TROPICAL LIFE SCIENCES RESEARCH

Effect of Tourism and Sedimentation on Coral Cover and Community Structure

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Highlights

- High coral cover found in site with the least anthropogenic impacts.
- High algal cover linked with increased tourism.
- Lowest coral cover found at site with high sedimentation.

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Effect of Tourism and Sedimentation on Coral Cover and Community Structure

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Abstrak: Terumbu karang adalah ekosistem yang paling mempunyai kepelbagaian biologi di planet ini. Terumbu karang hanya dijumpai dalam lingkungan pengecilan parameter julat yang sempit, yang meletakkan terumbu karang berisiko di seluruh dunia. Terumbu karang dipengaruhi oleh kesan antropogenik dan alam sekitar yang mengubah taburan genera karang. Memahami di mana jenis karang yang berbeza terletak dan bagaimana setiap genus terjejas oleh tekanan tempatan dan global adalah penting untuk pemuliharaan. Teknik *coral video transect* mula digunakan pada bulan Mei 2016 untuk membandingkan taburan genera karang di tapak yang dipengaruhi oleh faktor-faktor yang berbeza. Tapak yang mempunyai impak paling sedikit mencatatkan pelitupan karang yang paling tinggi, tapak yang berkaitan dengan sedimen mencatatkan pelitupan yang paling rendah, dan tapak yang mempunyai aktiviti pelancongan yang tinggi mempunyai pelitupan alga yang paling besar. *Acropora* didapati dominan di Kepulauan Bidong dan Pulau Redang, manakala *Favia, Fungia* dan *Porites* mempunyai perlindungan karang yang agak tinggi di setiap tapak.

Kata kunci: Terumbu Karang, Pelancongan, Pensedimenan, *Coral Video Transect*

Abstract: Coral reefs are the most biologically diverse ecosystem on the planet. They are only found within a narrow range of shrinking parameters, putting coral reefs at risk worldwide. They are affected by anthropogenic and environmental impacts which change the distribution of coral genera. Understanding where the different corals are located and how each individual genus is affected by local and global pressures is vital for conservation. The coral video transect technique was used in May 2016 to compare the spatial distribution of coral genera at sites affected by different factors. The site with the fewest impacts recorded the highest coral cover, the site associated with sediment recorded the lowest, and the site with high tourist activity had the greatest algal cover. *Acropora* was found to

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be dominant at Bidong Archipelago and Redang Island, and *Favia*, *Fungia* and *Porites* had relatively high coral cover at each site.

Keywords: Coral Reef, Tourism, Sedimentation, Coral Video Transect

INTRODUCTION

Coral reefs are one of the planet's most important ecosystems. Reefs cover less than 0.1% of the ocean floor but are the habitat for over a quarter of all marine species (Hoegh-Guldberg *et al*. 2017). They form structures that can be thousands of kilometres long, or hundreds of metres deep. Some are so large they can even be viewed from space (Kaiser 2011). The reefs are a nursery for commercial fish species and an important source of food and medicines (Jaleel 2013; Chen *et al.* 2015). They shelter 150,000 km of shoreline from storms and erosion, which allows low-lying islands to flourish (Burke & Spalding 2011). Coral reefs provide approximately 30 billion dollars annually in ecosystem services (De'ath *et al*. 2012).

Coral reefs are in decline due to climate change, marine tourism, increased nutrients and sedimentation, disease, changes in predator dynamics, and overfishing. Average coral cover has decreased from 34.8% to 16.3% over 40 years in the Caribbean (Jackson *et al*. 2014) and from 28% to 13.8% over 27 years on the Great Barrier Reef (De'ath *et al*. 2012). Coral distribution and the effect of different environmental and anthropogenic factors must be understood to conserve the remaining coral.

Travel and tourism in Malaysia generated a total contribution of 13.4% of the country's GDP in 2017 (Turner 2018). Many tourists are attracted to the country's abundant shallow tropical coral reef resources, with more than 550 species of coral in approximately 4000km^2 of reef (Reef Check Malaysia 2017). Thus, coral reefs are economically important making their protection vital.

Most of Malaysia's development is concentrated in the coastal zone, exposing coastal zone environments, such as coral reefs, to a great amount of anthropogenic impacts. These include overfishing, sedimentation, pollution, and eutrophication. Regions are protected by marine parks which prohibit fishing, but in unprotected areas corals are exploited (Praveena *et al*. 2012).

The percentage cover of Malaysian corals has been previously assessed by organisations such as Reef Check Malaysia (2017). These studies have primarily used methods such as the Line Intercept Transect (LIT) and Point Intercept Transect (PIT) (Praveena *et al*. 2012; Toda *et al*. 2007). The Coral Video Transect (CVT) technique was used by Safuan *et al*. (2015) to collect data on the islands of Bidong and Redang. They compared CVT and LIT methods and proved CVT to be an efficient technique for coral reef research.

This study aims to compare the spatial distribution of coral genera of a site with few anthropogenic impacts (Bidong Archipelago), one with prevalent tourism (Redang Island) and another affected by sediment (Tanjung Tuan). It is hypothesised that the percentage coral cover will be significantly higher in the

Bidong Archipelago than the other sites, and that the coral community structure will vary at each site. The substrate composition at each site will also be examined. Algal cover is expected to be highest at Redang Island, and Tanjung Tuan is expected to have the highest cover of sand.

MATERIALS AND METHODS

Study Sites

Bidong Archipelago

The Bidong Archipelago consists of the islands of Kaspak, Gelok, Yu Besar, Yu Kecil and Bidong. The largest of these, with an area of 1 km^2, is Bidong. The island is located 33 km Northwest of Kuala Terengganu, and 15 km East of Redang Island. The islands are uninhabited apart from a research station on the West of Bidong Island (Hamza *et al.* 2018). As such the Archipelago has relatively few anthropogenic impacts. Dive surveys were conducted at GPS coordinates of: 5°35'49.43"N, 103° 3'45.47"E, and 5°39'58.98"N, 103° 4'18.52"E. These coordinates are shown in Fig. 1.

Redang Island

Redang Island is a popular resort island located 25 km from Marang on the East coast of Terengganu. In 1994, it was designated as a marine park. There are 10 medium to large sized resorts that lead dive and snorkel excursions to the local fringing offshore and submerged reefs. 1,500 people live on the island, which is accessed by boats or by plane to Redang airport (Reef Check Malaysia 2017). This is a site with high tourist activity. Dive surveys were conducted at GPS coordinates of 5°43'55.98"N, 102° 59'51.80"E, and 5°46'57.71"N, 103° 2'20.01"E. These are shown in Fig. 1.

Tanjung Tuan

Tanjung Tuan is a region on the West coast of Peninsular Malaysia in the Malacca strait, near the town of Port Dickson. High density shipping lanes run through the Straits of Malacca which has impacted the coral reefs in the area. The main problem in this region is sedimentation rate due to development and agriculture (Praveena *et al*. 2012). Sedimentation rates range from 59.61 ± 17.57 mg/cm^2/day to 220.61 ± 145.52 mg/cm^2/day (Lee 2005). In this study this region represents a site impacted by sediment. Dive surveys were conducted at GPS coordinates of: 2°24'56.14"N, 101°51'14.82"E and 2°25'6.73"N, 101°51'20.70"E. These locations are shown in Fig. 2.

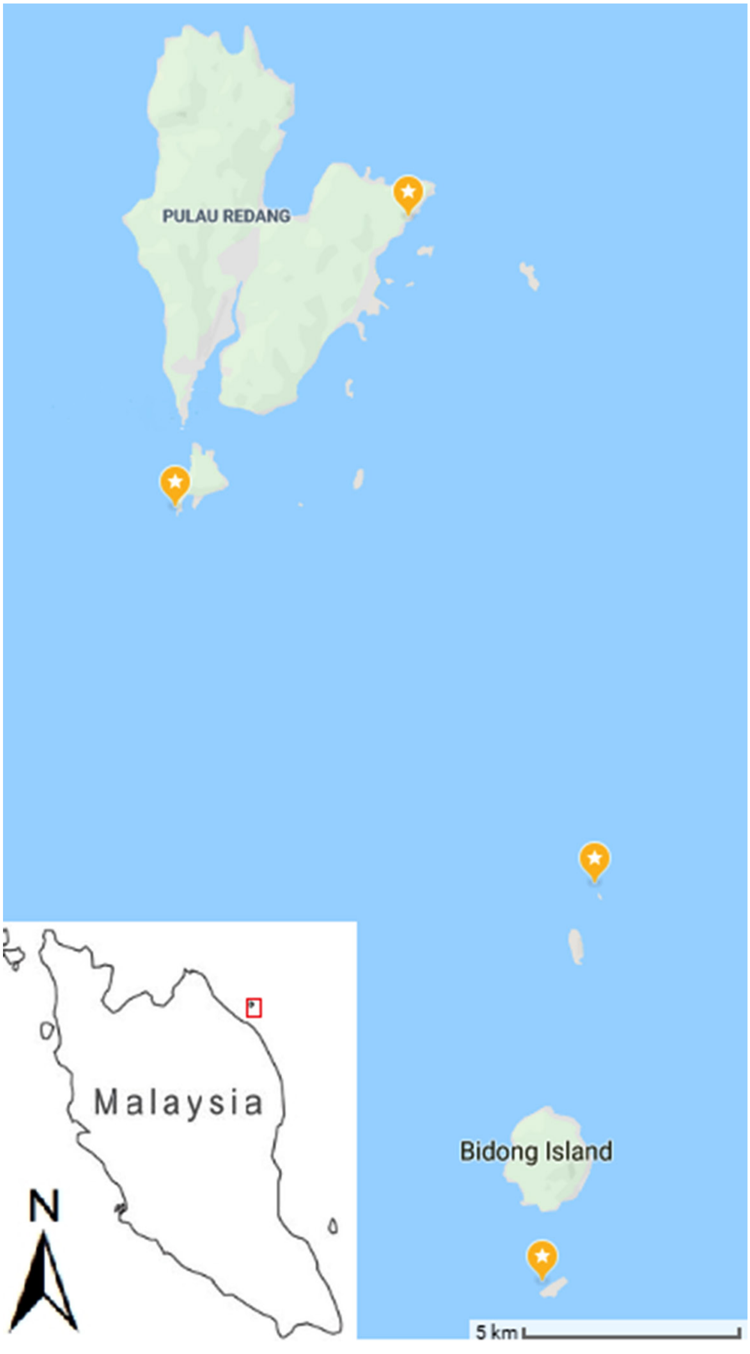

Figure 1: Map showing the location of Bidong Archipelago and Redang Island in relation to Peninsular Malaysia. Survey sites indicated with yellow stars (created using Google Maps).

Figure 2: Map showing the location of Tanjung Tuan in relation to Peninsular Malaysia. Survey sites indicated with yellow stars (created using Google Maps).

Coral Video Transect

Divers attached the end of a 100 m tape measure to a piece of substrate at 10 m depth before laying the tape in a direction horizontal to the shoreline. The tape was kept taut and depth of tape kept as close as possible to 10 m throughout. The 100 m transect tape was divided into 4 transects with 20 m per segment (n = 4) as outlined in Liew *et al*. (2012). A gap of 5 m was used to separate each transect. Once the tape had been laid the divers returned to the start point.

The details of the dive (date, time, site, depth) were recorded on a slate. A Lumix FT4 video camera (28–128 mm lens) with a Lumix 40 m Marine Case, first recorded the dive slate (wide angle with ratio of 16:4 and 1920 × 1080 resolution) and then the transect start point. The substrate to the right of the transect was recorded with the camera 50 cm from the substrate. The diver then swam at a rate of 4 m per minute recording the substrate with the camera perpendicular above the substrate. The same methodology was completed for all transects and sites.

The Coral Video Transects for Bidong Archipelago and Redang Island were conducted by a Heriot Watt dive team, with the assistance of the Universiti Malaysia Terengganu (UMT) dive team. Video for the Tanjung Tuan site was collected by the UMT team. Data was collected in May 2016.

Coral Point Count

'Video Image Master' was used to split each 20 m transect video into 30 individual frames. Each frame covered an approximate area of 0.16 m^2.'Coral Point Count with Excel Extension 4.0' (CPCe) was used to analyse the frames. First a code file was specified that contained a selection of possible identifications. The code used in this study contained 120 options, 80 of which were coral genera, following Veron (2000). The entire image was used as the border boundary and 50 simple random points were imposed onto each frame. A single frame analysis is shown in Fig. 3.

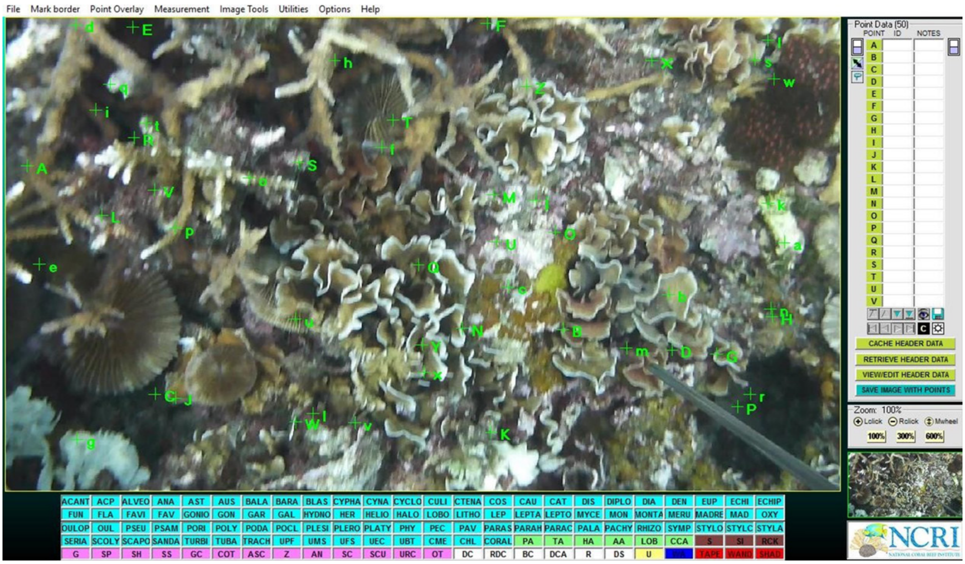

Figure 3: An example of a single frame being analysed using the CPCe software. 50 random points can be seen, illustrated by the letters in green. Each point was identified as being in one of the categories at the bottom of the screen. The categories were determined by the code file.

Each point was identified in CPCe. Coral was identified to genus level, algae were simply recorded as algae, and dead coral was recorded as either being dead, dead with algae, or being coral rubble. Bare substrate (e.g. sand, silt, rock) and other invertebrates (e.g. gorgonian, anemone, sea urchin, soft coral) were also recorded. Coral was defined as being 'dead' when it was a pure white colour, with no algal growth. If it had some algae, it was recorded as 'dead coral with algae'. If the coral was in many small dead pieces, it was recorded as coral rubble. If no underlying material could be seen due to being covered with algae or sand they were respectively recorded as 'algae', or 'sand'. Once all 30 frames from a 20 m transect had been analysed, the .cpc files were saved to excel.

Data Analysis

CPCe calculated the percentage cover of each video frame by each identification category. These were grouped to produce three main sets of data; one for each site. Each transect had an area of 4.8 m^2, and the total area of each site studied was 38.4 m^2, composed of 240 frames and 12,000 individual points.

Minitab Express was used to run an Anderson Darling test for normality for the percentage cover of each identification category at each site. All were found to be significantly different from normal and no functions could normalise the data. Non-parametric tests were therefore used. Mann-Whitney U tests were used to compare the percentage cover of each category at each site with those at the different study sites.

CPCe calculated the Simpson's and Shannon Wiener Indices of diversity for each transect. The Anderson Darling test showed that these data sets were normal, allowing parametric tests to be used. T-tests were used to compare differences in diversity indices at each site. Graphs were created using Microsoft Excel 2016, and error bars show standard deviation.

RESULTS

Substrate Composition

CPCe calculated the average percentage cover of coral, algae, other invertebrates, dead coral, and sand/silt/rock. Significantly more hard coral was found at Bidong Archipelago than Tanjung Tuan (N = 480, $p < 0.0001$), and at Redang than Tanjung Tuan (N = 480, $p < 0.0001$). Algal cover was significantly higher at Redang than Bidong (N = 480, $p < 0.0001$) and Tanjung Tuan (N = 480, $p < 0.0001$), and higher at Bidong than Tanjung Tuan (N = 480, $p < 0.0001$). There was also a significantly higher amount of dead coral at Bidong than both Redang (N = 480, $p < 0.0001$) and Tanjung Tuan (N = 480, $p < 0.0001$), and more dead coral (including dead coral with algae and coral rubble) at Redang than Tanjung Tuan (N = 480, $p < 0.0001$). Significantly more of the category sand, silt and rock was also found in Tanjung Tuan than both Bidong (N = 480, $p < 0.0001$) and Redang (N = 480, $p < 0.0001$), as well as in Redang than Bidong (N = 480, $p < 0.0001$). These results are shown in Fig. 4.

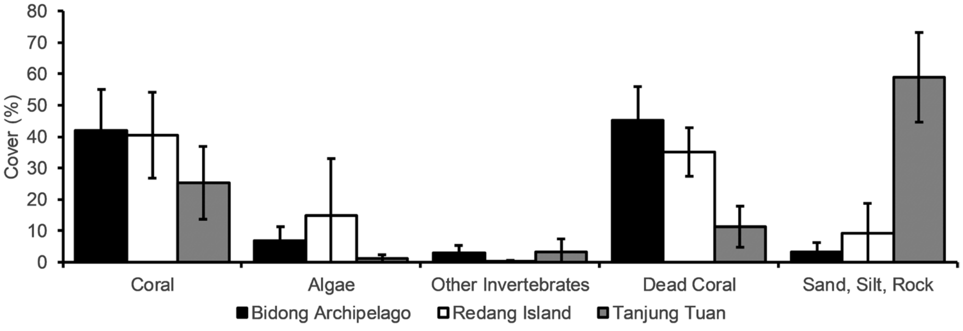

Figure 4: Average percentage coral, algae, other invertebrates, dead coral and sand/silt/rock cover at each of the study sites.

Hard Coral Cover by Genus

A total of 27 coral genera were found in the study. The genera found were: *Acanthastrea, Acropora, Alveopora, Astreopora, Diploastrea, Echinophyllia, Favia, Favites, Fungia, Goniopora, Lobophyllia, Merulina, Montastrea, Montipora, Oulastrea, Oxypora, Pachyseris, Palauastrea, Pavona, Pectinia, Platygyra, Pocillopora, Porites, Psammocora, Scapophyllia, Stylophora, and Turbinaria.*

The most common of these were *Acropora*, *Favia*, *Fungia* and *Porites*. The percentage cover of these genera was compared between different study sites using the Mann-Whitney U test. The coral cover of each coral species at each site can be seen in Table 1.

A significantly higher cover of *Acropora* was found in Bidong than Tanjung Tuan (N = 480, $p < 0.0001$), and in Redang than Tanjung Tuan (N = 480, $p < 0.0001$). Significantly more *Fungia* in Redang than Bidong (N = 480, $p = 0.0436$) and Tanjung Tuan (N = 480, $p < 0.0001$), and more in Bidong than Tanjung Tuan (N = 480, $p < 0.0001$). More *Favia* was found in Redang than Bidong (N = 480, $p = 0.0354$), and there was a higher cover of *Porites* in Redang than both Bidong (N = 480, $p < 0.0001$) and Tanjung Tuan (N = 480, $p < 0.0001$). These results are illustrated in Fig. 5.

Table 1: The percentage cover of each coral genus found relative to the total hard coral cover at each site.

Genus	Percentage Coral Cover		
	Bidong Archipelago	Redang Island	Tanjung Tuan
Acanthastrea	0.03	0.44	0.01
Acropora	25.55	21.69	2.41
Alveopora	0.02	0.00	0.00
Astreopora	1.78	1.11	0.46
Diploastrea	0.00	0.02	0.12
Echinophyllia	0.05	0.00	0.13
Favia	1.27	3.05	2.41
Favites	2.08	1.01	2.48
Fungia	2.39	3.67	0.33
Goniopora	0.01	0.00	3.03
Lobophyllia	0.01	0.00	0.04
Merulina	0.00	0.00	0.09
Montastrea	0.19	0.03	0.00
Montipora	0.09	0.18	0.51
Oulastrea	0.00	0.03	0.00
Oxypora	0.00	0.00	0.22
Pachyseris	0.39	0.05	4.87
Palauastrea	0.00	0.12	0.06
Pavona	2.42	0.00	0.00
Pectinia	0.01	0.00	0.26
Platygyra	0.20	0.08	0.56
Pocillopora	0.00	0.00	1.21
Porites	3.07	8.46	5.06
Psammocora	0.05	0.00	0.00
Scapophyllia	0.27	0.00	0.00
Stylophora	0.00	0.02	0.44
Turbinaria	1.85	0.47	0.66

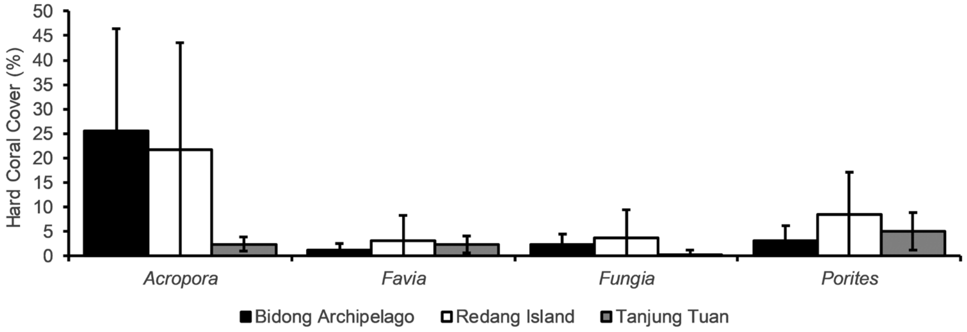

Figure 5: Average percentage cover of the video frames for the four most common hard coral genera, *Acropora, Favia, Fungia* and *Porites*, for each of the study sites.

Hard Coral Diversity

20 genera of hard coral were found at Bidong Archipelago, 16 at Redang Island and 21 in Tanjung Tuan. Bidong Archipelago recorded a genus density of 0.42/m^2, Redang Island of 0.33/m^2, and Tanjung Tuan of 0.44/m^2.

The CPCe program calculated the Shannon Wiener and Simpsons indices of diversity shown in Fig. 6. Two sample t-tests were used to compare the diversity between sites. Both the Shannon Wiener index and Simpsons index were found to be significantly higher at Tanjung Tuan than Redang (N = 480, p = 0.0055; N = 480, p = 0.0258).

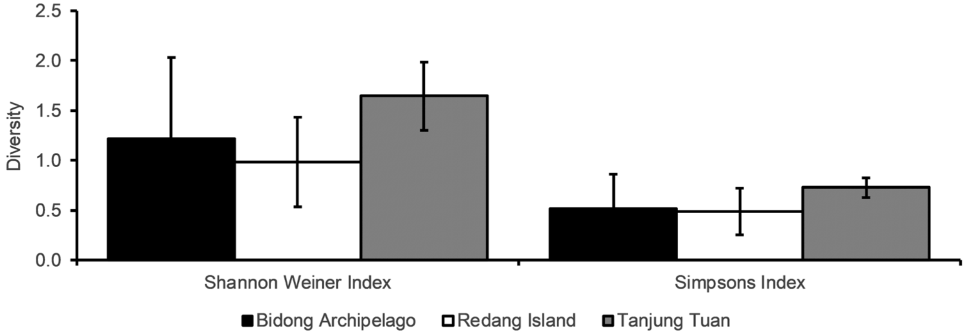

Figure 6: Coral diversity for Bidong Archipelago (N = 240), Redang Island (N = 240) and Tanjung Tuan (N = 240), using the Shannon Wiener and Simpsons index.

Abiotic Substrate Composition

The condition of coral and the amount of sand at a site can give important information about site health. Whether a coral is simply dead, is covered in algae or is rubble indicates how long it has been dead for, and sand cover can indicate sedimentation rate. These percentage covers were compared against each study site using the Mann-Whitney U test. Significantly more dead coral was found at Bidong Archipelago than both Redang Island and Tanjung Tuan (N = 480, $p = 0.0010$; N = 480, $p < 0.0001$). More dead coral was also present at Redang than Tanjung Tuan (N = 480, $p < 0.0001$). A greater amount of dead coral with algae was found at Bidong than both Redang and Tanjung Tuan (N = 480, $p = 0.0155$; N = 480, $p < 0.0001$) and more dead coral with algae was found at Redang than Tanjung Tuan (N = 480, $p < 0.0001$). No coral rubble was found in Tanjung Tuan. There was significantly more sand found in Tanjung Tuan than in Bidong and Redang (N = 480, $p < 0.0001$; N = 480, $p < 0.0001$), and more sand in Redang than Bidong (N = 480, $p < 0.0001$). These results are shown in Fig. 7.

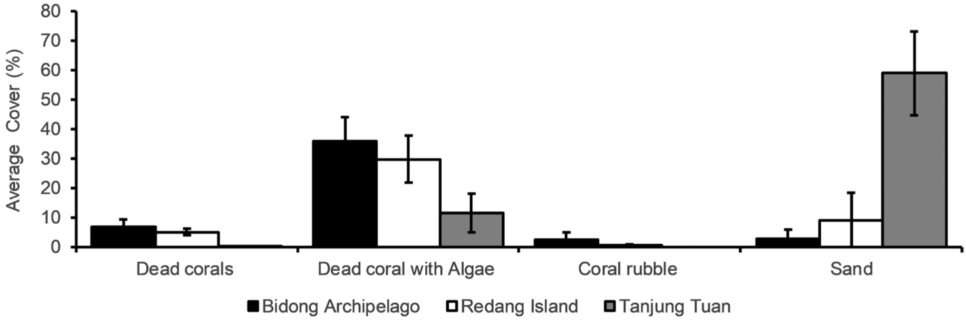

Figure 7: Percentage cover of dead corals, dead coral with algae, coral rubble, and sand.

Soft Coral

Soft corals were found at all sites surveyed. The percentage covers were compared against the other sites using the Mann-Whitney U test. This revealed that there was a significantly greater amount of soft coral at Bidong Archipelago than Redang (N = 480, $p = 0.0255$). This can be seen in Fig. 8.

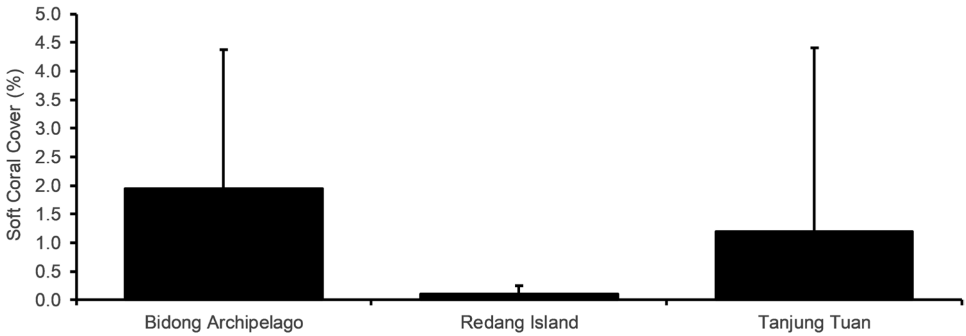

Figure 8: Percentage cover of soft corals at each site. The error bars show the standard deviation.

DISCUSSION

Substrate Composition

The study sites were chosen to represent different levels of anthropogenic impacts. Bidong Archipelago had relatively few impacts, Redang Island was in an area with prevalent tourism, and Tanjung Tuan was in a region affected by sediment. As predicted the greatest coral cover was found in Bidong, as previous studies have shown that both high turbidity and tourist activities can lead to coral mortality and decreases in coral cover (Edmunds & Gray 2014; Zaneveld *et al*. 2016; Fabricius 2005).

The highest algal cover was at Redang Island which indicates that the surrounding waters may be high in nutrients, which has previously been shown to lead to algal proliferation (Smith *et al*. 2006). This is supported by a study by Kaur (2006) which showed that Redang had increased concentrations of Nitrogen and Phosphorous in its groundwater due to pollution from tourism activities.

A higher algal cover was also found at Bidong than Tanjung Tuan. Environments impacted by sediment loads have increased turbidity which causes lower levels of light penetration and increased scour by granules which inhibits the growth of algae (Mwachireya *et al*. 2015).

A higher percentage cover of dead coral was recorded at Bidong and Redang than Tanjung Tuan. The category 'dead coral' includes 'dead coral', 'dead coral with algae', and 'coral rubble'. This result indicates that Bidong and Redang may have recently had a disturbance event. A study by Wee *et al.* (2017) reported that dead coral coverage at Redang increased from 37.14% in September 2013 to 52.26% in March 2014 after the North East Monsoon. The current study was conducted in May 2016, so it is likely that the North East Monsoon caused significant damage to the coral reef in the region in 2016 as well. Tanjung Tuan would have been sheltered from the full force of the Monsoon by the Malaysian mainland.

Hard Coral Cover by Genus

It was predicted that the coral community structure would vary due to the differing nature of the sites. Of the 27 genera found, the most common were *Acropora*, *Favia*, *Fungia* and *Porites*.

Acropora

A higher cover of *Acropora* was found at Bidong and Redang Island than Tanjung Tuan. Sediment can inhibit coral reproduction by settling on hard substrate and preventing coral larvae from settling (Babcock & Davies, 1991). Sediment also decreases light availability and limits the energy gained from photosynthesis.

This causes decreased lipid levels and a significant decrease in fecundity (Cantin *et al*. 2007). High sediment levels would have caused decreased coral settlement, energy production and fecundity, and led to a lower cover of *Acropora* in Tanjung Tuan.

Favia

Redang Island had a significantly higher cover of *Favia* than Bidong Archipelago. There are many factors that affect corals, and different coral genera will have different conditions in which they thrive. The results indicate that Redang had conditions that allowed *Favia* to be more successful. It was not possible to collect data on the different environmental conditions, so the differing variables at Bidong and Redang are not known. The islands are near to each other, so the main differences are likely to be levels of anthropogenic disturbance. A further study should investigate the environmental parameters at each island to see how they differ. This would indicate which conditions *Favia* are more suited to.

Fungia

Fungia were found to be most prevalent at Redang island, the site impacted by tourism that also recorded the highest algal cover. In nutrient enriched waters, algae grow on the surface of sessile hard corals. *Fungia* however, are free living, and are often found upside down. This would inhibit algal growth due to a shading effect and increased scour. This means *Fungia* may be less affected by increased nutrient levels than other immobile corals, leading to a higher coral cover. They have also been shown to recover rapidly after a disturbance (Chadwick-Furman *et al*. 2000), which indicates that Redang recently experienced a disturbance, such as the North East Monsoon.

Tanjung Tuan recorded the lowest cover of *Fungia*. *Fungia* can remove sediment via an inflation mechanism which can allow them to survive being completely buried. This is an active process, so constant exposure results in a significant loss of energy and resulting tissue mortality and death (Erftemeijer *et al*. 2012). *Fungia* therefore do not do well in environments where they are consistently exposed to sediment, such as Tanjung Tuan.

Porites

A significantly higher cover of *Porites* was recorded in Redang than the other sites. *Porites* has previously been shown to be tolerant of nutrient pollution in comparison to other genera (Pastorok & Bilyard 1985). In a nutrient enriched environment like Redang it would perform relatively well, leading to a higher coral cover.

Hard Coral Diversity

Both the Shannon Wiener and the Simpsons index of diversity showed that Tanjung Tuan had a significantly higher diversity than Redang Island. Compared to Bidong and Redang islands, Tanjung Tuan had a much lower cover of *Acropora,* most likely due to the low tolerance of Acropora species to high sediment (Ricardo *et al*. 2018). This gave a more even spread of coral genera leading to a higher diversity. There was also a greater species richness of coral at Tanjung Tuan, which may be due to the sheltering effect of the mainland from the North East Monsoon, allowing the less storm-resistant corals to survive.

Abiotic Substrate Composition

Bidong Archipelago and Redang Island recorded the highest cover of dead coral and dead coral with algae. This is most likely due to damage from the North East Monsoon. Tanjung Tuan recorded far lower levels which indicates that the mainland gave Tanjung Tuan protection from the storms.

There was a much greater cover of sand at Tanjung Tuan than the other sites. This gives an indication of the high levels of sedimentation within the region (Lee 2005). The site also recorded significantly less dead coral with algae. Increased turbidity from suspended sediment would have reduced the growth of algae on the dead coral (McClanahan & Obura 1997).

Soft Coral

Redang Island recorded significantly less soft coral cover than Bidong. Low soft coral cover and diversity is indicative of a recent disturbance event. The high cover of *Fungia* at Redang also alludes to the disturbance event, as they are known to recover quickly and respond well to a disturbance (Fabricius & De'ath 2001; Chadwick-Furman *et al*. 2000). This is likely due to the fact that the study was conducted shortly after the North East Monsoon. The corals at Redang Island have previously been shown to be affected by the 2014 Monsoon (Wee *et al.* 2017).

CONCLUSION

The study ultimately met predictions that coral cover and composition would vary at the different sites due to the different local stressors. The site with the least anthropogenic impacts showed the highest coral cover, the tourist destination showed the greatest algal cover, and the site impacted by sediment recorded the lowest coral cover and the highest Shannon-Wiener and Simpsons indices, as well as the most coral genera. *Acropora* was shown to be sensitive to sedimentation and more support was given of *Porites'* tolerance to increased nutrients. These findings show that different anthropogenic impacts have varied effects and need to be managed to protect the health of the coral reef.

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