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Eleven years consecutively coral reef rehabilitation in Tobok Batang, Bontang

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ABSTRACT

Coral reefs in Tobok Batang, a nearby estuary of Bontang Regency, have a vital role in the threatened ecosystem due to non-environmental-friendly fishing practices and a global threat in the form of coral bleaching. In response to these conditions, PT Pupuk Kalimantan Timur initiated the Kilau Samudera Program to support damaged coral reef recovery through community-based rehabilitation by developing and maintaining artificial reef modules. The study objective was, therefore, to determine the rehabilitation efficacy in Tobok Batang, through (1) coral growth informed by colony diameter, and (2) targeted reef fishes informed by abundance and biomass. Data was collected by purposive sampling in eleven clusters of three modules: pyramid, dome, and cube. The result shows that coral had been found attached in all these eleven clusters, while the targeted fishes had been found in most clusters. Clusters deployed in 2015 and 2017 have an average colony diameter of 30 cm (SE±), the two highest among the other clusters. The highest abundance of corallivores was found in the cluster deployed in 2017 and 2020 (9 ind/100 m^2). The highest herbivore abundance also was found in the cluster deployed in 2017 and 2020 (23 ind/100 m^2), while its highest biomass was found in cluster 2020 only (40 kg/100 m^2). The highest carnivore abundance was found in cluster 2017 only, with four fish per 100 m^2 as well as the biomass in the same cluster (9kg/100 m^2). All these cluster groups have provided new habitats in shallow waters, indicating that the cluster has a good position and probably good material composition that can trigger coral juveniles to attach, settle, and grow, which also became a unique habitat for some targeted reef fish. This study showed that the location and these three modules were proven effective for rehabilitating methods in damaged coral reefs.

Introduction

Globally, coral reefs provide a home for as much as 25% of the world's marine species (Mulhall M, 2009). It delivers services to tourism, fisheries, and coastline protection. The estimation of the global economic value of coral reefs is between US$29.8 billion and $375 billion per year (Costanza *et al.*, 1997; Cesar *et al.*, 2003). Unfortunately, coral reefs continue to decline caused of overfishing, sedimentation, and pollution from anthropogenic activities (Wilkinson C, 2008). Climate change, inform of mass coral bleaching associated with increasing sea surface temperature, has exacerbated these declines. Decreasing coral reefs' quality reduces reef fish abundance and other associated biota, as coral reefs are spawning, nursing, and feeding grounds (Rizal *et al.,* 2018). Naturally, the ecosystems can repair themselves but it takes a long time or is difficult to achieve (Clark and Edwards, 1995; Octavina *et al.*, 2021). Moreover, these decreases will impact coastal communities' welfare, as about 500 million people benefit from coral reefs' ecosystem services (Doney *et al.*, 2020). Alongside management interventions, active reef rehabilitation techniques are now being used in attempts to rebuild degraded reefs in Indonesia (Razak et al. 2022).

Geographically, Tobok Batang is located at coordinates 00º08'12.10" North Latitude and

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117°33'51.08" East Longitude and is located in the nearby estuary of Bontang Regency – East Borneo. Coral reef areas in the regency are about 5,454 hectares, with more than 2,500 hectares (46%) damaged, due to non-environmental-friendly fishing practices, like blast fishing and bottom trawl nets (Nursyamsi and Hiru, 2022). In response to this decline, PT Pupuk Kalimantan Timur (PKT) initiated the Kilau Samudera Program. Kilau Samudera's acronym to "Konservasi Taman Laut dan Sarana Media Terumbu Karang." Since 2011, this initiation has supported damaged reef recovery through community-based coral reef rehabilitation and has placed 11 (eleven) clusters and 3 (three) types of modules until 2021.

The study objective was, therefore, to determine the efficacy of the coral reef rehabilitation in Tobok Batang, through (1) coral growth informed by colony diameter, and (2) targeted reef fishes informed by abundance and biomass, to promote coral reef recovery.

Materials and Methods

Location and time of study

The study was conducted on 3 – 10 August 2022 in Tobok Batang, Bontang Regency, East Borneo (Figure 1).

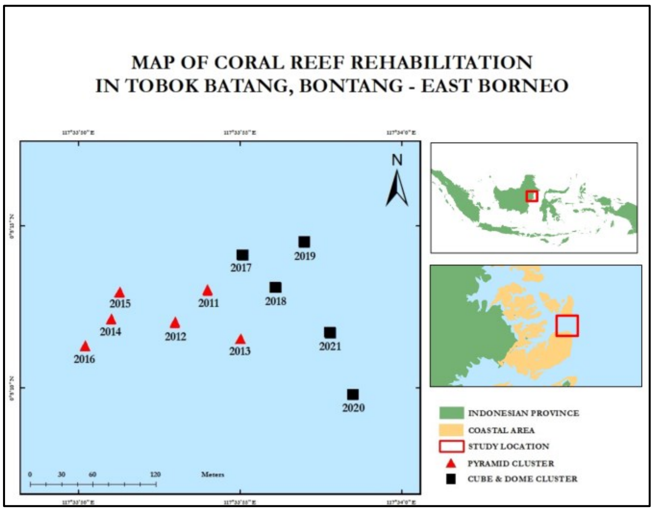

Figure 1. Tobok Batang's Reef Rehabilitation Area

Rehabilitation techniques and design

Three types of modules have been tried in eleven years consecutively reef rehabilitation in Tobok Batang, Bontang (Figure 2). The pyramid module has a polygonal base and flat triangular faces, with dimensions of length 60cm, width 60cm, and height 40 cm. The Dome module is curved, with a 40 cm diameter and height of 60 cm. While, the Cube module has a length of 60 cm, a width of 60 cm, and a height of 60 cm. These three concrete-made modules were built by Mix K-225 with a rough outer texture. Wire Mesh M6 was used for Pyramid and Dome modules, while 10mm steel reinforced for the Cube module. Pyramid and Dome were designed to have several holes to attract reef fish, as a study by Yanuar and Aunurohim (2015) that the fish's interest in the module appears to be positively correlated with the number of holes in the modules.

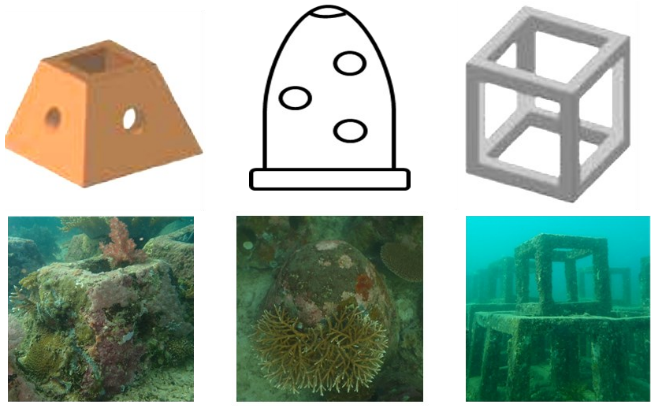

Figure 2. Perspective (above) and actual (below) modules images: pyramid (left), dome (middle), and cube (right)

Pyramid and cube modules have been arranged in groups to form large square clusters. These clusters deployed and arranged in 2011-2016 were informed of the pyramid module only. While the clusters deployed and arranged in 2017-2021 were informed of a cube with a dome module in the middle. These clusters have varying areas (Table 1).

Table 1. Estimate area (m^2) and number of modules

Year of Deployment	Est. Area (m^2)	Number of modules		
		Pyramid	Dome	Cube
2011	368	566	-	-
2012	650	1,000	-	-
2013	300	500	-	-
2014	264	500	-	-
2015	312	500	-	-
2016	240	500	-	-
2017	237	-	48	500
2018	280	-	50	500
2019	274	-	28	500
2020	280	-	5	500
2021	352	-	5	500

Data collection and identification

Data was collected in 11 (eleven) clusters of 3 (three) types of modules: pyramid, dome, and cube (Tabel 1).

Data sampling in these clusters followed purposive sampling (Luthfi *et al.*, 2017), in which each data coral sample was decided according to specific considerations. The pyramid and cube modules were haphazardly chosen on each side of large square clusters, with three (3) module samples on each side for the pyramid and one (1) module sample on each side for the cube (Figure 3). While six (6) dome modules were haphazardly chosen in each cluster (Figure 3). These are the samples of this study.

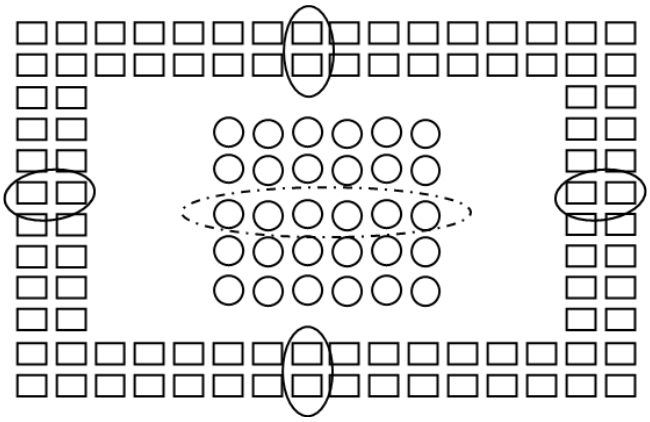

Figure 3. Layout sample of pyramid and cube (circle), and layout sample of the dome (dashed circle).

Coral colony diameter was only measured according to the colony length (cm). Only colonies that attached or settled within the targeted module were counted (Figure 3). This is the first time coral colony diameter measured in the location. Coral colony identification used a visual method regarding Kelley (2016) and Veron (2000) at the genus level.

Reef fish communities' data were collected by an underwater visual census with a modified time-swim around each cluster and measured according to total length (cm). Fish communities were grouped into three feeding groups: corallivores, herbivores, and carnivores. Reef fish identification used a method regarding Kuiter and Tonozuka (2001) and Allen *et al.* (2003) at the species level. These coral growth and reef fish were conducted by SCUBA diving technique.

Data analysis

The most common metrics of coral growth are linear and radial skeletal extension rates, measured as unidirectional changes in branch length or colony radius respectively (Pratchett *et al.*, 2015). Furthermore, to measure the average coral growth, the coral diameter was analyzed using a modified English *et al.* (1994) formulation: $\bar{x} = \sum / n$

$\bar{x}$: average colony diameter (cm)
$\sum$: sum of colonies diameter (cm)
N : total of samples

The fish communities data was presented into functional groups of corallivores, herbivores, and carnivores. The biomass measurement uses the conversion of the length-weight relationship through the equation (Froese and Pauly, 2023): $W = a \times L^b$

W : weight (gram)
L : total length (cm)
a and b : regression constants

Results

The result shows that coral had been found attached in all these eleven clusters, while the targeted fishes had been found in most of these clusters.

Coral growth in the cluster

The pyramid cluster consists of 6 cluster groups deployed from 2011 – 2016. Coral colonies in these cluster groups can grow rapidly into large colonies. The pyramid cluster deployed in 2015 grew rapidly with an average colony diameter of 30 cm (SE±6,50), the highest among these five others (Figure 4 and Figure 5). Pyramid's 2014 is the only cluster group with an average growth of less than 10 cm (SE±1,83).

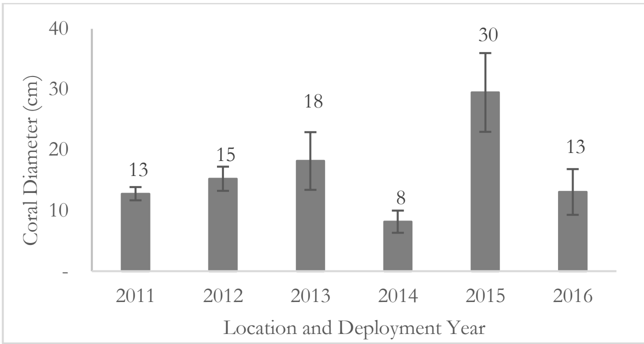

Figure 4. Coral diameter in the pyramid cluster

Figure 5. Acropora tabulate in the pyramid cluster deployed in 2015

The dome module consists of 5 groups deployed in the middle of the cube cluster in 2017 – 2021. Like

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a pyramid cluster, coral in this cluster group can grow rapidly into large colonies. The cluster deployed in 2017 grew rapidly with a coral colony average of 30,01 cm (SE±3,16), the highest among these five others (Figure 6). These results indicated that the cluster group deployed in 2017 has a good position and probably good material composition that can trigger coral juveniles to attach and settle.

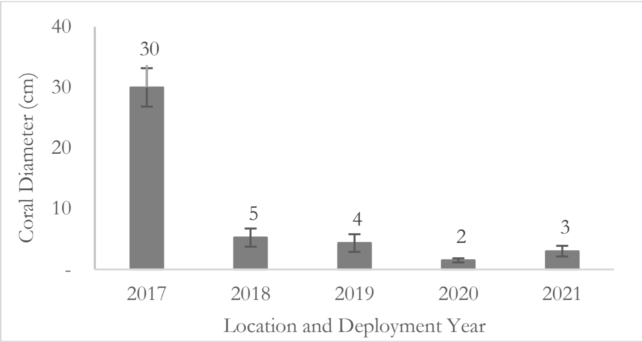

Figure 6. Coral diameter in the dome cluster

Figure 7. Acropora in the dome deployed in 2017

The cube cluster consists of 5 cluster groups deployed in 2017 – 2021. Coral colonies in these cluster groups can grow rapidly into large colonies. The cluster deployed in 2017 grew rapidly with a coral colony average of 14,45 cm (SE±1,07), the highest among these five others (Figure 8). These results indicated that the cluster deployed in 2017 has a good position and probably a good material composition that can trigger coral juveniles to attach and settle.

Based on observations in 11 cluster groups, the highest abundance of corallivore fishes was found in the cube cluster deployed in 2017 and 2020, with 11 and 9 individuals per 100 m^2. Figure 9 shows that the cluster group deployed in 2017 – 2021 has more corallivore fish abundance than those deployed in 2011 – 2016.

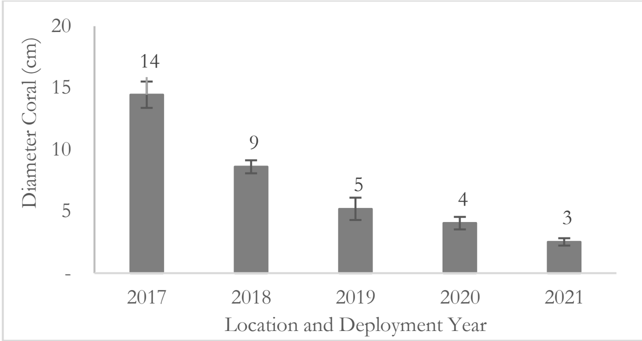

Figure 8. Coral diameter in the cube cluster

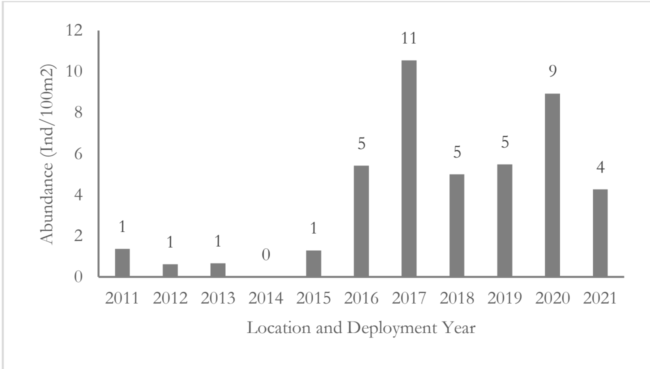

Figure 9. The corallivore abundance

Herbivore fish abundance was found in the range of 3 – 23 individuals per 100 m^2, with the highest abundance found in the cluster deployed in 2017 and 2020 (23 individuals). The highest biomass was found in the cluster deployed in 2020 (40kg/100 m^2) (Figure 10).

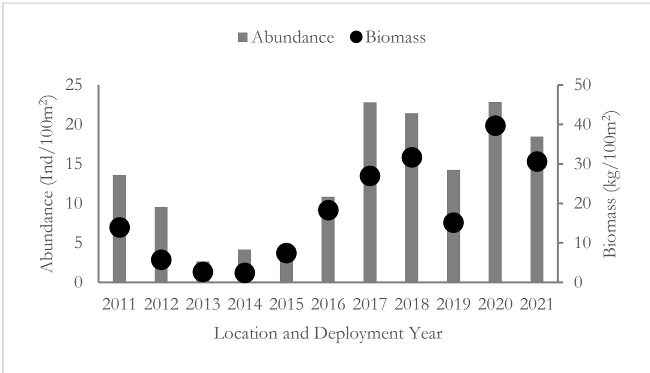

Figure 10. The herbivore abundance and biomass

Carnivore fish's highest abundance was found in 2017 (4 individuals per 100 m^2), as same as the highest biomass; 9 kg per 100 m^2 (Figure 11).

Discussion

The pyramids, dome, and cube clusters became benthic substrates for coral settlement. Clusters deployed in 2015 and 2017 have an average colony diameter of 30 cm (SE±), the two highest among the other clusters. These results indicated that the cluster deployed in 2015 and 2017 has a good position and probably good material composition that can trigger planula to attach and settle.

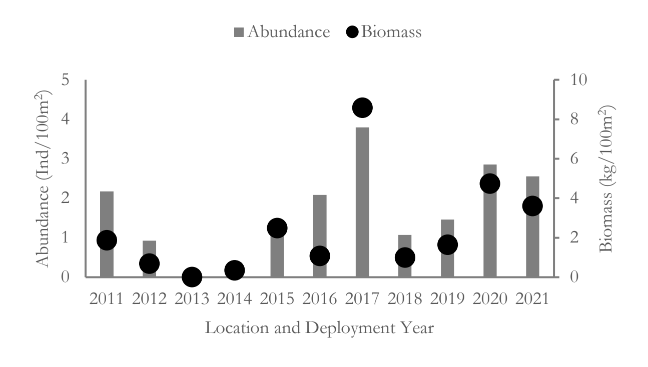

Figure 11. The carnivore's abundance and biomass

The 2016 mass coral bleaching in Indonesia indicated impacting the coral reef in Tobok Batang. NOAA Coral Reef Watch shows that the degree heating weeks on East Kalimantan in May – June 2016 was about 8 – 11 ˚C, potentially killing the corals (Liu, 2017; Wouthuyzen *et al.,* 2017). This condition is thought to be one of the causes of the low level of the lower pyramid cluster in 2011 - 2016, except in 2015. Regardless of a local human impact, considering that all clusters are in the same area and close to each other (Figure 1). Since mass coral bleaching, the 2017 cluster: dome and cube, has a significantly higher average diameter than the 2018 – 2021 clusters. With the absence of global threats, the composition of the 2017 cluster was interesting. Coral can grow an average diameter of 30,01 cm (SE±3,16).

Unlike other methods of artificial reefs, like tires, the concrete form of these 11 clusters is an excellent, environmentally friendly material. Its texture and chemical composition indicate that it is suitable for coral and reef fish recruitment or the process in which coral juveniles attach themselves to a solid substrate and begin to grow (Fitzhardinge and Bailey-Brock, 1989). Considering the statement regarding concrete texture and chemical composition, it is potentially interesting to recall and formalize the concrete arrangement of the cluster 2015 and 2017, with higher coral growth (Figure 6, Figure 7, and Figure 8).

These clusters of artificial reefs can significantly impact increasing coral cover, fish abundance, and species richness (Puspasari *et al.,* 2020). Reeffish also uses coral growth forms for protection from predators. All these clusters provide a space for reef fish, as shown by the abundance of reef fish in all clusters. The difference in fish abundance in all clusters in Figure 9, Figure 10, and Figure 11 was caused by the presence of coral attached, in line with Nybakken (1992) stating that fish play an essential role in the flow of energy and maintain the stability of the ecosystem.

The fish population or abundance is highly responsive to changes in fisheries pressures or management interventions (Micheli *et al.,* 2004). Tobok Batang's management and surveillance should be a priority to increase the fish population. Razak et al. (2022) state that these rehabilitation efforts have to be implemented alongside efforts to mitigate local threats to reefs and targeted at bypassing barriers to natural recovery (such as rubble or reduced recruitment) until the system reaches a point where the coral reef can recover naturally. Moreover, McClanahan and Jadot (2017) state that the relationship between fish biomass and human influences, including environmental characteristics, is less, but abundance strongly correlates with biomass.

Blast fishing activities are still found within the Bontang Waters (POLDA KALTIM, 2023). Management and surveillance must be implemented primarily to reduce the impacts of blast fishing. Blast fishing produces a field of rubble. This rubble movement was shown to be detrimental to small scleractinia, especially in high-current areas (Fox *et al.,* 2003).

Moreover, public awareness is a continuous process. The awareness activities usually follow a non-formal approach, in small groups or one-on-one contact, focusing on resource management and methods (White and Vogt, 2000). To ensure long-term coral conservation projects, the project must conduct training, workshops, and other public education activities on marine and coral reef ecology and sanctuary concepts as part of the public education process.

Conclusion

All these modules in clusters were proven effective for rehabilitation methods in Tobok Batang. All modules have provided new habitats for coral growth in shallow waters, as indicated by coral colony diameter. These cluster groups also become a unique habitat for some important reef fish. As long as coral and reef fish larvae abundance is high and water quality is good, Tobok Batang would be a good area for ecosystem recovery. Besides good areas for rehabilitation, Tobok Batang is potentially becoming a sustainable utilization area, such as reef-based marine tourism, education center, or even fishing grounds for some local anglers, following the marine zone.

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