TRANSACTIONS ON SCIENCE AND TECHNOLOGY

Enhanced fish diversity following active coral reef restoration efforts in Tun Sakaran Marine Park, Sabah, Malaysian coral triangle

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ABSTRACT Located in the heart of Malaysia's Coral Triangle – a region well-known for its outstanding marine biodiversity – are two Marine Protected Areas (MPAs), the Tun Sakaran Marine Park (TSMP) and Sipadan Island Park (SIP). The remote seascapes were both gazetted as an MPA in the same year, 2004, on widespread damaged coral reef ecosystems due mainly to the rampant use of prohibited fishing devices and unsustainable fishing practices targeting coral reef fishes. Our study was conducted in the TSMP, where active coral reef restoration and rehabilitation efforts using the coral frame method have been in place by the park management authority since 2011. The objectives of this study are 1) to determine the fish biodiversity and estimate the fish species abundance in TSMP, and 2) to determine the correlation between hard coral cover on coral frames and the diversity and abundance of reef fishes. Two coral reef restoration sites within TSMP were selected as the study stations. Underwater observations were made between July 2020 and January 2021, using Baited Remote Underwater Video Systems (BRUVS). Data on substrate type were obtained from photos taken by cameras placed adjacent to the deployed BRUVS, at the top of the coral frames. The photos were analysed to determine the types of substrate cover using the Coral Point Count with Excel Extension (CPCe) software. The results show a total of 3,208 individual fishes, identified into 146 species from 27 families. The three most abundant families, which make up just over half (52%) of the total abundance are Caesionidae, comprising 19.73% of the total composition, followed by Pomacentridae (16.05%) and Labridae (15.93%). Moon Wrasse, *Thalassoma lunare* is the most abundant species comprising 11.47% of the total abundance of fishes observed, while only four species of elasmobranchs, all batoids, were recorded. Notably, two of the four batoid species are listed as vulnerable in the IUCN Red List of threatened species. As for the type of substrate cover on the coral frame, a total of 2,750 points were categorized from 50 photos combined from both sites. Our results show that there are no significant differences ($p>0.05$) between hard coral cover on coral frames and the reef fish abundance, and between the percentage of hard coral cover on coral frames and the reef fish species at both sites. This is likely due to the low percentage of hard coral cover on the coral frames at both sites which is below 50%, with Site 2 exhibiting a slightly higher cover (37.96%) compared to Site 1 (27.70%). Despite the low percentage, it is noteworthy that the hard coral cover on the coral frames in both sites appears denser and structurally more complex than the adjacent depleted coral reefs. We conclude that active coral reef restoration and rehabilitation efforts are important in accelerating the re-colonization of damaged coral reefs by coral reef inhabitants, particularly by juvenile coral reef fishes. Lessons learned from this study may help park managers in refining coral reef restoration techniques of the damaged reefs.

KEYWORDS: Artificial reefs; hard coral cover; coral reef fishes; marine protected area; Malaysia's Coral Triangle, coral frame
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INTRODUCTION

Coral reef ecosystems are important in various ecological, aesthetic, economic, and cultural functions (Maragos *et al.*, 1996). It protects the shoreline, which acts as the first line of defence against erosion by reducing the force of the waves and the production of sediment (Elliff & Silva, 2017). Energy from waves could be dispersed by reef crests of fringing reefs which act as breakwaters (Gallop *et al.*, 2014; Rogers *et al.*, 2016). Coral reefs provide critical ecosystem services, including fisheries, coastal protection, and tourist income, to millions of people (de Groot *et al.*, 2012; Barbier, 2017; Woodhead *et al.*, 2019). However, coral reef faces a significant threat from anthropogenic factors such as overfishing, global climate change, coral disease, sedimentation, extensive coastal development, the introduction of invasive species and the release of pollutants (Hughes *et al*., 2003; Hoegh-Guldberg *et al*., 2017).

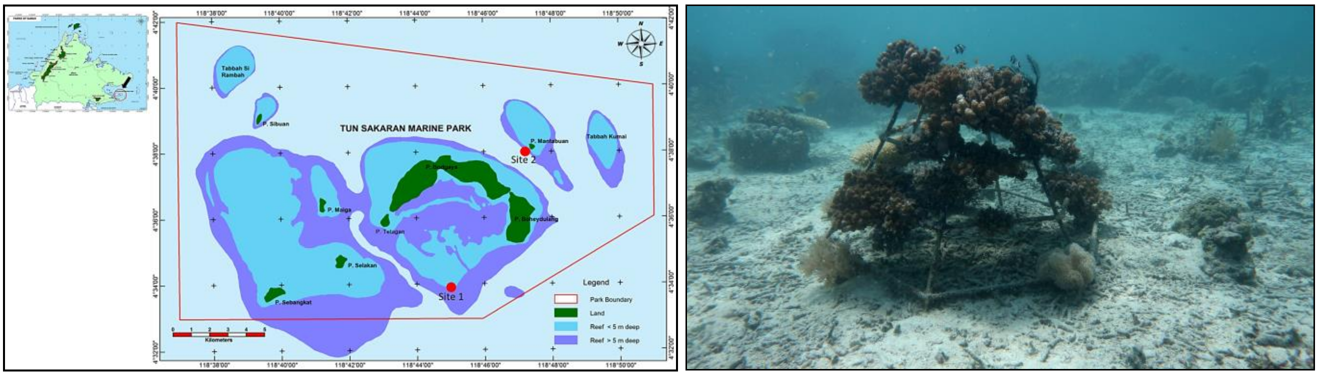
Various method has discussed MPA as one of the best effective management tools in protecting fragile coral reef ecosystems. With the gazettement of MPA, various activities such as fishing, tourism, research, and others could be regulated through enforcement regulation/laws. Other than that, artificial reef is another common method in restoring damage coral reefs. The artificial reef comes in many forms and materials. Artificial reef deployed and left underwater in hoping that the structure will be grown by corals and inhabited by marine organism which is a passive effort.

Tun Sakaran Marine Park (TSMP) was gazetted in 2004 as Marine Protected Area (MPA), located at the heart of Coral Triangle Initiative (CTI) - a region well-known for its outstanding marine biodiversity. Coral and fish diversity in TSMP are recorded to be the highest in Malaysia (Semporna Island Project, 2001). Unfortunately, in Tun Sakaran Marine Park, TSMP itself facing threats from number of factors that happen in the park recently such as bleaching in 2017 (unpublished), mass Crown of Thorn starfish outbreak in 2018 (unpublished) and unsustainable fishing practices that happen a long time before the gazettement of the park (2004) (Semporna Island Project, 2001). An annual survey on the status of coral reefs in TSMP by Reef Check Malaysia showed that 25% of the natural reefs were in excellent condition, 33% were in good condition, and 25% were in fair condition while the remaining 17% were in poor condition (Reef Check Malaysia, 2018). However, in TSMP, a more active effort of reef rehabilitation program was introduced through the project of coral frames. The coral frame method which adopts the techniques and technology of Seamarc Ptv. Ltd. from the Maldives has been used in TSMP since 2011. This strategy is to repair damaged coral reef based on a small scale, of which is then expected to eventually make a significant difference, versus a big-scale restoration program, which is not only difficult but cost in-effective and time-consuming (Wood & Ng, 2014). Each coral frame was made from iron bar in shape of spider web which was covered by sea sands before being deployed underwater. The frames were then planted with branching corals fragments and were taken care off until they can survive on their own. Throughout the restoration process, monitoring and maintenance of the artificial reefs were carried out regularly by TSMP personals. This active restoration effort was carried out using this method which ensure the survival of the planted hard corals on the artificial reefs.

Since the beginning of these coral reef restoration efforts, monitoring of the 'recovery' phases on the population structure of coral reef fish has been minimal, and mainly done to monitor the coral fragment on the structure are intact. The purposes of this study are to establish the diversity and abundance of the reef fish in coral reef restoration sites within TSMP, to determine the percentage type of substrate (hard coral, soft coral, recently killed coral, nutrient indicator algae, sponge, rock, rubble, sand, silt, and others) found on coral frames and to determine the correlation between hard coral cover on coral frame towards the diversity of reef fish as well as their abundance. The finding from this study will be beneficial to the park’s management efforts in rehabilitating the overall coral reef ecosystem within the TSMP through deployment of coral frame as artificial reefs. Lesson learns from this study could help park’s managers in planning and managing the coral reefs restoration programmes in the marine parks.

METHODOLOGY

The study took placed at Tun Sakaran Marine Park, TSMP, Semporna, Sabah, Malaysia which is situated at the east coast of Sabah and 18 km northeast of Semporna town (Figure 1a). TSMP located at between latitude 4°33′N to 4°42′N, and longitude 118°37′E to 118°51′E with an area of 350 km². TMSP comprises of eight islands with two submerged coral reefs. Fringing coral reefs observed on the outside of all the main islands and smaller outlying islands (Semporna Island Project, 2001). Two study sites were selected within TSMP. There were Death End Channel (Site 1) and Mantabuan Reef (Site 2). Site 1 (Death End Channel) located at the southern rim reef which is based on sunken southern rim reef of Bodgaya volcano which has 10km long and depth of 30m at the east side and 20m depth at the west side of the rim reef. The Death End Channel is about 100m wide and 1.5km in length. The channel opens towards the seaward side but it closes towards the lagoon (thus called by its name). The substrate mainly rubble, rock, and sands. Adjacent to the artificial reef were shallow reefs with good coverage of hard corals. At Site 2 (Mantabuan Reef) located at South-West of Mantabuan Island where the stretch of reefs starting from the west side of the island up to the northern end has wide shallow reef top and gentle-sloping profile. The main reef slope is at the angle of 30° and continue at least 33 m where the substrate are mainly rubble and sand especially below 17 m depth (Semporna Island Project, 2001). In Site 1 there are 30 coral frames were placed on that site since 2014 (Pauzi *et. al.*, 2018) whereas in Site 2 there are total 125 coral frames placed (Figure 1b) since 2011 (Wood & Ng, 2014). The coral frames were placed at shallow depth of 4 – 10m at Site 2 and at Site 1 only single depth of 10m. The surveys were done at this depth range. Field works have been carried out 12 times starting from 27th July 2020 until 6th January 2021 during daylight hours between 0800 to 1500.



(a) (b)

Figure 1. (a) Study sites located within Tun Sakaran Marine Park, Semporna, Sabah. (Source: Sabah Parks, 2015). (b) Coral frame structure planted with hard corals has become habitats for reef fish in a degraded coral reefs ecosystem in TSMP.

Baited Remote Underwater Video (BRUVS) were deployed for 60 minutes near the artificial reef within each study site. Action camera, which was attached one metre in front of the bait, was used to record all the videos of fish found on this study. For each deployment, 200g of oily bait fish (*Decapterus* spp.) were used – these were roughly chopped and put into a mesh bag to attract fish to the camera viewpoint. The fish seen in the video were identified to the lowest taxonomic level possible by referring to Fish Base websites and published books (Debelius, 2007; Bergbaur & Kirschner, 2014; Allen *et al.*, 2005).

Relative abundance of the identified fish was also calculated using MaxN, which is a metric of species' local abundance based on the maximum number of individuals observed in a single frame of video, (Ebner *et al.*, 2008; Loiseau *et al.*, 2016). These data were then calculated to get the diversity index using Shannon-Weiner diversity index given in Equation (1).

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \quad (1)$$

where H' is the Species diversity index, pi is the proportion of individuals of each species belonging to the i th species of the total number of individuals, and S is number of species or species richness. Kruskal-Wallis Test was also performed to determine the differences in terms of reef fish diversity at both study sites.

The types of substrate cover on the coral frames were determined using Coral Point Count with Excel Extension, CPCe version 4.1 software (Kohler & Gill, 2006). Photos guided with a PVC quadrat with 100 x 100cm dimension were taken from the top of the coral frame placed adjacent the deployed BRUV. There was total 25 photos taken from each of the study site. All photos were then run through the CPCe software. Substrate types were categorized into Standard Reef Check Guideline such as Hard Coral, Soft Coral, Recently Killed Coral, Nutrient Indicator Algae, Sponge, Rock, Rubble, Sand, Silt, and others (Hodgson *et al.*, 2006). In addition, Shadow, Tape & Wand category (which representing non-substrate categories) were also included which are compulsory to have in CPCe software.

Data were then further analysed for relationship between i) percentage of hard coral cover on coral frames versus diversity of reef fish (Shannon-Weiner Diversity Index) and ii) percentage of hard coral cover on coral frame versus relative abundance of reef fish. To identify the level of relationship, a Pearson correlation index was calculated using JASP (version 0.16, year 2020) software (Sampson, 2020).

RESULT AND DISCUSSION

Total of 3,208 individual fish were observed during this study with 146 species from 27 families. The mean for Shannon-Weiner diversity index of both sites is almost similar with only a fraction of differences with the value of 2.687 versus 2.823 at Site 1 and 2 respectively. Kruskal-Wallis Test for species richness showed that there were significant differences ($p<0.05$) at both of study sites ($h(1)=4.708$, $p=0.03$). However, there were no significant differences ($p>0.05$) in terms of reef fish diversity (Shannon-Weiner Diversity Index) showed that at both studies sites ($h(1)=0.301$, $p=0.583$).

Caesionids (fusiliers) recorded the highest abundance with 19.73% species composition found on BRUV footage. This was followed by the Pomacentridae (damselfishes; 16.05%) and Labridae (wrasses; 15.93%). The Moon Wrasse, *Thalassoma lunare* lead the list of top 10 of the most abundant fish which comprises of 11.47% of total abundance of fish found on coral frame artificial reefs and this was followed by other species as shown in Table 1.

Table 1. Top 10 most abundant (average relative abundance – MaxN) species recorded on coral frame within TSMP from 12 field surveys.

Family	Species	Site 1	Site 2	Total
Labridae	*Thalassoma lunare*	18.58	12.08	30.67
Caesionidae	*Caesio caerulaurea*	16.67	12.67	29.33
Nemipteridae	*Pentapodus caninus*	10.17	15.08	25.25
Caesionidae	*Pterocaesio digramma*	10.00	10.92	20.92
Pomacentridae	*Dascyllus trimaculatus*	16.58	-	16.58
Pomacentridae	*Dascyllus reticulatus*	13.33	0.33	13.67
Pomacentridae	*Abudefduf vaigiensis*	9.67	-	9.67
Acanthuridae	*Naso caeruleacauda*	5.58	0.33	5.92
Nemipteridae	*Pentapodus emeryii*	4.42	0.08	4.50
Fistulariidae	*Fistularia commersonii*	2.42	1.83	4.25

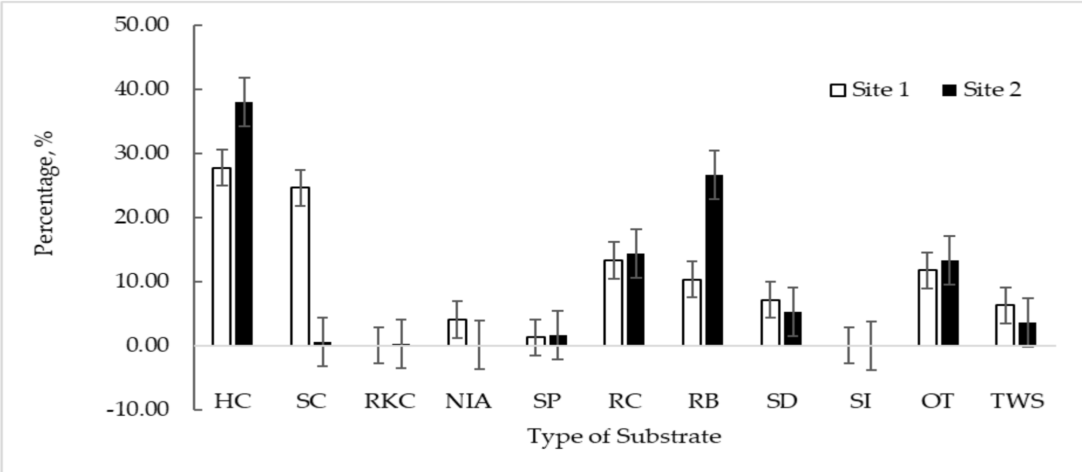
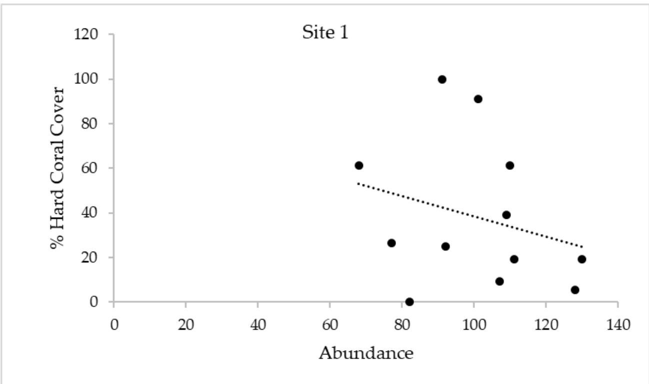
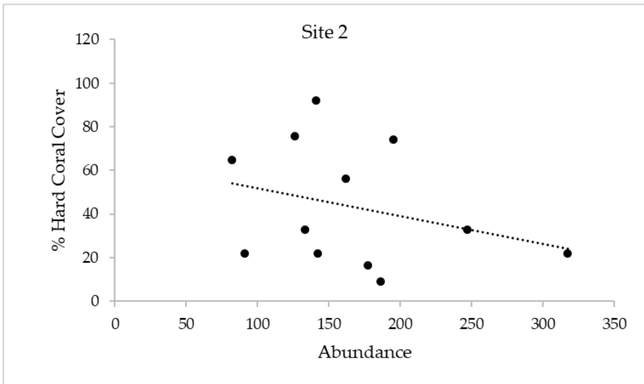


Figure 2. Percentage of substrates type on coral frame at coral restoration sites within TSMP, Semporna. (HC: Hard Corals; SC: Soft corals; RKC: Recently killed corals; NIA: Nutrient's indicator algae; SP: Sponges; RC: Rock; RB: Rubble; SD: Sands; SI: Silt; OT: Others; TWS: Tape, Wand & Shadows)



(a)



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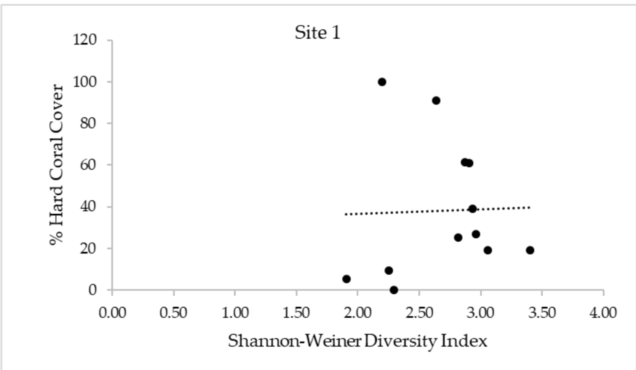

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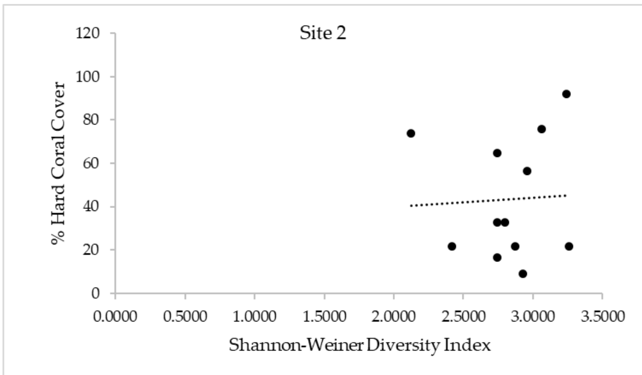

(d)

Figure 3. (a) Negative correlation between percentage of hard coral cover on coral frame and reef fish's abundance in Site 1. (b) Negative correlation between percentage of hard coral cover on coral frame and reef fish abundance in Site 2. (c) Positive correlation between percentage of hard coral cover on coral frame and reef fish's diversity (Shannon-Weiner Diversity Index) in Site 1. (d) Positive correlation between percentage of hard coral cover on coral frame and reef fish's diversity (Shannon-Weiner Diversity Index) in Site 2.

Site 1 recorded a total of 26 families (110 species) whereas Site 2 recorded 25 families (102 species). Slightly higher relative abundance (MaxN) was seen in Site 2 with 1,999 individuals of fish counted compared to 1,209 individuals of fish in Site 1. Notably, four of species of batoid or rays (*Pateobatis fai, Pastinachus ater, Taeniura lymma* and *Aetobatus ocellatus)* were observed, each with only one individual observed, and only a single sighting.

As for type of substrate cover on coral frame, a total of 2,750 points were categorized in 50 photos combine in both of sites. Result shows that higher percentage of hard coral cover on coral frame at Site 2 (37.96%) compared to Site 1 (27.70%) (Figure 2). Site 2 also showed higher percentage of rock and rubble substrate type which is mainly a death coral fragment that were planted on coral frames however soft coral recorded higher coverage for Site 2. In terms of correlation, there was negative correlation between percentage of hard coral cover on coral frames towards the reef fish abundance at both sites (Figure 3a & 3b). However, the percentage of hard coral on coral frame has positive correlation with the reef fish's diversity (Shannon-Weiner Diversity index) for both sites (Figure 3c & 3d).

Results of the Pearson correlation for Site 1 and Site 2 indicated that there is a non-significant very small negative relationship between the percentage of hard coral cover and reef fish's abundance on coral frame artificial reef at both sites, Site1 ($r(10) = -0.263$, $p = 0.409$) and Site 2 ($r(10) = -0.304$, $p = 0.337$). As for relationship between percentage of hard coral cover and reef fish's diversity (Shannon-Weiner Diversity Index) on coral frame artificial reefs, the results indicated that there is a non-significant very small positive relationship on both sites, Site 1: ($r(10) = 0.0289$, $p = 0.929$) and Site 2: ($r(10) = 0.0472$, $p = 0.884$).

DISCUSSION

It was recorded that each of the coral frame could be planted with 60-90 coral fragments, and preferably branching corals of *Acropora* spp. and *Pocillopora* spp. (Wood & Ng, 2014). Maintenances were carried out on regular basis especially during the early months of deployment as the frames needs to be clean from algae and replacing dead coral fragments with new fragments. As soon as the coral fragments are observed as growing healthily, the maintenance works are discontinued, as the same report (Wood & Ng, 2014) indicated that the fragments are now able to survive on its own. During the period where there is no maintenance, the dead coral fragments were left attached on the frame substrate permanently. Site 1 showed lower live hard corals and higher in soft corals. The soft corals were observed to have grown over the dead hard corals which is a suitable substrate for them.

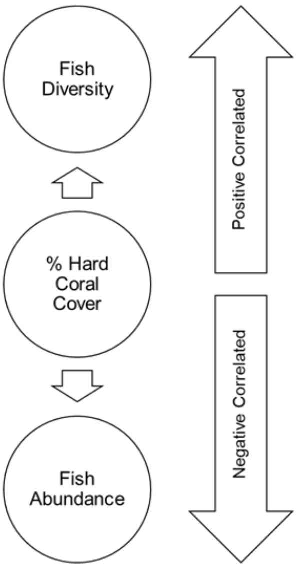

Figure 4. Conceptual framework correlation of percentage hard coral cover on coral frames towards the diversity and abundance of fish.

Positive correlation was seen between hard coral cover on coral frames towards the diversity of fish (Figure 4). This indicated that the planted hard coral on these artificial reefs is important in supporting diverse species of reef fish. The higher the coral cover the more diverse reef fish that it supports which also include four species of elasmobranch species where two of the species (White Spotted Eagle Ray, *Aetobatus ocellatus* and Broad Cowtail Ray, *Pastinachus ater*) are listed as vulnerable in the IUCN Red List of threatened species (Kyne *et al.*, 2016; Sherman *et al.*, 2021). The rays were recorded in the on-going active restoration and rehabilitation of coral reefs at TSMP.

The observation of the (four) rays in the coral reef restoration sites within TSMP is an indication of the area as an important habitat for these vulnerable species. This further supports the necessary action by Sabah Parks to restore these damaged ecosystems. TSMP area is an important site for ray species too this was proven by previous study by Sherman *et al.* (2018) which had recorded the occurrence of *Neotrygon orientalis* and *Taeniura lymma* in BRUV within TSMP water.

Other study found that the increase structural complexity of artificial reefs has yielded to increase of the fish community biodiversity on the artificial reef (Charbonnel *et al.*, 2002; Sherman *et al.*, 2002; Hackradt *et al.*, 2011; Lingo & Szedlmayer, 2006; Hixon & Beets, 1989) and in general, higher fish biodiversity is found on higher complex habitats (Gratwicke & Speight, 2005; Luckhurst & Luckhurst, 1978; Risk, 1972). In natural reef environment too showed that hard coral as well as the coralline algal cover has a positive correlation with fish diversity (McClanahan & Arthur, 2001).

Rehabilitation of degraded reefs was successful by using two natural species of hard corals taken from within the vicinity of the MPA. Mainly branching corals such as *Pocillopora* spp. and *Acropora* spp. were planted onto the coral frames which has attracted small common species such as Pomacentridae to inhabit these artificial reefs. Previous studies by Wood & Ng (2014) on the coral frame of TSMP, showed that the first fish colonizing the artificial reefs were tiny juvenile pomacentrids (Dascyllus species) and unidentified wrasse which was observed nine months after deployment. In addition, the observed fish living in grown coral fragments provide shelters for them (Wood & Ng, 2014). Non-reef associated species like the family of Caesionidae were present abundantly roaming around on top of coral frames. Active reef restoration, through planting of hard corals on coral frames, has help in accelerate the rete of rehabilitation efforts of passive reef restoration where the environmental stressors, especially from fishing are ceased by designating the area as an MPA.

In terms of abundance, negative correlation was observed between the percentage of hard coral cover and abundance of reef fish. This indicated that planted coral on these artificial reefs did not give any significant effect towards the fish's abundance. Study had shown that the percentage of life have positive relationship with reef fish species and their abundance (Bell and Glazin, 1984). Another study at natural reefs also yields the same finding where the hard coral cover on natural reef has positive relationship towards the fish's abundance (Komyakova *et al.*, 2013; Ehrenfeucht, 2014). It is concluded that type of artificial structure and its structural complexity are important factors in determining species of fish living on the artificial reefs. Since this study were caried out during the Covid-19 Pandemic, where movement control order was in place, it had limited the data collection through field works which is significant in data analysis process. More data are needed and usage of other monitoring methods such as underwater visual survey might lead to more concrete result. As of now, this study could conclude that the coral cover on coral frames did not give significant effect towards the fish abundance.

It was learned that this restoration method is an effective active reef restoration method within TSMP waters and suggested that this effort should be continued by Sabah Parks. The programme should be expanded on larger areas especially focusing on poor coral reef found around TSMP water. There are few areas within TMSP reef that was categorized into poor state based on their percentage live coral cover. Out of 12 permanent survey sites, four of them were categorized as 'poor' live coral covers (<25% coverage) (Reef Check Malaysia, 2021) in which needed to rehabilitated using this method.

More efforts were needed to maintain the coral frame as cleaning are necessary in the early stages which also need additional funding or budget to cover the cost. This will put challenges to the park management in terms of logistic, manpower and budgeting to conduct regular maintenances activities. Despite of that, regular monitoring was done by the Sabah Parks with the help of other related agencies (Semporna Island Project and Department of Fisheries Malaysia) through a dedicated team of staffs. These factors are important in ensuring the success of reef rehabilitations programmes by using artificial reefs. It is one of four important factors listed that should be address in any marine ecosystem rehabilitation programmes (Abelson *et al.*, 2020).

Wood & Ng (2014) explain that the program was participated by local communities from Selakan Island which located inside of the MPA. Such move would give opportunity for local community in contributing their parts on the reef rehabilitation efforts by Sabah Parks for their own benefits. It is also a good education tools in improving local communities' awareness towards conservation of the marine environment.

CONCLUSION

Although the study has a limited dataset, the findings suggest that engaging in active coral reef restoration and rehabilitation efforts plays a crucial role in expediting the recovery of impaired coral reefs, particularly in terms of attracting juvenile coral reef fishes. Consequently, the coral reef restoration and rehabilitation initiative by Sabah Parks through installation of coral frames at TSMP, have demonstrated anticipated positive outcomes. Lessons learned from this study include providing Park Managers the information on carrying out long-term monitoring within the artificial reefs, how to refine coral reef restoration techniques, and that the coral frames should be custom-made based on the bottom profile of the reef.

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