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Coral reef fish population in the western extremity of the Coral Triangle

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Abstract

The central and north west coast of Sabah lies along the western extremity of the Coral Triangle, within which are situated several marine protected areas (MPAs). In the present study we determined *in situ* coral reef fish populations in several localities along the west coast of Sabah, by exploring species abundance, richness and diversity of ten economically important fish species. The underwater surveys were conducted from May to December 2015. During this eight- month period, surveys at each site were undertaken once every two months. Dives were conducted during the daylight hours. A total of 171 individuals from the targeted fish species were enumerated from the 349 still images and 220 minutes of video footage. Abundance was observed mainly in the semi-protected MPA (n=110) with only one fish species recorded with more than 2 individuals at protected MPA and unprotected sites. We observed a correlation between fish species richness and coral topographic complexity, with study sites at the semi-protected MPA having the most complex topography landscape, and accordingly recording the highest Shannon-Wiener index (H= 2.85). Higher abundance recorded at study sites in the unprotected sites and semi-protected MPA indicate that such areas could potentially become *de facto* MPAs. A long-term monitoring, assessment and evaluation of the multiple degrees of variables involved such as length-weight relationship, type of habitat, variation in depth, and species behaviour are recommended in order to understand better the relationship and dynamics between these variables.

Keywords: Coral reef fish, Fisheries, Marine protected areas, Coral Triangle, Sabah, Borneo

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Introduction

The coastal marine environment of Sabah supports an extraordinary diversity of reef fishes, many of which are commercially important and much sought-after seafood. These include the families of groupers (Serranidae), wrasses (Labridae), emperor breams (Lethrinidae), and grunts (Haemulidae) (e.g., Chin, 1998; Biusing, 2001; Manjaji-Matsumoto, 2007; Manjaji-Matsumoto et al., 2017). Increasing demand by both local and international consumers has resulted in a significant decline in wild populations, the status of which is currently unknown. Moreover, as is elsewhere in the region, dependence on wild-caught adult and juvenile reef fish as seed for the continuing expansion of capture-based aquaculture sector has put the wild stock of the population under pressure (Manjaji-Matsumoto, pers. observation), which in some cases has led to overfishing (Heemstra and Randall, 1993; Zhu and Yue, 2008).

The central and north west coast of Sabah lies along the western extremity of the Coral Triangle (Green and Mous, 2008). Carpenter et al. (2011) in their review on the phylogeography of the Coral Triangle seascape in search for an improved marine resources management scheme, attributed its high levels of biodiversity to the beginning of the Miocene about 23 million years ago.

Within Sabah's west coast waters are situated several marine protected areas (MPAs), including the well-established Tunku Abdul Rahman Park (TARP) and the newly-established Tun Mustapha Park (TMP), the latter being gazetted in May 2016 and is the largest MPA in Malaysia (Lim and Bakar, 2016).

MPAs have long been acknowledged to support biodiversity conservation and fishery management. Studies have shown that MPAs not only improve the biomass of fish, but they harbour greater numbers of large individuals (Chung et al., 2012; Abesamis et al., 2014; Russ et al., 2015). An important effect of this is a spill-over of larvae and adult biomass from MPAs to adjacent unprotected areas, and this by default helps maintain local population and preserve natural meta-population (Cowen et al., 2006; Planes et al., 2009).

In the present study we determined *in situ* coral reef fish populations in several localities along the west coast of Sabah, by exploring species abundance, richness and diversity of ten economically important fish species.

Materials and Methods

Study areas

A total of 15 dive sites in MPAs and non-MPAs within two localities along the central- and north- west coasts of Sabah were selected for this study (Figure 1). The first locality includes two small islands within the Tunku Abdul Rahman Park (TARP), Gaya Island (06°01'57.80" N, 116°01'29.30" E) and Sulug Island (05°57'45.90" N, 115°59'29.00" E), and another two small islands outside of the TARP boundary. The latter two islands located within the Sepanggar Bay are Sepanggar Island (06°04'22.30" N, 116°04'14.30" E) and Udar Island (06°04'45.66" N, 116°05'12.67" E).

The second locality includes three semi-protected reef sites within the Tun Mustapha Park (TMP), Maliangin Besar Island (07°04'47.90" N, 117°02'37.40" E), Maliangin Kecil Island (07°04'25.20" N, 117°01'38.80" E), and Patanunan Island (07°06'36.70" N, 117°05'38.40" E).

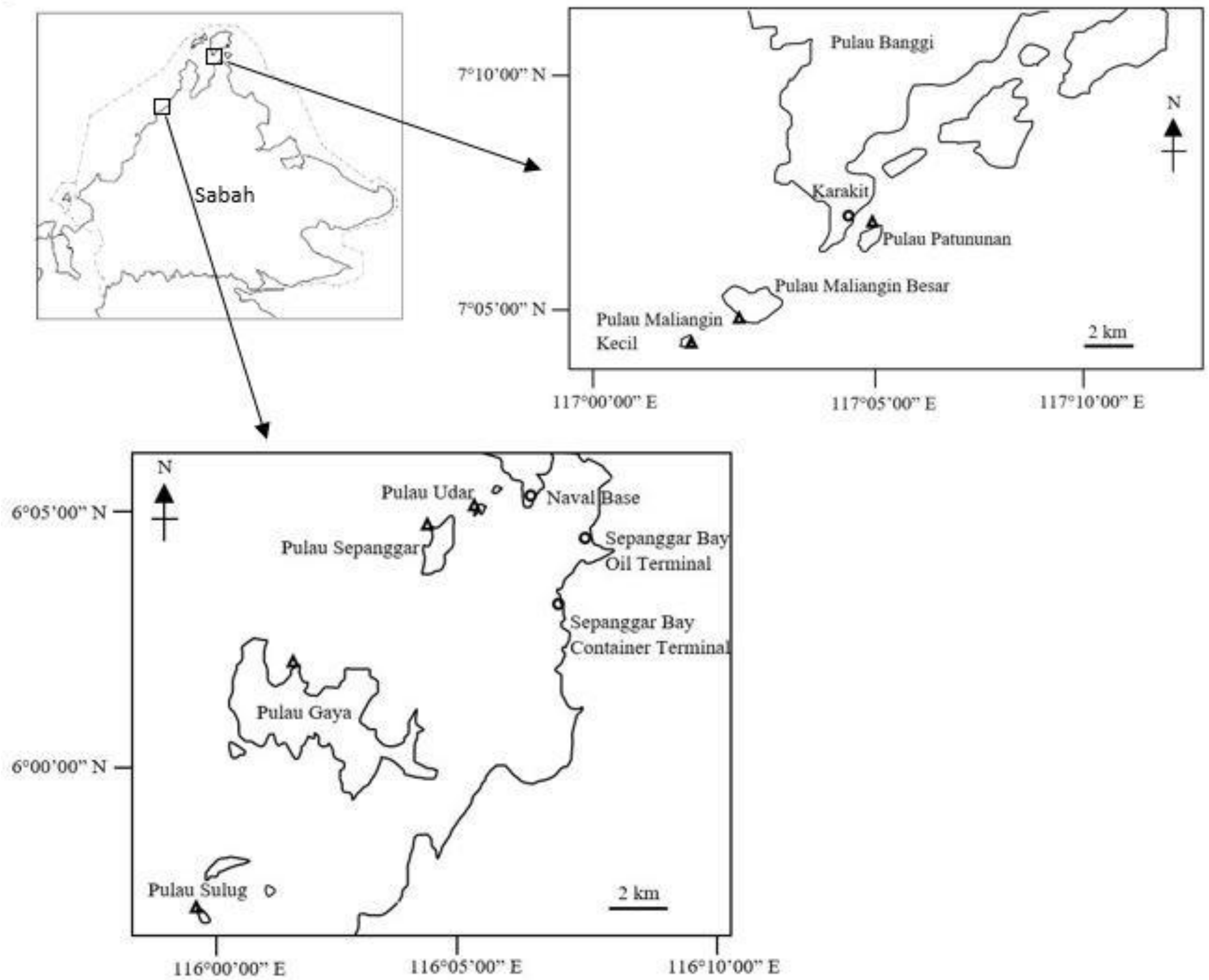

Figure 1. Map of the study area. Δ= dive sites. Ten dive sites are located off Kota Kinabalu, of which 5 represent protected reef sites and 5 represent nonprotected reef sites. Another 5 sites are located off Kudat, which represent semi-protected reef sites.

TARP is located approximately 1.6 nm off Kota Kinabalu city, covering an area of 4,929 hectares (Board of Trustees of Sabah Parks, 2011). This MPA is characterised by daily heavy boat traffic as the park is an attraction for nature tourism and water sports activities.

The unprotected reef sites in Sepanggar Bay are open to the public without any restrictions. However, the proximity of this area to the Sepanggar Naval Base somewhat deters trespassers from entering the surrounding waters.

TMP consists of over 50 islands and covers an area of 898,762.76 hectares, with 80,000 people living in the coastal areas of this northern region of Sabah. Members of the Banggi Youth Club, consisting of a small group of scuba divers trained and supported by WWF Malaysia, are entrusted with the responsibility of protection of a few uninhabited small islands, including Maliangin Besar, Maliangin Kecil and Patanunan islands surrounding the Banggi Island.

Underwater video survey

The underwater surveys were conducted from May to December 2015. During this eight- month period, surveys at each site were undertaken once every two months. Dives were conducted during the daylight hours between 7:00 to 17:00 at depths between 3 to 15 m.

All underwater surveys were conducted using underwater video technique where the diver-operated digital video camera (SJCAM; Model SJ5000) along a randomly-deployed 100 m belt transect at each site. An underwater video survey technique supplements the classic "lines transect method" due to time and cost-effectiveness, larger data set production and permanent record for re-visitation (Marsh et al., 1984, Ando et al., 2004, Pelletier et al., 2011).

Using this technique, the video operator records footages of the benthic coral colony aggregation along the transect line. These footages are then played back on a computer screen to capture information on the ten fish species, their abundance, richness and diversity as well as coral colony aggregation and topographic complexity.

The ten fish species are *Cephalopholis miniata*, *Cheilinus fasciatus*, *Diagramma melanacrum*, *D. pictum*, *Epinephelus fasciatus*, *Hemigymnus melapterus*, *Lethrinus erythropterus*, *L. ornatus*, *Plectorhinchus vittatus* and *P. lessonii*. Fish that was continuously moving in and out of the footage was not counted to avoid duplication.

As for the coral colonies and their topographic complexities, these are grouped and categorized following Arias-Gonzalez et al. (2011), as shown in Table 1.

Table 2. The six groups of coral colonies and six categories of coral topographic complexities (after Arias-Gonzalez et al., 2011).

Coral colonies		Coral topographic complexity	
Group code	**Description**	**Category code**	**Description**
0	without colony	1	flat
1	isolated colonies	2	semi-flat
2	small patches	3	low rugosity
3	large patches	4	high rugosity
4	massive corals	5	complex
5	spurs and grooves	6	very complex
6	ridges		

In general, the underwater visibility was fair throughout the survey period, with the exception of a few dives.

Statistical data analysis

The distribution data of fish species was first tested with Permutational multivariate analysis of variance (PERMANOVA) using the Primer 7 software package with log-scale transformation on the abundance data. This was to overcome the highly skewed distribution of the fish species across the study sites. To detect the differences in fish abundance between the sites, marine protection status with three levels: protected, semi-protected, and unprotected, was applied as a fixed factor in the one-way PERMANOVA. Any correlation detected was then presented in non-metric multidimensional scaling plots (nMDS). The model tested was based on Bray-Curtis similarity and 9999 times number of permutations. If any significant differences existed, pairwise PERMANOVA was used to determine the differences between the different levels of the fixed factor. Due to the low number of unique permutations (<999) which proved insufficient to determine permutation p-value for the factor, Monte-Carlo p-values, P(MC) were used instead to provide an approximation of the difference based on asymptotic theory (Anderson *et al.*, 2008). Similarity Percentage Breakdown (SIMPER) was further used to identify the taxa that contributed to the differences. The Shannon-Wiener diversity index was computed in order to compare coral colony aggregation and topographic complexity across the study sites.

Results

A total of 171 individuals from the targeted fish species were enumerated from the 349 still images and 220 minutes of video footage. Sightings were zero for three of the target species, i.e. Longfin Emperor *Lethrinus erythropterus*, Ornate Emperor *Lethrinus ornatus*, and Coral Hind *Cephalopholis miniata* (Table 2), and no more than three individuals for four species, i.e. Blackfin Slatey *Diagramma melanacrum*, Lesson's Thicklip *Plectorhinchus lessonii*, Indian Ocean Oriental Sweetlips, *Plectorhinchus vittatus*, and Blackeye Thicklip *Hemigymnus melapterus*. Relatively frequent sightings were observed for Painted Sweetlips *Diagramma pictum* (n=26), Redbreasted Wrasse *Cheilinus fasciatus* (n=46), and Blacktip Grouper *Epinephelus fasciatus* (n=92).

Table 2. Abundance of target fish species as recorded in the study sites with different levels of protection status. **A** – protected, **B** – unprotected, and **C** – semi-protected sites; **A1** – Gaya Island; **A2** – Sulug Island; **B1** – Sepanggar Island; **B2** – Udar Island; **C1** – Maliangan Besar Island; **C2** – Maliangin Kecil Island; **C3** – Patanunan Island.

Species list	**A**		**B**		**C**			**Total**
	A1	**A2**	**B1**	**B2**	**C1**	**C2**	**C3**	
Diagramma melanacrum	0	0	0	0	0	0	3	3
D. pictum	0	0	0	0	0	2	24	26
Plectorhinchus lessonii	0	0	0	1	0	0	0	1
P. vittatus	1	0	0	0	0	0	0	1
Cheilinus fasciatus	0	0	0	0	6	7	33	46
Hemigymnus melapterus	0	0	0	0	0	2	0	2
Lethrinus erythropterus	0	0	0	0	0	0	0	0
L. ornatus	0	0	0	0	0	0	0	0
Cephalopholis miniata	0	0	0	0	0	0	0	0
Epinephelus fasciatus	10	10	21	18	3	16	14	92
Total	11	10	21	19	9	27	74	171

Non-metric MDS plot based on target fish abundance showed relatively distinct groups when marine protection status of the study sites was selected as a factor. PERMANOVA performance confirmed these differences (Figure 2; Pseudo-F = 4.1197, P (perm) = 0.015) with pairwise test indicating that fish abundance in semi-protected marine park was different from that in both protected and unprotected marine areas but not between protected marine park and unprotected marine areas (Tables 3 and 4; P (MC) = 0.0128 and 0.0086 respectively).

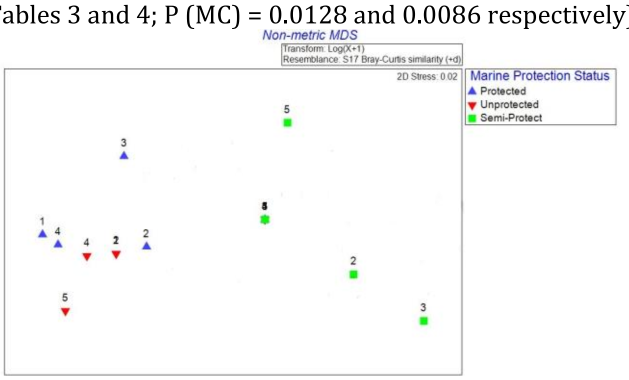

Figure 3. Non-metric MDS show that the cluster of groups between semi-protected sites and others were more pronounced than when just comparing between protected and unprotected sites. It was observed that overlapping occurred in all three sites.

Table 3. PERMANOVA with 9999 number of permutations. Permutation method was unrestricted permutation of raw data with three levels of Marine Protection Status as a factor.

PERMANOVA	**NP**	**Permutation method: Unrestricted permutation of raw data**					
Source	df	SS	MS	Pseudo-F	P (perm)	Unique perms	P(MC)
Ma	2	5157	2578.5	4.1197	0.015*	5845	0.0092
Res	12	7510.6	625.89				
Total	14	12668					

NP = No. of permutation: 9999
* = significant < 0.05.

Table 4. Pairwise test with 9999 number of permutations.

Groups	**t**	**P (perm)**	**Unique perms**	**P(MC)**
Protected, Unprotected	0.53675	0.6838	66	0.7464
Protected, Semi-protected	2.259	0.0224	56	0.0128*
Unprotected, Semi-protected	2.558	0.023	41	0.0086*

* = significant Monte-Carlo p values

One-way SIMPER analysis indicated that three species *Epinephelus fasciatus*, *Cheilinus fasciatus* and *Hemigymnus melapterus* accounted for 92.12% of the dissimilarity in Protected/Semi-protected marine parks and 94.80% in Unprotected/Semi-protected marine parks (Table 5). In both cases, the abundance of *E. fasciatus* was higher in protected and unprotected sites while *C. fasciatus* and *H. melapterus* were higher in the semi-protected site.

Shannon-Wiener diversity indices in the unprotected areas and protected MPAs recorded poor scores (H’ = 0.30 and 0.21, respectively) whereas the index was relatively high (H’ = 2.85) in the semi-protected MPA. Although their presence varied from station to station, massive coral colony aggregations were repeatedly observed at the protected MPAs compared to unprotected areas and semi-protected MPAs. Semi-protected MPAs registered the most massive coral ridge structures and the highest topographic complexity. The topography at the protected MPAs were inconsistent, ranging from flat to complex landscape whereas the unprotected areas and semi-protected MPAs exhibited constant topographic characteristics (Figure 3).

Discussion

Abundance of Target Fish Species

Abundance was observed mainly in the semi-protected MPA (n=110) whilst the only species that recorded more than 2 individuals at the protected MPA and unprotected areas was the Blacktip Grouper *Epinephelus fasciatus.* Contrary to many studies demonstrating the benefits of protected marine parks which result in higher abundance compared with adjacent unprotected marine areas (Costello, 2014; Edgar et al., 2014; Watson et al., 2014), the coral reefs at the dive sites within the protected MPA were so badly degraded that the abundance of target fish species was lower than those at the unprotected areas and semi-protected MPA (n=21 and n=40, respectively).

Both human activities and natural events can lead to degradation. In the case of the TARP study sites, TARP suffered severe coral reduction when the area was hit by tropical storm Greg in 1996 (Spait, 2001). The situation is further aggravated by repetitive, small- scale destructive anthropogenic activity triggering large and unpredictable environmental impairment. In 2010, TARP received 340,092 visitors, a 14% increase from 2009 and ever increasing in future (Board of Trustees of Sabah Parks, 2011). The high number of visitor arrivals leads to an increase in domestic waste, traffic, and must-do water sport activities (snorkelling and diving), all of which increase marine life disturbances. The casual snorkeler or diver often displays dangerous behaviour or habits underwater. For example, 95% of inexperienced snorkelers make at least one contact with the seabed every 10 minutes and the flapping (of flippers) causes sediment to rise (Luna et al., 2009). These negatively affect the behaviour of many species of marine animals as well as coral colonies. As TARP is a mere 1.6 nm away from Kota Kinabalu city, sea pollution is a major ongoing problem. Heavy rains often wash solid wastes from the mainland into the marine park area. These wastes drift from island to island, becoming trapped on beaches or rocky shores, and even sinking to the sea bottom. Large quantities of debris may alter water chemistry, reduce species abundance and potentially affect marine life when ingested (Engler, 2012; Gall and Thompson, 2015). In addition, the illegal human settlement adjacent to the TARP lacks proper waste management, and places further burden on the ecosystem.

Table 5. One –way SIMPER analysis of target fish abundance showed discrimination between study sites.

Protected & Unprotected						
Av. Dissimilarity = 53.23%	Av. Abund Protected	Av. Abund Unprotected	Av. Diss	Diss/SD	Contribution	Cum %
Epinephelus fasciatus	1.26	1.23	43.21	1.2	81.19	81.19
Plectorhinchus vittatus	0.14	0	5.86	0.46	11.01	92.19
P. lessonii	0	0.14	4.16	0.48	7.81	100
Cephalopholis miniata	0	0	0	Undefined	0	100
Diagramma melanacrum	0	0	0	Undefined	0	100
D. pictum	0	0	0	Undefined	0	100
Lethrinus erythropterus	0	0	0	Undefined	0	100
L. ornatus	0	0	0	Undefined	0	100
Cheilinus fasciatus	0	0	0	Undefined	0	100
Hemigymnus melapterus	0	0	0	Undefined	0	100
Protected & Semi-protected						
Av. Dissimilarity = 100%	Av. Abund Protected	Av. Abund Semi-protect	Av. Diss	Diss/SD	Contribution	Cum %
Epinephelus fasciatus	1.26	0	57.32	1.69	57.32	57.32
Cheilinus fasciatus	0	0.64	25.28	0.76	25.28	82.59
Hemigymnus melapterus	0	0.14	9.53	0.41	9.53	92.12
Plectorhinchus vittatus	0.14	0	7.88	0.48	7.88	100
Cephalopholis miniata	0	0	0	Undefined	0	100
Diagramma melanacrum	0	0	0	Undefined	0	100
D. pictum	0	0	0	Undefined	0	100
Plectorhinchus lessonii	0	0	0	Undefined	0	100
Lethrinus erythropterus	0	0	0	Undefined	0	100
L. ornatus	0	0	0	Undefined	0	100
Unprotected & Semi-protected						
Av. Dissimilarity = 100%	Av. Abund Unprotected	Av. Abund Semi-protected	Av. Diss	Diss/SD	Contribution	Cum %
Epinephelus fasciatus	1.23	0	60.12	1.88	60.12	60.12
Cheilinus fasciatus	0	0.64	25.21	0.76	25.21	85.34
Hemigymnus melapterus	0	0.14	9.47	0.41	9.47	94.8
Plectorhinchus lessonii	0.14	0	5.2	0.5	5.2	100
Cephalopholis miniata	0	0	0	Undefined	0	100
Diagramma melanacrum	0	0	0	Undefined	0	100
D. pictum	0	0	0	Undefined	0	100
Plectorhinchus vittatus	0	0	0	Undefined	0	100
Lethrinus erythropterus	0	0	0	Undefined	0	100
L. ornatus	0	0	0	Undefined	0	100

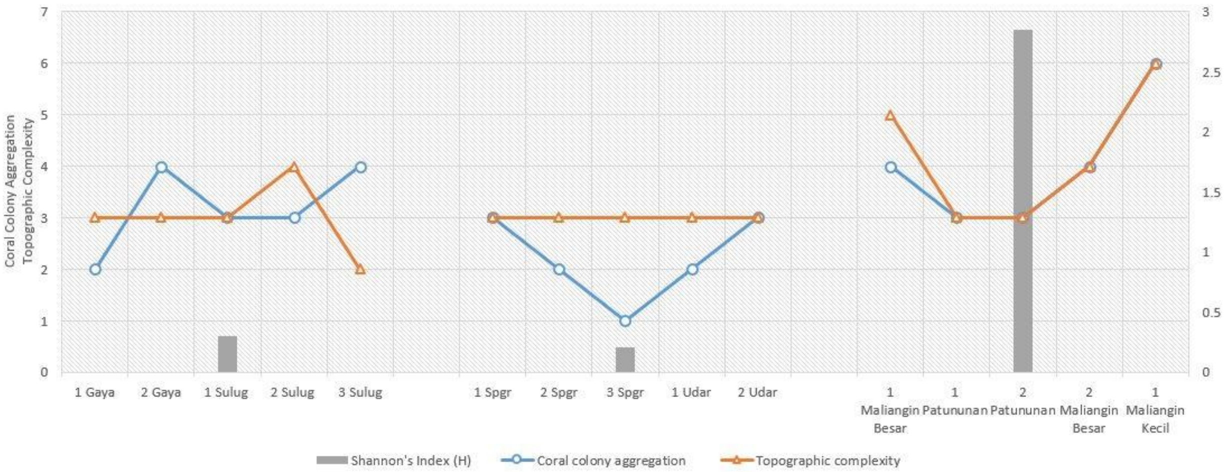

Figure 4. Shannon-Wiener diversity in comparison to coral aggregation and topographic complexity.

Study sites at the unprotected areas and semi-protected MPA surprisingly exhibited better abundance than those at the protected MPA. Despite the presence of Mari Mari Lodge on Pulau Sepanggar offering several tourism packages, visitor arrivals to this island are relatively slow compared to the well-known TARP. The island is also home to coastal fishing villagers. Observation made during this study suggests that the higher fish abundance in the unprotected areas and semi-protected MPA may be due to the establishment of the Royal Malaysian Naval Base, the Sepanggar Bay Oil Terminal and Container Terminal close to Udar Island. The restricted zone adjacent to Udar Island naturally deters fishermen from entering the area, and as a consequence, the area may have unintentionally become an isolated undisturbed area, or *de facto* MPAs, also referred to as MPAs in practice but not in law (Wahle and Aluli, 2008).

The fish population in study sites in the semi-protected MPA can be distinguished statistically from that of the other two sites by abundance and diversity. Blackfin Slatey *Diagramma melanacrum* (n=3), Painted Sweetlips *Diagramma pictum* (n=26), Redbreasted Wrasse *Cheilinus fasciatus* (n=46), and Blackeye Thicklip *Hemigymnus melapterus* (n=2) from the targeted species were found exclusively in these study sites. Even the common species, the Blacktip Grouper *Epinephelus fasciatus,* which was also sighted in the other two MPAs, recorded higher population (n=92) there.

The semi-protected MPA sits within the newly established TMP within the Coral Triangle. TMP is an important fishing ground, with a daily catch of approximating 100 tonnes of fish valued at US$ 200,000 (WWF, 2015). It is home to 360 species of fish including many commercially important ones, aquarium ornamental fish species and high -value species for the lucrative live reef fish trade (LRFT) (Lim and Bakar, 2016). However, fisheries assessments conducted in the area point to early stage Malthusian overfishing indicating that sustainable fishing is in jeopardy (Teh et al., 2005; Teh and Sumaila, 2007). Destructive fishing practices in TMP such as cyanide fishing and blast fishing have reduced both fish abundance and habitat quality (Brown et al., 2015). Both TMP and the east coast of Sabah are being exploited for the LRFT (Daw et al., 2002). Despite these threats, higher abundance was recorded for the targeted fish species at the semi-protected MPA. While the higher abundance could be attributed to the pre-existing established target fish species population in the area, another contributing factor could be the two low-fishing June-September and December-February seasons providing some relief to the wild stock from fishing pressure (Teh and Sumaila, 2007).

Coral, Topographic Complexity and Diversity

Studies carried out in the past have indicated a correlation between topographic complexity and species richness (Ruitton et al., 2000; Garcia-Charton and Perez-Ruzafa, 2001; Walker et al., 2009). A similar relationship was observed in this study, with study sites at the semi-protected MPA having the most complex topography landscape accordingly recording the highest Shannon-Wiener index (H= 2.85). Sites at the protected MPA (H= 0.30) and unprotected areas and semi-protected MPA (H= 0.21) recorded much lower diversity indexes with lower rugosity. However, this relationship is not as clearly articulated when the degrees of topographic complexity are compared across all three MPAs. Topographic complexity affects fish behaviour in the way it responds to risk and threat such as predation. In a complex environment, fish tend to behave more carefully owing to visual impairment and restricted movements (McCormick and Lönnstedt, 2013). While it is arguable how increased topographic complexity helps prey fish avoid or escape from predators, or aids predators capture their prey (Schultz and Kruschel, 2010), the advantages or disadvantages of topographic complexity may vary in shallow and deep habitats (Roberts and Ormond, 1987; Walker et al., 2009). It is also important to note that fish are highly mobile and require continuous connected habitat for population sustainability, such that habitat topographic complexity alone is an insufficient parameter to measure fish diversity or habitat suitability (Pittman et al., 2010). Study sites at the semi-protected MPA recorded the highest average massive coral aggregation compared to the sites at the protected MPA (large patches) and unprotected areas and semi-protected MPA (small patches). Live coral coverage is often regarded as one of the important factors in reef communities, where greater live coral coverage leads to increased diversity and abundance, but more studies suggest that this relationship is far more complex (Beldade et al., 2015; Howlett et al., 2016). Other factors that need to be taken into account include reef fish species dependency on coral for food, refuge and habitat use, throughout the various stages of development.

Conclusions

The study findings revealing the low abundance and diversity counts of commercially important reef fish as well as coral aggregation at the study sites in the protected MPA suggest that such parks have not been very effective in protection and conservation of Sabah's marine and coastal ecosystems. While the reasons are still unclear as to whether the causes are due to natural events or are human impacted, the management of marine parks must reconsider the current strategies. Fortunately, the newly-gazetted semi-protected TMP, exhibited acceptable targeted fish species abundance and diversity levels with relatively healthier coral aggregation. However, as the TMP measures more than one million hectares, and includes nearly 800,000 locals people it is a massive but an important undertaking to engage these stakeholders in marine biodiversity protection and conservation, ensuring and maintaining the marine park as one of the most diverse marine habitats on earth. Higher abundance recorded at study sites in the unprotected areas and semi-protected MPA indicates that such areas could potentially become *de facto* MPAs. Unprotected areas and semi-protected MPAs face less threats from tourism-related activities, and are expected to fare better in marine biodiversity conservation. A long-term monitoring, assessment and evaluation of the multiple degrees of variables involved such as length-weight relationship, type of habitat, variation in depth, and species behaviour are recommended in order to better understand the relationship and dynamics of these variables. It is crucial to impose effective enforcement of the MPAs to prevent small-scale but destructive fishing of commercially important reef fish species and to explore the role of aquaculture in conserving these species.

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