CORAL REEF REHABILITATION

09/01/2019 ANNUAL REPORT

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The 2018 Coral Reef Rehabilitation Program was conducted under a research permit from the Marine Parks Department of Malaysia.

The work presented here was conducted by the Coral Reef Rehabilitation Project Officer Alberto García-Baciero (Spain), with the assistance of the Sea Turtle Program and Hatchery Officer Eva Horcajo-Berná (Spain) and Leonor Aymara Luna who collaborated as Coral Reef Rehabilitation Assistant.

This program succeeded due to the collaboration of volunteers from all over the world that came to help mainly with the Sea Turtle Conservation Program but decided to get involved in many of the activities presented here.

Many thanks as well to the dive centers Scuba Doo Dive Center and Tiongman Scuba Dive Center for their continuous support through the season with rental equipment and as well as their physical effort and dedication.

We also acknowledge our sponsor´s continuous support Juara Lagoon Outward Bound, Little Planet Experiences and the United World College South East Asia (UWCSEA) from Singapore.

Ultimately, we would like to extend our gratitude to Reef Check Malaysia for their constant support and cooperation in several environmental activities such as coral reef surveys, the recycle program and their involvement engaging the local community in Tioman Island.

Coral Reef Rehabilitation

ANNUAL REPORT

INTRODUCTION

Coral reefs are biologically important ecosystems providing goods and services to marine tropical and subtropical regions (Moberg and Folke, 1999). Coral reefs are important firstly because of its biodiversity where coral reefs are usually compared to tropical rainforests due to similar high biodiversity and low nutrient surroundings. Coral reefs around the world represent only 0.25% of the world's oceans but they hold around 25% of the total marine biodiversity (Costanza et al., 1997). Moreover, the quality of local reefs has been a key source of economic growth for local people and businesses. In Peninsular Malaysia, coral reefs are distributed all around the country.

Kampung Juara is located within the marine park on the east side of Pulau Tioman on the east coast of Peninsular Malaysia. From the past 10 years there has been a significant increase in the number of tourists due the island's unique geography, beautiful beaches and rich marine environment (Omar *et al.*, 2014). The development of infrastructures in Tioman has been growing from the past few years very extensively. There are numerous buildings including jetties, a government clinic, schools, houses, resorts and even duty free shops. Significant development has been seen around the island recently that might have been due to Tioman being declared a duty free island in September 2002. ReefCheck Malaysia assessed in 2017 that the reefs around Tioman are considered to be in 'Good' condition (66.36% live coral cover), which is above the average for reefs of the Sunda Shelf region (54.21%).

Threats to coral reefs

Local unregulated tourism practices can cause physical damage to the coral through contact from careless swimmers/snorkelers/divers (Davenport *et al.*, 2001). Corals can also be damaged by higher levels of water pollution which can be caused by increased boat traffic/sewerage run off/use of sunscreen (Danovaro *et al.*, 2008).

In addition to this, coral reefs are globally under threat (Wilkinson, 2008; Jordan *et al.*, 2010; Unsworth *et al.*, 2010). Global warming is causing seawater temperatures to raise leading to 'coral bleaching' (PW Glynn, 1991) and the increased carbon dioxide in the atmosphere is causing the acidification of the ocean, which affects the coral's ability to grow their 'reef building' structures (K. R. N. Anthony *et al.*, 2008). Therefore, the threat to these fragile ecosystems is urgent and conservation efforts should be made to preserve and restore them before they degrade beyond regeneration.

CORAL REEFS AS AN IMPORTANT ECOSYSTEM

Coral reefs are some of the most diverse and valuable ecosystems on Earth. They are biologically important not only for the marine life, but for humanity.

Biological importance of coral reefs

Coral reefs are important for many different reasons aside from supposedly containing the most diverse ecosystems on the planet. They:

- Provide the oxygen we breathe. Corals are animals that form close mutualistic associations with endosymbiotic photosynthetic algae (zooxanthellae). The zooxanthellae algae, through photosynthesis, remove carbon dioxide from the air and make carbohydrates available as food for both the zooxanthellae and the coral polyps. Eventually, much of the carbon removed from the air will reside on the ocean bottom in the form of limestone produced by coral polyps.

- Provide habitats for many marine organisms. Coral reefs are very diverse structural complexes. Coral colonies grow in multiple ways in the reef allowing the marine life to occupy different ecological niches. From a lobster or an eel living in a small hole to a shark hiding in a cave or a grouper resting under a big table coral. Scientists estimate that there may be another 1 to 8 million undiscovered species of organisms living in and around reefs (Reaka-Kudla, 1997).

- Provide an important source of food and nutrients. Coral reefs support an incredible diversity of fish. Algae, soft coral, sponges and invertebrates create the base of this food chain. From small herbivorous fish to large predatory fish, all find food and protection on the reef. Alongside, reef fish is an equally diverse array of marine crustaceans, reptiles and mammals. Both from the smallest crustacean to the biggest fish or mammal depend on the reef for food. Each animal plays an important role in the reef ecosystem. Removing one species from the reef could have drastic consequences on the reef health.

- Assist in nitrogen fixing. Coral reefs are net sources of fixed nitrogen. This input of new fixed nitrogen into the reef ecosystem helps to sustain net productivity under oligotrophic conditions and to compensate for net nitrogen export from the system, for instance by currents. Recent studies revealed that corals harbor ubiquitous diverse communities of diazotrophs (i.e., nitrogen-fixing bacteria and *Archaea*) consisting of mostly heterotrophic bacteria.

Coral reefs and humans

It was estimated coral reefs provide close to US$30 billion each year in goods and services (Cesar H. *et al*, 2003). Reducing biodiversity through the extinction of species inevitably leads to the breakdown in ecosystem health and function.

- Coastlines protection from the damaging effects of wave action and tropical storms. Coral reefs break the power of the waves during storms, hurricanes, typhoons, and even tsunamis. By helping to prevent coastal erosion, flooding, and loss of property on the shore, the reefs save billions of dollars each year in terms of reduced insurance and reconstruction costs and reduced need to build costly coastal defenses - not to mention the reduced human cost of destruction and displacement.

- Income. Healthy reefs contribute to local economies through tourism and fisheries. Diving tours, fishing trips, hotels, restaurants, and other businesses based near reef systems provide millions of jobs and contribute billions of dollars all over the world. Coral reefs generate $36 billion in global tourism value per year (Spalding *et al.*, 2017). Of that $36 billion, $19 billion represents actual "on-reef" tourism like diving, snorkeling, glass-bottom boating and wildlife watching on reefs themselves. Within Southeast Asia, the potential sustainable economic value of coral reefs is substantial, as is the potential economic loss if these resources are degraded. One estimate puts the value of coral reefs at US$115,740 per hectare per year. This places Malaysia's reefs, with a cover of 4,000 sq. km, at a value of RM145 billion per year (Reef Check Malaysia, 2013). According to research conducted at Universiti Utara Malaysia, Tioman's reefs have a total economic value of RM3.4 billion per year. This is largely based on the ecosystem services that reefs provide, which includes fisheries, tourism and coastal protection.

- Source of food. Coral reefs are vital to the world's fisheries. They form the nurseries for about a quarter of the ocean's fish, and thus provide revenue for local communities as well as national and international fishing fleets. An estimated one billion people have some dependence on coral reefs for food and income from fishing. If it is properly managed, reefs can yield around 15 tonnes of fish and other seafood per square kilometer each year.

- Medicine: Reefs are home to species that contain pharmaceutical compounds that have potential for treatments for some of the world's most prevalent and dangerous illnesses and diseases.

<u>Goals and objectives</u>

At Juara Turtle Project (JTP), we recognize the need to maintain coral health, particularly in the vicinity of Juara and Tioman Island. Our goal is to help saving coral reefs around the world. The reefs are changing very fast due to climate change and local threats. For reefs to survive, the corals themselves will have to adapt to these environmental changing conditions. As we know, evolution happens in a very slow way. For corals to evolve and be adapted to these new changes will take decades, while climate change and ocean acidification are moving very fast. This is translated into corals will not be able to resist these changes in the next few decades. JTP decided to develop artificial structures to recover the health of the damaged reefs around Juara Bay. Encouraging local communities, international volunteers and students into coral reef conservation, we hope there will be a short-term respond from these stakeholders to give an opportunity to this essential ecosystem.

The objectives then are:

- To maintain and increase coral populations by expanding the coral reef habitat area near Juara.
- To promote biodiversity and increase abundance of marine fauna that uses coral reefs as a habitat. Eg. Fish, turtles, crustaceans, mollusks, etc.
- To raise awareness of the importance of coral reefs with the local community and tourists.
- To research and determinate the most suitable methodology for the coral health and the better growth species.

METHODOLOGY

The study area

Tioman Island lies between 02°48´52.1"N and 104°10´29.3"E, 32 km off the east coast of Peninsular Malaysia in the state of Pahang (Fig. 1). The land and coastal areas up to 2 nautical miles around the Tioman Island was established in 1994 as a Marine Park under the Fisheries Act (1985) to protect its biodiversity (DMPM, 2011).

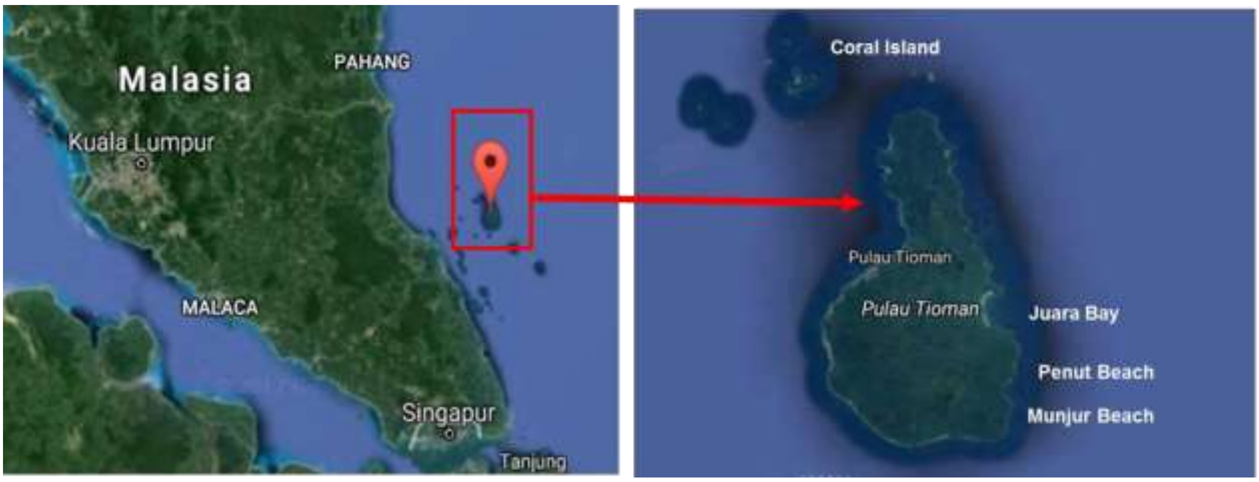

Fig. 1. Location of Tioman Island

Juara Bay is located within the marine park on the east side of Tioman. The bay is sheltered from the open ocean and so water visibility is good usually around 10m. There are 3 reefs within the bay, all with similar substrate characteristics and shape (Fig. 2).

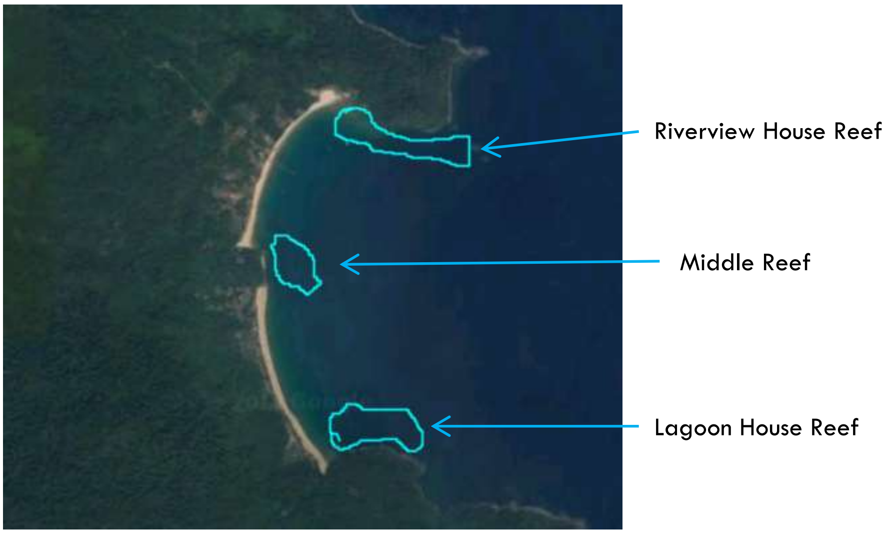

Fig. 2. Coral reefs location in Juara Bay

Despite these similarities, the Middle Reef was selected for rehabilitation due to the high presence of rubble areas (Fig. 3), meaning the reef used to be healthy few decades ago. These areas were in depths between 4 to 8 meters, which corresponded with the same depth where the fragments were collected.

Fig. 3. Zone of rubble in the Middle Reef

Targeted Species

The selected species were mainly branching corals belonged to the genus *Acropora*. *Acropora* is the most representative genus in the world with no less than 364 nominal extant species (Veron & Wallace, 1984). *Acropora* belongs to the group of Scleractinian corals, also known as stony corals or just hard corals, which are the primary reef builders in the oceans. Their polyps secrete calcium carbonate to form a skeleton. A minority of species lives as single polyps, but most stony coral species are colonial, and the structures they build 'grow' over time. They form a myriad of shapes: boulders, branches, fingers, plates, and encrustations.

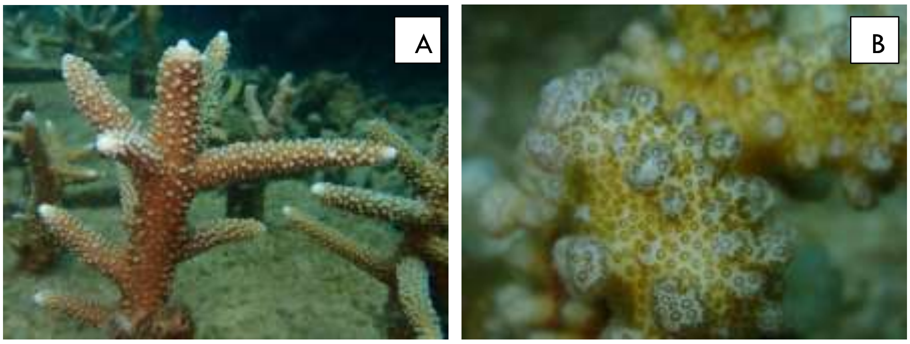

Fig. 4. Two species targeted for rehabilitation. A) *Acropora muricata*. B) *Pocillopora damicornis*

In Tioman, the genus *Acropora* has the highest average cover (Shabudin *et al.*, 2016). To increase coral diversity in the rehabilitation zones, other species from genus *Montipora*, *Pocillopora*, *Porites* or *Hydnophora* were also transplanted. Abiotic factors like water temperature, depth, salinity and currents were considered.

<u>The collection</u>

Between May and July, coral fragments were collected from the seafloor, never from a living colony, doing SCUBA or free diving. The east coast of Tioman is strongly influenced by a monsoon period from December to February. It causes multiple colonies will break down into smaller pieces. Some of these fragments will fall on natural hard substrates, like rocks, developing naturally in new colonies. However, the majority of these broken pieces will fall on sandy bottoms or non-stable substrates having no chance of survival.

The fragments had a size between 5 and 20 centimeters and they were collected in depths between 4 and 7 meters from different reefs. Buckets were used to place the fragments until their transplantation, which happened within the shortest possible time. The depth was also considered as many species get stressed with depth changes. Fragments collected from shallower reefs were transplanted on shallower structures than those fragments collect in deeper areas.

<u>The structures</u>

Two different methodologies were implemented: a non-permanent PVC nursery and a permanent `in-situ´ rehabilitation area.

PVC-tree Coral Nursery

The coral nursery is a simple framework of PVC pipe that resembles the shape of a tree (Fig. 5) (dimensions height ~3.5m, length ~2m). It is tethered to the ocean floor and buoyed with a subsurface float. The nursery floats in the water column and is able to move with storm-generated wave surges. This dissipates wave energy preventing damage to the tree structure or the corals themselves.

Fig. 5. PVC structure used as a coral nursery

It has capacity for 60 fragments distributed in different depths (2.5m; 3m; 3.5m; 4m; 4.5m; 5m) separated 20 cm each other (Fig. 6A). It was located 200 meters from the shore at a depth of 7m (+/- 1.5m tidal change) over a sandy seabed. The fragments were hanging 3-5 centimeters from the pipes using monofilament line (Fig. 6B), which let the fragments to grow easily over it.

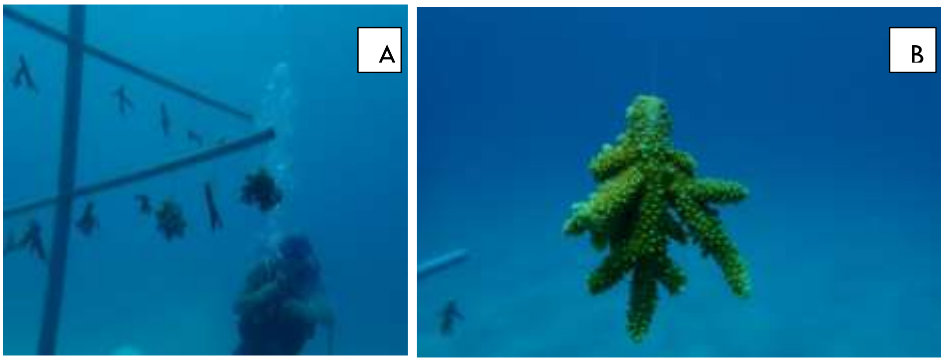

Fig. 6. A) Coral fragments arragment in the branches. B) Branching coral hanging

The advantage of constructing a mid-water nursery away from the reef and above the seabed is that it is isolated from coral predators, disease vectors and sedimentation. The nursery was in place for a period of time of 3 months. Corals take between 1 to 3 months to get fixed on the new substrate. Therefore, the fragments from the nursery had to be transplanted at least 3 months before the monsoon period.

Artificial concrete blocks

Concrete blocks were selected as the best option to rehabilitate the Middle Reef, which is the most damaged reef in the bay. The blocks weighed between 30 to 40 kilograms, being heavy enough to secure the rubble and stop any movement produced by waves or currents. The dimension of each block was 50×30×20 cm, containing 5 or 6 pieces of reinforcement bar and 2 or 3 pieces of PVC pipe (Fig. 7). The fragments were attached to the rebar using cable ties. Marine epoxy was also applied to provide more security to the fragments and to reattach the non-branching corals.

Fig. 7. Concrete block used as an artificial substrate for reef rehabilitation. Note the fragments are attached either with cable ties or epoxy putty.

The rehabilitation area was previously delimitated with a string and cleaned from living broken colonies. The blocks were made on land and transported by boat to the area. Doing SCUBA with lift bags, the blocks were sunk to the specific location.

<u>Transplantation</u>

All fragments collected were transplanted as quickly as possible on the new structures, within a period of less than 2 hours from the collection time. Fragments both from the PVC nursery and from the reef were transplanted into the concrete blocks. Cable ties or/and marine epoxy putty were used as attachment methods.

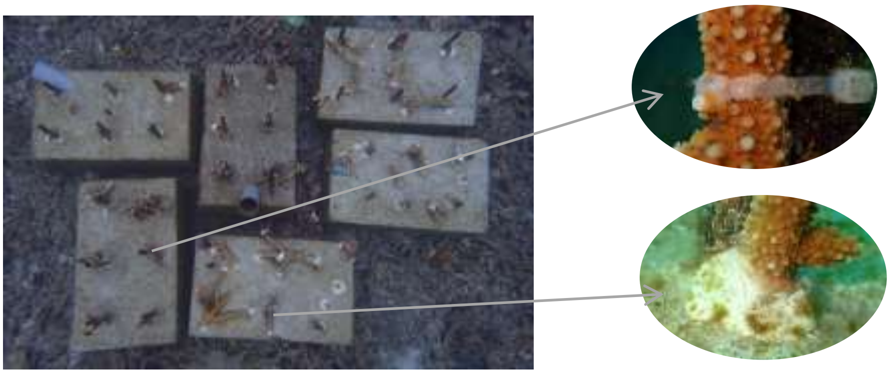

Fig. 8. A) Concrete blocks disposition over a zone of rubble. B) Fragment attached with cable tie. C) Fragment attached on the base with epoxy putty.

Doing SCUBA, JTP staff members with the help of volunteers secured between 5 to 8 coral fragments on each block (Fig. 9). Cable ties were selected as the most suitable method to attach the branching corals and the finger-like corals (*Acropora* and *Porites*). Cable ties are a type of fastener, for holding items together. Because of their low cost and ease of use, cable ties are ubiquitous, finding use in a wide range of other applications. Instead, the cauliflower and foliaceous corals (*Pocillopora* and *Montipora*) were attached using marine epoxy putty (Fig. 8). It is a substance formed by 2 components clay-like consistency. Once the components are kneaded into each other it creates an exothermic chemical reaction that activates the substance for use by catalyzing an epoxide polymerization reaction, making the substance quickly cure "hard as steel".

Fig. 9. Volunteer attaching new coral fragments in a concrete block.

Mantainance and coral growth monitoring

Several times per week, staff members, interns and volunteers were scuba dive to clean the structures and record biodiversity data. Each dive was in average 100 minutes. Toothbrushes and scourers were used to remove algae and other organisms that get fixed on the structures. The more organisms are living on the structures, the more the competence for food or for the substrate will increase. Big algae concentration decreases the coral growth and sometimes it can even stop it (JE Tanner, 1995; L McCook *et al.*, 2001).

Fig. 10. Volunteer maintening the transplanted fragments using a toothbrush.

The PVC nursery was maintained every 2 days, removing algae, barnacles and other molluscs from the pipes. About the concrete blocks, for the first 2 months blocks surface, rebar and PVC pipes were clean every 2 days. Then, they were cleaned just once or twice a week. Fish species were count within a radio of 1 meter around the blocks and within a distance of 2 meters above.

Despite the coral growth rate was not recorded, staff members used a camera (Olympus TG-5) with and underwater case to monitor the coral growth. 7 branching corals were selected and from July 1 photo was taken every 2 weeks. By the end of the season, one photo from each month was selected and they were put together for comparison.

Measuring biodiversity of ecological communities

The response of the fish community to the experimental treatments was assessed by visual census using SCUBA. Every time staff members went diving to transplant or maintain the structures, the different number of species was recorded in an underwater slide as well as the number of individuals. A diver counted the fishes within a radius of 2.5 m and up to 2 m in the water column. Fish data was taken 40 times from May to October. Video footages of the rehabilitation area were used to complement the information recorded visually. The data was recorded at the beginning of the dive to avoid the inclusion of any fish attracted by the algae removed.

Data of species abundance and diversity was recorded from the rehabilitation area. The goal was to determine if there was an increase in the number of fish species or/and individuals from each species through the season and for a better understanding of what species occupied the different ecological niches first.

Biological diversity can be quantified in many different ways. The main factors taken into account when measuring diversity are richness and evenness. Species richness (D) is the number of different species represented in an ecological community. It is simply a count of species, and it does not take into account the abundances of the species or their relative abundance distributions. Then the more species present in a sample, the 'richer' the sample. Nevertheless, there are a couple of indices that do take into account sample size:

- Menhinick´s index (D_{Mn})

$$D_{Mn} = \frac{S}{\sqrt{N}}$$

where *N* is the total number of individuals in the sample and *S* the species number.

- Margalef´s index (D_{Mg}). It is calculated as the species number (S) minus 1 divided by the logarithm of the total number of individuals (N).

$$D_{Mg} = \frac{(S-1)}{\ln N}$$

On the contrary, species diversity is a more complex measure of how many different types of taxa are present in communities. It takes into account both species richness as well as the dominance/evenness of the species. There are numerous diversity indices used in ecology to measure diversity, but we chose two:

- Simpson´s diversity index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species).

$$D = 1 - \sum_{i}^{S} \frac{n(n-1)}{N(N-1)}$$

where *n* is the number of individuals belonging to the *i* species and *N* is the total number of individuals in the sample.

- Shannon-Wiener´s index (H) is the ratio of the number of species to their importance values (e.g. biomass or productivity) within a trophic level or community.

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

where *S* is the total number of species in the sample, *i* is the total number of individuals in one species and p_i is the number of individuals of one species in relation to the number of individuals in the population (relative abundance).

Species evenness refers to how close in numbers each species in an environment is. It is a measure of biodiversity which quantifies how equal the community is numerically, and one index used to calculate it is Pielou´s evenness index (J).

$$J = \frac{H'}{H'_{Max}}$$

Where *H´* is the number derived from the Shannon diversity index and H'_{Max} is the maximum possible value of *H´* (if every species was equally likely), equal to:

$$H'_{Max} = \ln S$$

RESULTS

PVC Nursery

In April, a total of 50 branching corals were attached on the PVC nursery. On the structure, all fragments survived being successfully transplanted 4 months later on the concrete blocks.

Artificial concrete blocks

30 concrete blocks were sunk from May until August, 20 of them between May and July in an area called Zone 1, and 10 more blocks were sunk in August in another area called Zone 2. Out of 196 fragments transplanted, 176 succeeded in surviving, 117 in the Zone 1 and 59 in the Zone 2 (89.80%). The main cause of death was due to a stress response caused during the transplantation.

Table 1. Chronological diagram of the different coral rehabilitation labors

	January	February	March	April	May	June	July	August	September	October	November	December
Construction			■	■		■	■					
Sinking					■	■		■				
Fixation					■	■	■	■	■	■		
Maintenance					■	■	■	■	■	■		

The majority of these fragments were transplanted in May. A total of 89 were attached in the Zone 1 (see Fig. 11). During June and July we were focused on maintenance labors and only 12 and 14 fragments were attached respectively. 28 new fragments were attached in August of which 19 were in the Zone 2. In September the number of fragments transplanted increased to 33 mostly due to reattaching labors. The last group of fragments was transplanted in early October with a total of 20. 2 staff members, interns and volunteers spent more than 70 hours under the water, 50 of them or more just for maintenance labors.

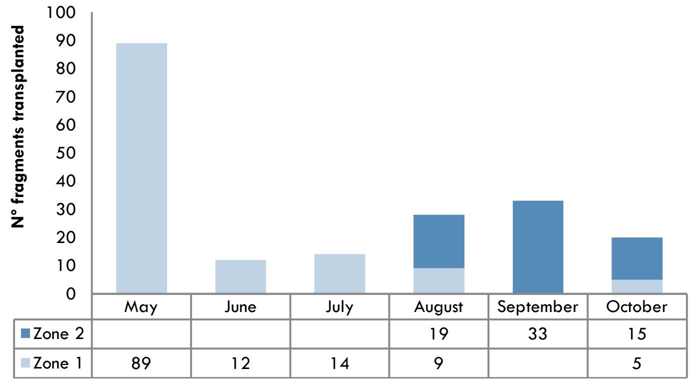

Fig. 11. Fragments transplanted on each rehabilitation zone through the season.

In terms on taxonomy, JTP worked mainly with corals from the family *Acroporidae* (81.25%). The rest were corals from the families *Poritidae* (9.09%), *Pocilloporidae* (6.82%) and *Merulinidae* (2.84%).

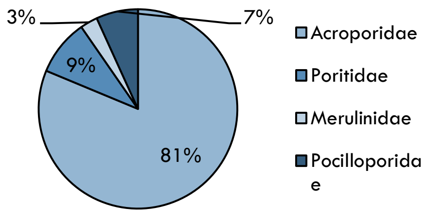

Fig. 12. Percentage of coral families used in the rehabilitation zones

More than 11 species were used to create a diverse artificial reef. Primarily, JTP worked with the species *Acropora muricata* (27.27%) and *Acropora microphthalma* (36.93%).

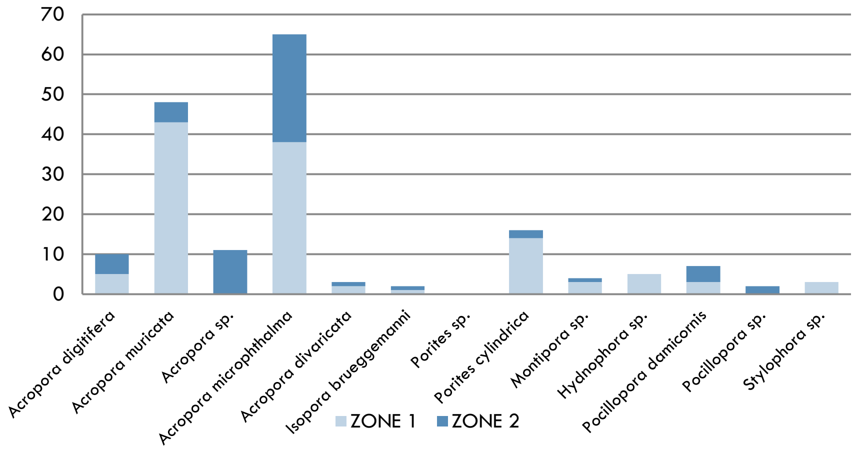

Fig. 13. Total numbers of fragments from each species used in the different rehabilitation zones.

Despite the fragments were attached using cable ties and in some cases marine epoxy putty, currents and waves can impact negatively the structures, making slower the natural coral fixation process. For that reason, JTP staff members spent extra time reattaching the loose fragments.

Although growth rates were not recorded, photo-comparison techniques were used to observe how the fragments were growing. 7 fragments were continuously monitored taking 1 photo every 2 weeks. The results were impressive, showing some significant growth in just 1 month.

Fig. 14. Morphological variation of two branching corals throuth the season.

Biodiversity data and ecological indices

During the duration of the project, a total of 29 different species belonging to 13 families and 4 classes were observed (see Table 2) in 40 sightings. 2 species could only be identified to genus level.

Table 2. Species identified in the rehabilitation zone.

Class	**Order**	**Family**	**Species**	**(n)**
Actinopterygii	Perciformes	Chaetodontidae	*Chaetodon octofasciatus*	15
		Gobiidae	*Gobiodon okinawae*	4
			Istigobius goldmanni	14
		Labridae	*Cheilinus chlorourus*	1
			Epibulus insidiator	2
			Gomphosus varius	4
			Halichoeres cosmetus	13
			Halichoeres melanochir	23
			Halichoeres melanurus	11
			Hemigymnus melapterus	2
			Stethojulis trilineata	4
			Thalassoma lunare	43
		Nemypteridae	*Scolopsis sp.*	4
		Pomacentridae	*Amblyglyphidodon curacao*	15
			Neoglyphidodon melas	2
			Neoglyphidodon nigroris	42
			Pomacentrus chrysurus	86
			Pomacentrus nigromanus	39
			Pomacentrus philippinus	13
			Pomacentrus simsiang	58
			Pomacentrus sulphureus	1
			Pomacentrus-littoralis	12
		Scaridae	*Scarus sp.*	8
		Serranidae	*Cephalopholis boenak*	52
	Tetraodontiformes	Tetraodontidae	*Arothron mappa*	1
Cephalopoda	Octopoda	Octopodidae	*Octopus cynea*	1
Gastropoda		Plakobranchidae	*Thurdilla gracillis*	2
Holothuroidea	Synallactida	Stichopodidae	*Stichopus chloronotus*	25
	Apodida	Synaptidae	*Synapta maculata*	7

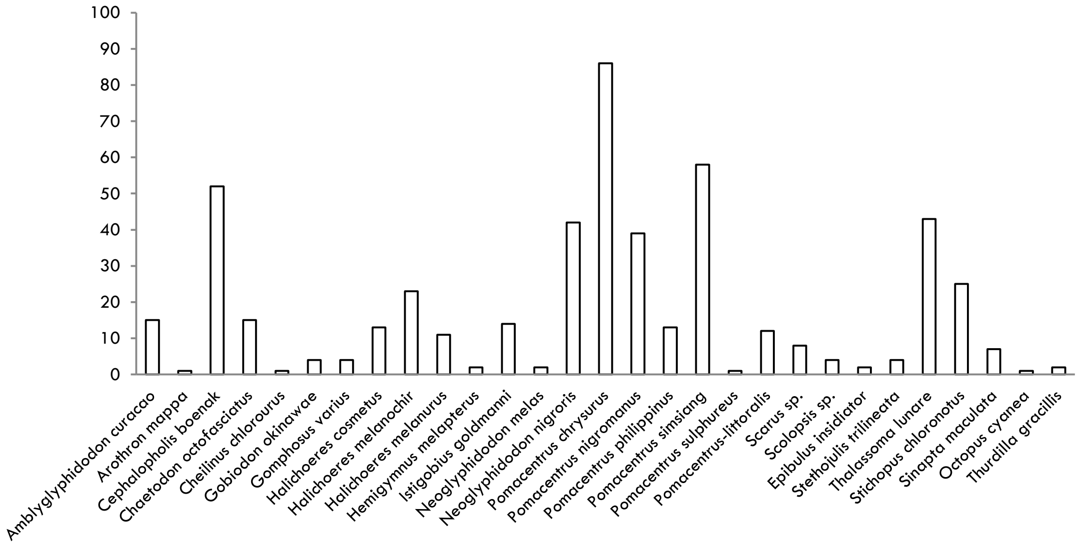

Fig. 15. Total individuals for each species observed in the rehabilitation zone.

Relative species abundance (pi) refers to how common or rare a species is in relation to the other within the community. It follows very similar patterns over a wide range of ecological communities. Most of the species observed were rare or represented by few individuals (between 1 and 9). The number of species with more than 20 individuals was significantly lower than the number of species represented by between 1 and 15-20 individuals.

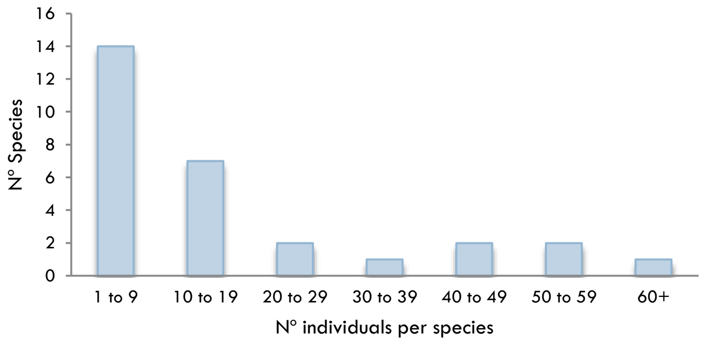

Fig. 16. Relative species abundance of the species recorded in the rehabilitation zone.

Two communities may be equally rich in species but differ in relative abundance.

Table 3. Total number of individuals for each species identifies in the rehabilitation zone and their relative abundance.

Species	Nº Individuals	Relative abundance (%)
Amblyglyphidodon curacao	15	2,98
Arothron mappa	1	0,20
Cephalopholis boenak	52	10,32
Chaetodon octofasciatus	15	2,98
Cheilinus chlorourus	1	0,20
Gobidon okinawae	4	0,79
Gomphosus varius	4	0,79
Halichoeres cosmetus	13	2,58
Halichoeres melanochir	23	4,56
Halichoeres melanurus	11	2,18

Hemigymnus melapterus	2	0,40
Istigobius goldmanni	14	2,78
Neoglyphidodon melas	2	0,40
Neoglyphidodon nigroris	42	8,33
Pomacentrus chrysurus	86	17,06
Pomacentrus nigromanus	39	7,74
Pomacentrus philippinus	13	2,58
Pomacentrus simsiang	58	11,51
Pomacentrus sulphureus	1	0,20
Pomacentrus-littoralis	12	2,38
Scarus sp.	8	1,59
Scolopsis sp.	4	0,79
Sparus insidiator	2	0,40
Stethojulis trilineata	4	0,79
Thalassoma lunare	43	8,53
Stichopus chloronotus	25	4,96
Sinapta sp	7	1,39
Octopus cyanea	1	0,20
Thurdilla gracillis	2	0,40

Class *Actinopterygii* (bony fish) was predominant with 25 species. Each species was diversely represented. Species such as *Pomacentrus chrysurus* or *Cephalopholis boenak* were highly represented, wheres species such as *Arothon mappa* or *Octopus cinea* were poorly represented (see Fig. 15). Both families Pomacentridae and Labridae were had 9 species, but *Pomacentridae* was more diverse with 311 individuals represented whereas *Labridae* had 103 individuals.

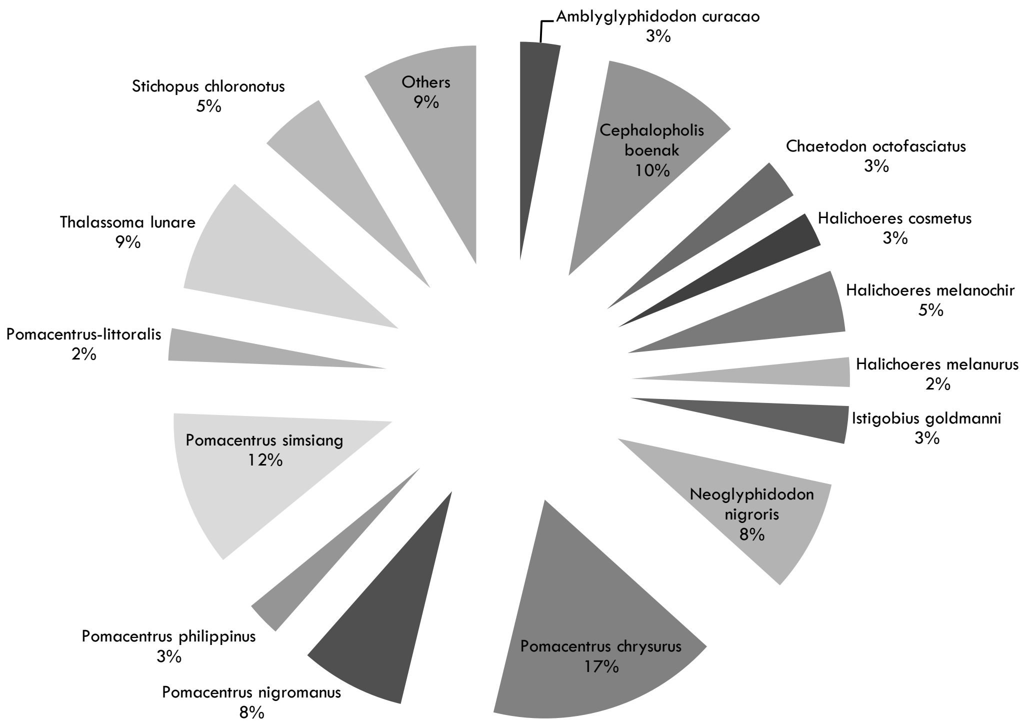

Fig. 17. Relative species abundance of Class *Actinopterygii* (bony fish).

Biological diversity indices were calculated to determine how diverse the rehabilitated area became after the transplantation (see Table). Margalef's Diversity Index (D_{Mg}) and Menhinick's Index (D_{Mn}) were calculated as representatives of species richness indices. Two species diversity indices were used: Simpson´s diversity index (D) And Shannon-Weiner Index (H). Pielou Evenness Index (J) was calculated as representative of evenness.

Table 4. The calculated indices in this report. Menhinick´s Index (D_{Mn}); Margalef´s Diversity Index (D_{Mg}); Simpson´s Diversity Index (D); Shannon-Wiener Index (H) and Pielou Evenness Index (J)

Diversity Statistics

D_{Mn}	D_{Mg}	D	H	J
1.2918	4.4997	0.9184	2.7756	0.8243

SUMMARY AND DISCUSSION

During the 2018 season, there were transplanted a total of 196 coral fragments, from which 176 succeeded in surviving (89.80%). Most of the fragments were attached on the Zone 1 (117) and the rest, 59, in the Zone 2. The 50 fragments from the PVC nursery were successfully transplanted in the Zone 1 in July, after 4 months of safe growth. 60 dives were in total devoted to rehabilitation efforts, spending more than 600 minutes between maintenance and transplantation labors.

The first dive was conducted by the end of April to delimitate the potential areas for rehabilitation. In the meantime, the PVC structure was placed under water. The most amount of fragments was transplanted in May once the sea conditions allowed us to start diving. During the first week, it was possible to attach 50 fragments on the PVC nursery and to sink 30 concrete blocks due to the good ocean condition. 89 coral fragments were attached on these concrete blocks over the following days.

The next 2 months, but especially June, were devoted to maintenance labors. 2 staff members with the help of interns and volunteers spent more than 70 hours underwater though the season. During July all fragments from the PVC nursery were transplanted in the concrete structures and during August, another group of blocks was sunk. As a result, 28 new fragments were attached, 19 of them in the Zone 2.

Both cable ties and epoxy putty succeeded as an attachment tool, but cable ties were more efficient as the fragments never got detached.

Despite a natural reef is formed by multiple species with multiple growth forms, branching corals from genus *Acropora* were selected as the main type for rehabilitation (Fig. 4A) as it has the highest average cover in Tioman. To increase coral diversity but also to provide more habitats, other species with different growth patterns were transplanted. *Porites cylindrica*, *Montipora* sp. *Acropora digitifera* or *Pocillopora damicornis* were some of them. All these species belong to the group of Scleractinian corals, which are considered the reef builders.

The succeeded fragments grew significantly though the season, especially those who belong to the family Acroporidae, as it is showed in the Fig. 14. For 2019 season new techniques will be implemented to obtain mathematically growth rate estimation.

On the other hand, biological and ecological data was recorded to measure the richness and diversity of the study areas. 40 dives were conducted in total to compile data of the different taxa that was interacting within the rehabilitation areas. The different behaviors were recorded as well as the different species and the number of individuals from each species. 29 different species were identified and most of them belonged to the Class *Actinopterygii*, with 25 different species. Within this class, family *Pomacentridae* was the most represented with 9 species and 268 individuals. This family has been described as a keystone species because of their role in the maintenance of coral and algal assemblages within their communities. As the species described feed on algae and are described as territorial (Klumpp et al., 1987), it make sense then to find this family highly represented.

Species richness and diversity indices were calculated to measure biodiversity (see Table 4). Diversity indices are used to obtain a quantitative estimate of biological variability that can be used to compare biological entities, composed of direct components, in space or in time. As it was described above, it is important to distinguish 'richness' from 'diversity'. When interpreted in ecological terms, each one of these indices corresponds to a different thing, and their values are therefore not directly comparable. Species richness quantifies the number of species in a community. The value of richness indices will increase if the number of species increases.

Simpson's Diversity Index (1-D) is used to calculate a measure of diversity, taking into account the number of species as well as its abundance. The index measures the probability that two randomly selected individuals from a sample will be the same and its value will always fall between 0 and 1, where 1 represents complete diversity and 0 represents complete uniformity. In this case, a value of D=0.9184 represents a high value of diversity, meaning the probability that two randomly selected individuals from the area will be the same is very low. The Shannon-Wiener Index (H) accounts for both abundance and evenness of the species present. It increases as both the richness and the evenness of the community increase and its value for real communities typically fall between 1.5 and 3.5. In this case, we obtained a value of H=2.7756. A greater number of species and a more even distribution both increase diversity as measured by H. We can compare the actual diversity value to the maximum possible diversity by using a measure called evenness. Pielou´s Index (J) value is constrained between 0 and 1. The less evenness in communities between the species (and the presence of a dominant species), the lower J is. In this case we had J= 0.8243, meaning the community around the rehabilitation area was quite equal.

Among the following years these indices will be used to compare biodiversity associated with the artificial structures within the rehabilitation areas or with natural reef areas, measuring if the number of species is increasing.