Sulu-Reef Prosthesis, a new method to restore a degraded reef.

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Abstract

The practice of dynamite fishing is common throughout all Southeast Asia, representing one of the main cause of reef degradation in the Philippines. In 2016 Sulubaaai Environmental Foundation established a 40 ha Marine Protected Area (MPA) on Pangatalan Island (Shark Fin Bay) and designed a Sulu-Reef Prosthesis (SRP) made out from concrete in order to restore the degraded local reef. From 2017 to date SEF has deployed more than 200 SRPs on different coral rubble patches inside the MPA. In detail, SEF located a variety of SRPs 1000 (0.37 m^2), SRPs 700 (0.28 m^2) and SRPs 450 (0.2 m^2), for a total of 178 m^2 of artificial surface available for recruitment. This new restoration technic allowed to attach more than 1600 coral fragments belonging to 15 coral genus for a total amount of 28 different species. Results shows 76.63% survivorship rate with an attachment rate higher than 70%. Growing trend (Ecological volume) of branching forms seems significative influenced by the starting size while massive and thin forms did not show any differences between size groups. This new technic has the potential to facilitate resiliency of numerous reefs within coral repartition areas, since it allows to work with different genus increasing and/or maintaining the local biodiversity.

INTRODUCTION

Coral reefs are one of the most diverse ecosystems on the planet, they cover only 0.1- 0.2% of the Earth's surface but about 35% of the described marine species rely on them (Reaka-Kudla, 2005). However, studies attest that over the past 30-50 years shallow coral reefs have been endangered by destructive fishing activities, pollution, sedimentation and changes in water temperature and chemistry (Hoegh-Guldberg et al., 2017). Destructive fishing methods are common in areas where a large human population and severe economic condition combine to promote careless activities among fishers (Saila S. B., Kocic V.Lj., 1993). Nowadays, even if considered illegal in many countries, blast-fishing still represent the main cause of reef destruction in South-East Asia (MCMANUS and JR., 2002; Raymundo et al., 2007). The main implications of this fishing method are to lead to loss of coral cover which directly causes a decrease in fish abundance and biodiversity over time. Thus, unconsolidated rubble persists, topographic complexity is lost, and recruitment, fish habitat and reef function are greatly reduced (Fox et al., 2003; Raymundo et al., 2007). One way to restore degraded coral reefs is through active restoration, including actions such as adding artificial structures (Mendoza and Henkel, 2017; Subhan, 2017), transplanting corals fragments (Raymundo et al., 2007) or developing new technics in indoor facilities and then proceed with the transplantation in field (Forsman et al., 2015; Page et al., 2018). Artificial structures might represent a good solution to bring rubble fields back to the previous coral reef state, since they act as new substrates for fish and invertebrate colonization, they stabilize rubble fields (Fox et al., 2019), decrease water motion and sedimentation (Mendoza and Henkel, 2017). The goal of this study was to test a low-cost new method that doesn't involve the use of plastic or chemicals (e.g. glues or epoxy adhesives) to create substrates suitable for fish recruitment while replanting corals in rubble fields.

METHODOLOGY

Site description:
The restoration action took place within the Pangatalan Marine Protected Area (MPA), in shark fin bay, north Palawan (Philippines). Established in 2016, the MPA covers 40 ha, included 11.3 ha of coral cover: a fringing reef surrounding the island and an isolated patch reef on the North side. The reef rises to 14 m depth and its state varies between good (coral cover > 40%) and critical (coral cover < 15%) (Fig.1). Replicate photo quadrat transect on the crest and on the slope within the MPA in 2016 bisected the healthy reef from the dead reef and revelated an unbalanced amount of coral alive (27% on the crest, and 24% on the slope) and rubble cover (44% and 58% respectively). Fish community was also characterized by video recording transects.

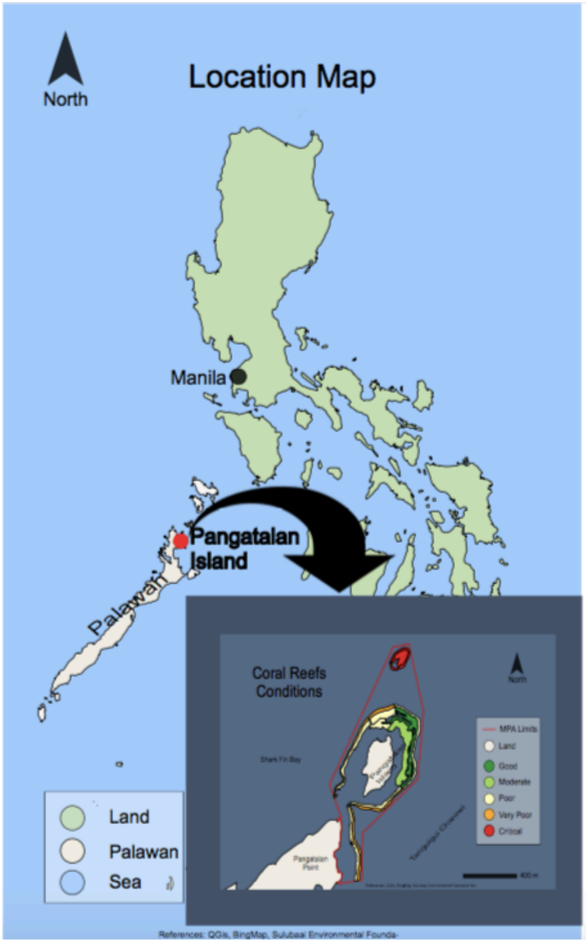

Figure 1: Pangatalan Island with coral reef condition map

Sulu-Reef Prosthesis (SRP):
SRPs have been engineered by Sulubaai Environmental Foundation (SEF) in 2016. They are made out of concrete and 3 models with different sizes have been created: SRP 1000 (0,91 m^2), SRP 700 (0,87 m^2), SRP 450 (0,73 m^2) (Fig. 2A). All the models are manufactured in 2 pieces and made in Pangatalan Island by using a durable steel molder. The assembling is made underwater and steel bars on sides and tops can allow attaching between 8 and 12 coral colonies in each SRP. This design makes possible to place the structures in different parts of the reef (flat, slop and bottom reef). It is also possible to fix a high variety of corals types, such as branching, massive and thin forms.

In 2016, a large rehabilitation project has started and SRPs have been allocated within 4 sites where coral mortality was high and structural strength was lost. Sixty coral fragments have been chosen randomly in 3 sites, for a total of 180 coral colonies, and the ecological volume has been monitored. Surveys have been conducted every month for 12 months and pictures of the tagged corals have been taken using a 30 cm stand connected to the camera, color and coral attachment have been annotated. Pictures have been processed with *ImageJ* software and length, width and high have been collected and used to calculate the ecological volume (EVI) through the following formula $EVI = h\pi r^2$ where $r = \frac{w+l}{4}$ (Frias-Torres et al., 2018). The EVI at time zero was used to build 3 classes of size: small (EVI <

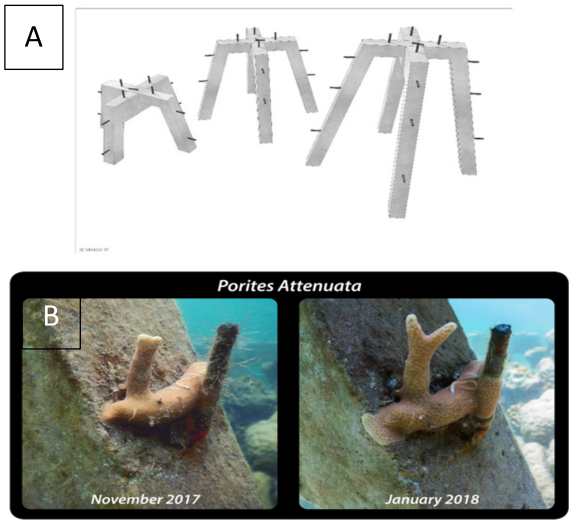

Fig. 2: A) Model of SRP 1000, SRP 700 and SRP 450. **B)** attachment of branching form to SRP and Steel bar.

21cm³), medium (EVI between 21 and 215 cm³) and Big (EVI >215 cm³). To evaluate the growth trend over time the EVI reached after 3, 6 and 12 months has been analyzed. Moreover, according to the shape of the coral colony, our data are organized in 5 different coral type groups: (1) branching (*P. cylindrica*), (2) branching-bush (*A. elseyi, Acropora striata*), (3) branching-plate (*A. loripes, A. millepora, A. granulosa and A. hyachintus*) , (4) massive (*P. lobata, F. favus, F. stelligera, F. complanata, A. ocellata, G. fascicularis, C. microphthalma and M. curta*) (5) thin (*P. speciosa, P. rugosa, P. frondifera, P. cactus, L. mycetoseroides, Montipora sp.1*)

Statistical analysis:

In order to avoid error type III, the following groups have been created : branching (branching, branching bush and branching plate), massive and thin forms. Repeated measure ANOVA was used to test difference in EVI for 3, 6 and 12 months. Variations in growth rate have been examined with 2 way-ANOVA with the interaction of the factors (size :type) on branching type, and one-way ANOVA with size as a single factor on the massive and thin form. Following hypotheses have been tested: 1) there is an ideal starting size for each coral type that has to be considered in coral restoration; 2) Pattern of growth changes in relation to size and type. All analyses were conducted in Rstudio and model diagnostics were assessed visually and by the distribution of residuals.

RESULT and DISCUSSION:

More than 200 SRPs have been located in Pangatalan's coral reef between 2017 and 2019 for a total of 1647 coral fragments within our 4 restoration sites. The positioning of SRPs create patches of artificial reef (178 m^2 of surface available for recruitment) with an estimated cost of 1050 PHP/m^2 ($20.22/$m^2$). Comparable studies regarding rehabilitation projects that require substrate stabilization range from $25.85/$m^2$ to $35-277/$m^2$ (Edwards et al., 2010; Williams et al., 2019). SRPs have been created with the idea to be suitable for different parts of the reef, with the main goal to be used for the restoration of different coral genus to maintain the local coral reef biodiversity.

Similarly to another restoration method (Williams et al., 2019), SRPs intercept coral cuttings that are unstable giving them a better chance to survive but, despite their similarity, SRPs might have better plasticity. Indeed, through this new method, SEF has been able to work with 15 coral genus varying between branching (e.g. bush, plate, digitate etc.), massive and thin forms, while most of the coral restoration studies seem to use mostly Acroporids and Pocilloporids fragments keeping a low diversity in genus but with a higher variety in species (Edwards et al., 2010; Frias-Torres et al., 2018; Williams et al., 2019).

The attaching rate within all the sites is 70.97% (Fig. 2B), with 14.32% of the fragments resulted fused to the concrete, 27.32% to the steel bar and 29.02% grown over both, steel bar and concrete.

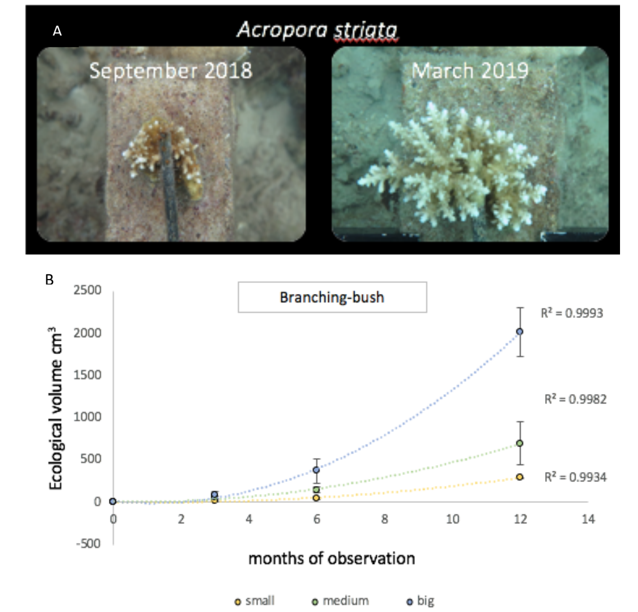

Fig. 3: A) Growth of branching-bush type (*Acropora striata*) in 6 months. B) Exponential growth of Branching bush forms which showed a significative increase (*p = 0.032*) for big fragments over time

At 3 months post-out-plantation low mortality and detachment within sites (n.3) were observed: 9.76 ± 4.73% (average ± ES). after approximately 6 months a slight increase in mortality and detachment rate of 16.3 ± 6.35 was observed, with some colonies detaching or ether dying. Cumulative survival of outplants during 1-year observation was calculated to be 76.63% ± 10.85. Overall, the survivorship obtained after 1 year, was higher compared to Williams et al. (2019) where the live coral cover was only 40 % after the first year. A lower survival rate has also been reported by Page at al.(2018) for the offshore out-plantings (18% and 40%), while high survivorship occurred for coral planted in-shore (80% and 100%) and from Villanueva et al. (2012) where only 63% of the corals survived. Probably our data on survivorship might be higher if data were considered per singular species, however we prefer to report cumulative data in order to validate the plasticity of our method. Mortality of corals seems to be related to the size of out-planting (Edwards et al., 2010), however, the lack of information in literature makes difficult to understand which is the best size in restoration activities. It is essential to investigate the existence of an ideal size for corals deployed to degraded reefs and to include it in restoration protocols to optimize outplant survivorship. Micro-fragmenting studies shown that small corals colonies (~ 1 cm^2) might have a growing rate 10 times faster than big coral colonies (~ 50 cm^2) (Forsman et al., 2015; Page et al., 2018). However, in current coral reef restoration practice, the recommended size in transplanting is 7-10 cm in diameter for branching species and 4-5 cm in diameter for massive, sub-massive and encrusting species (Edwards et al., 2010). The ideal size for out-planting of branching, massive and thin types of corals have been tested here. Repeated measure ANOVA on the growth after 3, 6 and 12 months show that the branching-bush type had significative increase over time (F = 9.105, p = 0.032) (Fig.3-4). Two-Way ANOVA with the interaction of the factors *Type*:*Size* for the growth reached after 12 months in branching group reported a high significative difference for the factor size (F=10.26, p < 0.001). A detail investigation with Tukey Post Hoch test defined this difference between Medium *Vs* Big (p = 0.004) and small *Vs* Big (p< 0.001) with the big fragments of branching-bush (EVI> 215 cm^3) having the best performance. No difference has been found between small (EVI < 21cm^3) and medium (EVI included between 21 and 215 cm^3) groups, suggesting that these two sizes have a comparable growing pattern in branching types. However, looking at the EVI graph. of branching-plates (Fig.5), it seems that medium and big

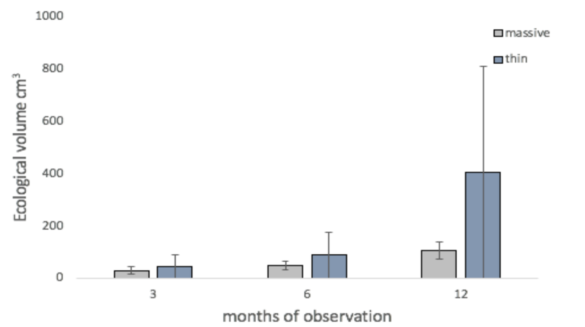

Figure 5: Ecological volume of Thin and massive form reached after 3m 6 and 12 months

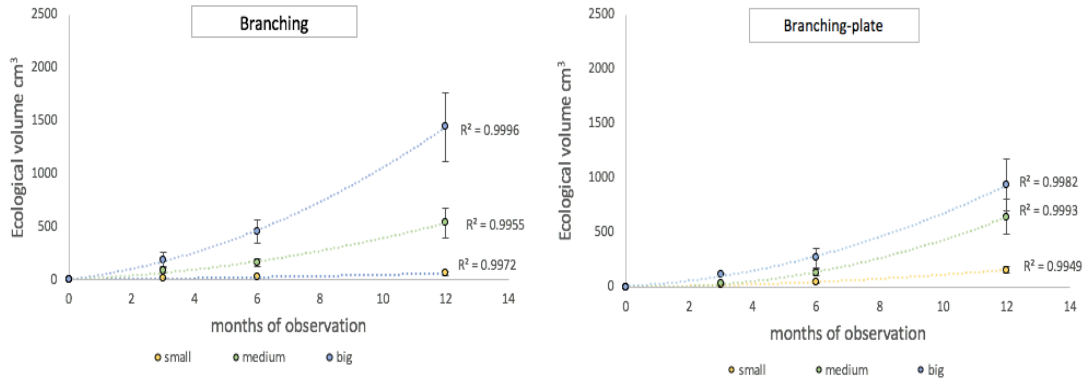

Fig. 4: Ecological volume of Branching and branching-plate forms over time. Big colonies of Branching forms showed a notable increase in size, while medium and big coral cuttings of branching-plate forms had a comparable EVI over time.

fragments have a comparable curve over time than small fragments, suggesting those as ideal starting sizes in restoration for this type. Thin and massive forms did not show any differences between EVI and size forms (F = 3.33, p = 0.07 and F = 1.64, p = 0.25 respectively) (Fig.4), suggesting that difference size grow at the same way over time. However, in this study only the EVI has been analyzed, and further analysis on the calcification and growing rate are needed to better understand the ideal size in out-planting for these two forms.

CONCLUSION

Artificial reef are considered a powerful tool in coral restoration with several benefits such as increase the habitat strength of rubble field (Raymundo et al., 2007), to offer refuge and nursery ground to young stage of reef species (Fox et al., 2003, 2019) or to increase recruitment (Subhan, 2017). However, it seems that artificial reefs are not considered a promising restoration and remediation approach by coral reef restoration ecologists looking at the poor number of publications dealing with coral reef restoration (Abelson, 2015). In this study, data on coral colonies coming from observations one year through the application of a new restoration methodology has been presented. This pilot study tested an approach to speed-up a natural recovery of a coral reef hardly damaged by blast fishing using low-cost local technology. Coherently with other authors (Edwards et al., 2010; Fox et al., 2019; Williams et al., 2019), our findings support the conclusion that a simple structure provides a stable substrate that can increase the natural resiliency and successfully restore a coral reef. Additionally, we provided information on the existence of an ideal starting size for branching, while we need more investigation on massive and thin corals. Our findings may optimize results in future coral out-planting actions trying to solve the actual lack of data in restoration protocols.

POLICY IMPLICATION OF THE STUDY

The present study, being of an exploratory nature, raises many opportunities for future approach on coral restoration, in fact, further research will be required to better shape and further elaborate our findings. SEF tested the ideal size of coral colony in out-planting activities, but more observations are necessary to understand the efficiency of this method in coral restoration.

Following our finding our future actions will be:

- To investigate changes in fish communities and coral recruitment on SRPs sites
- To use our findings to implement our dataset and to design new artificial structures
- To introduce our findings to the local communities, in order to inspire young generation to take the initiative to look after their natural resources, protecting and restoring them.

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