostomum from Turbinidae family are conspicuous herbivorous gastropods that are commonly found across intertidal and subtidal reefs (Worthington & Fairweather 1989). The population and size distribution of turbinid gastropods on intertidal reefs undergo alterations across environmental gradients that are associated with changes in elevation (Worthington & Fairweather 1989; Bruton et al 1991). In Pulau Redang, species such as *A. rhodostomum* exhibit longer shell lengths compared to other marine reef gastropods, likely due to their cone-shaped shells that enhance their survival in harsh environmental conditions (Chapman 1997). The notably high values of wet weight and dry weight in *A. rhodostomum* suggest that the species' reproductive cycle is supported by a plentiful availability of food and nutrients (Li et al 2011). Being a common coral reef-associated gastropod, *A. rhodostomum* plays a vital role as an algae grazer on coral reef surfaces (Meyer et al 2005). This may be attributed to the higher percentage of algae on coral reef surfaces in Pulau Lima (PL) in comparison to other sites, despite a reduction in algae coverage in Pulau Redang following the Pabuk storm aftermath (Lee et al 2020).

The Condition Index (CI) serves as a valuable tool for evaluating various ecophysiological aspects such as reproduction, growth, mortality, parasitic infection, and secretion, under specific environmental conditions to monitor the health of organisms (Mercado-Silva 2005; Mladineo et al 2007). *D. rugosa* was found to fall within the 'thin' fitness category, indicating a resting gonad undergoing the gametogenesis phase (Rahim et al 2012). In contrast, *M. spinosa* exhibited the lowest condition index, reflecting a significant reduction in tissue weight and declining protein and lipid levels during the spawning season (Sahin et al 2006). The ecological indices derived from this study suggest that the diversity of marine snails within shallow coral reefs of Pulau Redang is relatively low. The Shannon index (H') value can be interpreted according to the classification proposed by Wilhm & Dorris (1996). A value below 1 indicates significant pollution, a value between 1.0 and 3.0 suggests moderate pollution, while a value exceeding 3.0 represents a non-polluted environment. Based on this index, Pulau Redang is categorized as experiencing moderate pollution. The analysis of diversity could be influenced by natural physical disturbances such as the Pabuk storm, which caused damages leading to subsequent declines in both the percentage and population of coral reefs in Pulau Redang (Lee et al 2020). However, at both Pulau Lima and Terumbu Kili in 2020, the indices of Evenness (J') and Equitability (Ep) demonstrated a high level of species evenness. Gastropods from the Muricidae family have been observed to inhabit a wide range of coastal and marine habitats (Radwin & D’Atilio 1976; Apte 1998; Mills et al 2007), including deep-sea environments (Egorov 1993), rocky tide pools (Yamamoto 1997), oceanic coral reefs (Boucher 1986), and various latitudinal regions (Bouchet et al 2002). Muricidae gastropods also exhibit a tendency to aggregate and cluster together, conserving water and body moisture to prevent dehydration (Zhang et al 2016). These behavioral traits aid these murex snails in adapting and successfully surviving in challenging environments (Baharuddin et al 2018). Despite a decline in the number of *M. spinosa* individuals recorded in Pulau Redang, the species remains present across all three sites, with a Frequency of Incidence (FoI) of 60%. This finding is supported by their smaller body size, which enables effective concealment in narrow spaces, enhancing their ability to find shelter in adverse challenging environmental conditions (Mohammad Basir et al 2022). Nevertheless, the distribution of *M. spinosa* remains constrained by specific environmental factors, including wave exposure, the presence of predators, scarcity of food sources, and fluctuations in both air and sea temperatures (Kumbhar & Rivonker 2012).

The limited scientific information on the status of marine gastropods within shallow coral reefs in Pulau Redang poses constraints on both current and future coral reef conservation and management efforts. Consequently, conducting additional research in the future is of paramount importance to attain a profound understanding of the roles of marine gastropods, especially corallivorous gastropods, during phases of coral mortality and recovery in Pulau Redang.

Conclusions. The diversity of coral-grazing gastropods in Pulau Redang is low, with Shannon-Wiener index values below 2. *D. rugosa*, a common corallivore, and *A. rhodostomum*, which has the largest shell size, are notable species. The abundance of *D. rugosa* decreased after the Pabuk storm in 2020, which caused significant coral damage. This study provides essential data on marine gastropods in Pulau Redang, helping to create a comprehensive list of corallivorous gastropods. Future research should also examine the effects of seawater temperature, coral bleaching, and interactions between gastropod species. This research is crucial for monitoring and preserving coral reef health.

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