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Examining the effectiveness of bored pile coral for coral rehabilitation

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Abstract. *Putri NP, Muharam MR, Ritonga A, Ruswanti CD, Arthen D, Munasik. 2024. Examining the effectiveness of bored pile coral for coral rehabilitation. Biodiversitas 25: 153-161.* Semut Island is located in Kiabu Village, Anambas Islands, Riau, Indonesia, and has suffered significant damage to its coral cover due to blast fishing. To address this issue, Anambas Foundation initiated a coral reef rehabilitation on Semut Island using a customized artificial reef called Bored Pile Coral (BPC), a cylindrical structure made of concrete hammered into the seabed. This research aims to examine the effectiveness of BPC by monitoring its performance. Therefore, from February 2022 to January 2023, 1,500 BPCs were deployed and attached with corals covering an area of 170 m^2. We quantified five ecological indicators, i.e., coral cover, survival rate, recruitment, growth rates, and fish biomass. Results showed an increase in coral cover from 3.8% to 8%. The survival rate was 64%, and the mean monthly growth rates varied among three genera: *Pocillopora* sp. (0.235±0.02 $month^{-1}$), *Acropora* sp. (0.22±0.03 $month^{-1}$) and *Porites* sp. (0.08±0.02 $month^{-1}$). The monthly mean fish biomass data showed the biomass was 427,25 Kg/Ha and increased 3,9 times since the beginning of the research. BPC's structure has been proven to act as stable media for hard corals, although the modification may be necessary to enhance structural complexity and suitability for carnivorous fish habitats.

Keywords: Anambas, artificial reef, coral rehabilitation

Abbreviations: BPC: Bored Pile Coral

INTRODUCTION

Coral reef conditions have suffered due to the factors associated with global warming (ocean acidification, sea level rise, thermal stress). Other stressors, such as human activities and destructive fishing practices, also affect coral reefs (Halpern et al. 2015). In Indonesia, it is estimated that anthropogenic impacts threaten more than 85% of coral reefs (Baum et al. 2015; Lizcano-Sandoval et al. 2018). Anambas Islands is an archipelago in Riau located in the South China Sea, between East Malaysia and West Kalimantan, Indonesia. Most coral decline in Anambas Islands is caused by unsustainable fishing, resulting in reduced productivity of coral reefs and biological diversity. Coral reef conditions in the Anambas Islands are generally moderate, with an average hardcover coverage of 47% and only 5% classified as being in good condition (Harahap et al. 2014). The local community heavily relies on these coral reefs for food security and livelihood. However, the degradation of the reefs poses a significant threat as it can diminish their value in terms of socio-economic benefits, shoreline protection, and other important aspects (Bayraktarov et al. 2020). Therefore, to address this issue, numerous coral reef rehabilitation projects have been developed to enhance recovery and restore heavily degraded reef systems to their natural state by using sexual reproduction (releasing fertilized coral larvae) and asexual reproduction (coral fragmentation; coral gardening; coral tree) (Boström-Einarsson et al. 2020; Duarte et al. 2020).

Active intervention is needed in areas with low awareness of marine environmental threats and conservation efforts, where natural recovery is insignificant and insufficient (Perry et al. 2015; Morais and Bellwood 2018). Coral reef rehabilitation uses artificial reefs to imitate the natural reef's characteristics, acting as coral substrates utilizing concrete in dome shapes (Ng et al. 2016). The structure will also create approximately similar ecological functions for reef fishes by providing critical habitat that will increase the abundance and diversity of coral fishes and other associated fauna (Kittinger et al. 2013; Folpp et al. 2020; Hammond et al. 2020).

The coral rehabilitation experiments and artificial structures have been deployed in many countries. They are effective at growing corals but hardly ever carried out on long-term monitoring extensively. For instance, the recovery data of the coral colonies, diversity and abundance of reef fish and invertebrate populations remains insufficiently tested despite its crucial role in the coral reef ecosystems that would improve the prospects of long-term ecosystem stability (Sato et al. 2020; Lamont et al. 2021). Coral fragmentation is the most commonly used in coral rehabilitation by directly out-planting coral fragments from the donor site to the rehabilitation site. Coral fragmentation has many advantages, such as being inexpensive, providing large amounts of corals within short periods, allowing the corals to grow faster, not requiring advanced expertise or technology, and highly public engagement because volunteers can easily take part in the process (Horoszowski-Fridman et al. 2015; Papke et al. 2021).

Bored Pile Coral (BPC) is a customized artificial reef using a coral fragmentation method to assist in the replacement of ecological and function of the degraded habitat. The BPCs will provide additional natural substrates for corals to settle on and enhance the habitat complexity (Paxton et al. 2020). This research aims to examine the structure of BPCs, the impact on coral cover, survival rates, growth rates, and changes in fish populations over 11 months on Semut Island. The study also aims to assess the effectiveness of BPCs in coral reef rehabilitation and provide valuable insights for future coral rehabilitation projects.

MATERIAL AND METHODS

Study area

This research was conducted on Semut Island, located at 106.247389° E longitude, 2.719039° N latitude, and five miles off west Kiabu Island, Anambas Islands, Indonesia (Figure 1). This research was carried out for 11 months, from February 2022 to January 2023. Semut Island was chosen as the rehabilitation site based on several criteria: water quality, herbivore fish, sedimentation rate, algae level, temperature, and salinity, which were suitable for coral reef rehabilitation. Semut Island is mostly covered with rubbles and rocks, and the reef ecosystem is approximately nine hectares wide. The coral rehabilitation site was chosen for a 170 m^2 section of the degraded reef; adjacent to this site, corals naturally grow very well at 1-3 m depth. Based on environmental similarities, Kiabu Island was chosen as the donor site for the fragments. Therefore, 20 pilot designs of BPCs were deployed in four different areas covering four wind directions (Gembili, Catok, Pinang Bay, and Telang) around Kiabu Island to test the performance and stability over time in January 2022.

Design and construction of the bored pile coral

BPC is a structure made of concrete with a cylinder shape that is 15 cm in height and 15 cm in diameter; the weight is about 2 kg, consisting of 25 cm steel rebar with 12 mm in diameter was placed at the center of the concrete (Figure 2). The BPCs were then hammered into the seabed at the depths of 3-6 m at the distance between each BPC was 50-100 cm. The BPC structure was placed into the seabed by divers using a hammer. Coral fragments were then immediately attached with marine epoxy after BPC installation.

Data analysis

Coral cover

Coral cover percentage was performed with a UPT (Underwater Photo Transect) from February 2022 to January 2023 by installing a 50 m belt transect parallel to the coastline, and the digital images were then analyzed with Coral Point Count with Excel extensions (CPCE) (English et al. 1994). Additionally, coral cover was assessed at a control site located 50 meters from the rehabilitation site, and the data was taken annually during reef health monitoring in March 2021, March 2022, and March 2023.

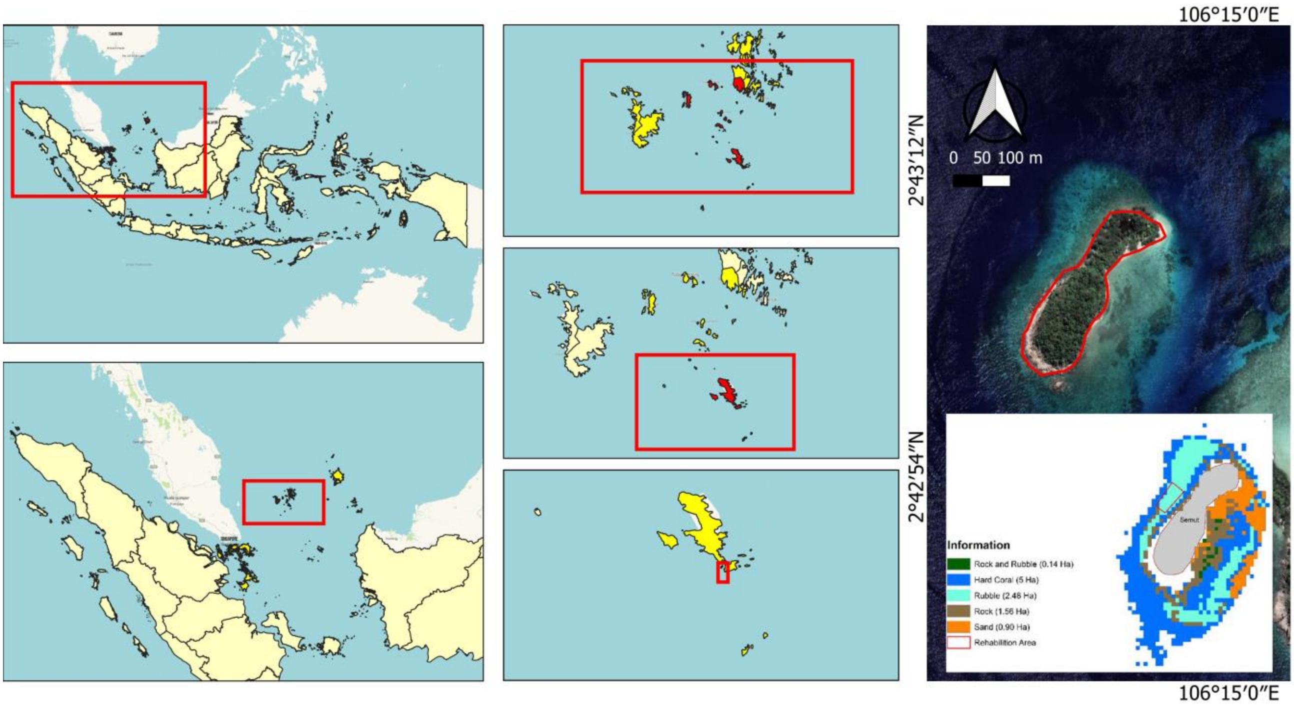

Figure 1. Map of Semut Island of Anambas Islands District, Indonesia and distribution of benthic data

Figure 2. Construction of bored pile coral

Coral growth

Three different coral genera were chosen (*Acropora* sp., *Pocillopora* sp., and *Porites* sp.) and then tagged with a specific code for growth rate monitoring. Three fragments for monitoring represented each genus; therefore, nine were chosen as samples. According to Octavina et al. (2021), the formula for calculating coral growth is:

$$\beta = Lt - L0$$

Where:

β : Growth rate (cm/month)
Lt : Coral colony size at time -T
L0 : Coral colony size at time T0

Survival rate

Survival rate was examined monthly in 200 BPCs along the 50 m permanent belt transect. Ten fragments from each genus (*Acropora* sp., *Pocillopora* sp., and *Porites* sp.) were randomly chosen to monitor its survival. Survival rate measured by calculating the number of survivors divided by total transplanted corals and multiplied by 100% (Mahmoud et al. 2019).

$$S = \frac{(Nt)}{N0} \times 100\%$$

Where:

SR : Survival rate of hard corals (%)
Nt : Number of transplanted corals at a certain time
N0 : Number of transplanted corals at the beginning of the research

Coral recruitment

Coral recruitments were measured and identified up to the genus level.

Reef fish analysis

Reef fish monitoring was analyzed according to the National Research and Innovation Regency (BRIN), Indonesian standard protocol with a belt transect of 70 m in length and 5 m in width, with the total observed areas being 350 m (English et al. 1994). The observer dived along the transect during daylight hours from 9:00 AM to 15:00 PM to avoid the temporal variability in fish assemblages throughout the day. All fish individuals were counted and identified up to the lowest taxonomic level (species), while the unidentified fish were labeled with special codes for later identification. All fish species were then identified using "Reef Fish Identification - Tropical Pacific" book by Gerrard Allen (Allen et al. 2003) and "Pictorial Guide to Indonesian Reef Fish " book by Kuiter and Tonozuka (Kuiter and Tonozuka 2004). Surveys included separate counts of Surgeonfish (Acanthuridae), Butterflyfish (Chaetodontidae), Grunts (Haemulidae), Parrotfish (Scaridae), Sea Basses (Serranidae), Snappers (Lutjanidae), Emperors (Lethrinidae), Rabbitfish (Siganidae). The total number of fish observed along the belt transect was multiplied by the average size of fish to determine the fish biomass. Bio Fish, a reef-fish biomass analyst application, analyzed the fish biomass data. Fish biomass was also taken at the control site annually during reef health monitoring in March 2021, 2022 and 2023.

RESULTS AND DISCUSSION

Genus diversity

This project has successfully planted 1,500 fragments from 10 genera onto 1,500 BPCs from March until May 2022 (Figure 3). Most of the fragments were predominated by the genus *Acropora* sp. and *Pocillopora* sp. Broad variations of genera were also attached to maintain the diversity, such as *Porites* sp., *Pachyseris* sp., *Anacropora* sp., *Galaxea* sp., *Goniopora* sp., *Lobophyllia* sp., *Montipora* sp., *Astreopora* sp., *Favites* sp. *and Favia* sp.

Coral cover and survivorship

Coral cover examination using the UPT method increased from 3.8% in February 2022 to 8% in January 2023 (Figure 4). In addition, the rubble percentage in February 2022 was 78%. In January 2023, the value declined to 60.1%. The overall survivorship percentage for 200 BPCs was 64% monitored monthly. From June 2022 to October 2022, 164 fragments (82%) survived. Then, the survival rates declined drastically, leaving only 128 fragments with a percentage of 64% in January 2023 (Figure 5). During the west monsoon season, many fragments were detached through natural processes such as typhoons and wave exposure, while the surviving corals showed an outstanding recovery.

Growth rates

The mean monthly growth rates varied between three genera in which *Pocillopora* sp. (0.235±0.02 $month^{-1}$) had the highest growth rate compared to *Acropora* sp. (0.22±0.03 $month^{-1}$) and *Porites* sp. (0.08±0.02 $month^{-1}$) (Table 1) (Figure 6).

Recruitment

Results showed that only 15 coral recruits of *Porites* sp. grew on 200 BPCs until January 2023 (Figure 7). The recruitment ranges from 3 mm to 8.5 cm. Moreover, we discovered a sea urchin and giant clam who lived and took shelter in the BPC pilot unit we deployed in Gembili.

Table 1. Growth rates (cm month^{-1}) of the three genera over six months of monitoring

Time	*Pocillopora* sp.			*Acropora* sp.			*Porites* sp.		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Jul-22	2.4	2	2.5	2.1	2.2	3.7	3	0.8	1.5
Aug-22	2.9	2.4	2.9	2.5	2.4	3.9	3.2	0.9	1.5
Sep-22	3.2	2.8	3.1	2.8	2.7	4.2	3.2	1	1.6
Oct-22	3.5	3	3.4	3	2.8	4.5	3.3	1.1	1.7
Nov-22	3.7	3.1	3.5	3.2	3	4.7	3.4	1.1	1.8
Dec-23	3.8	3.3	3.6	3.3	3.1	4.9	3.6	1.2	1.8
Mean±SD	0.225±0.130	0.26±0.134	0.22±0.130	0.24±0.114	0.18±0.07	0.24±0.054	0.1±0.1	0.1±0.07	0.06±0.054
Mean±SD		0.235±0.02			0.22±0.03			0.08±0.02	

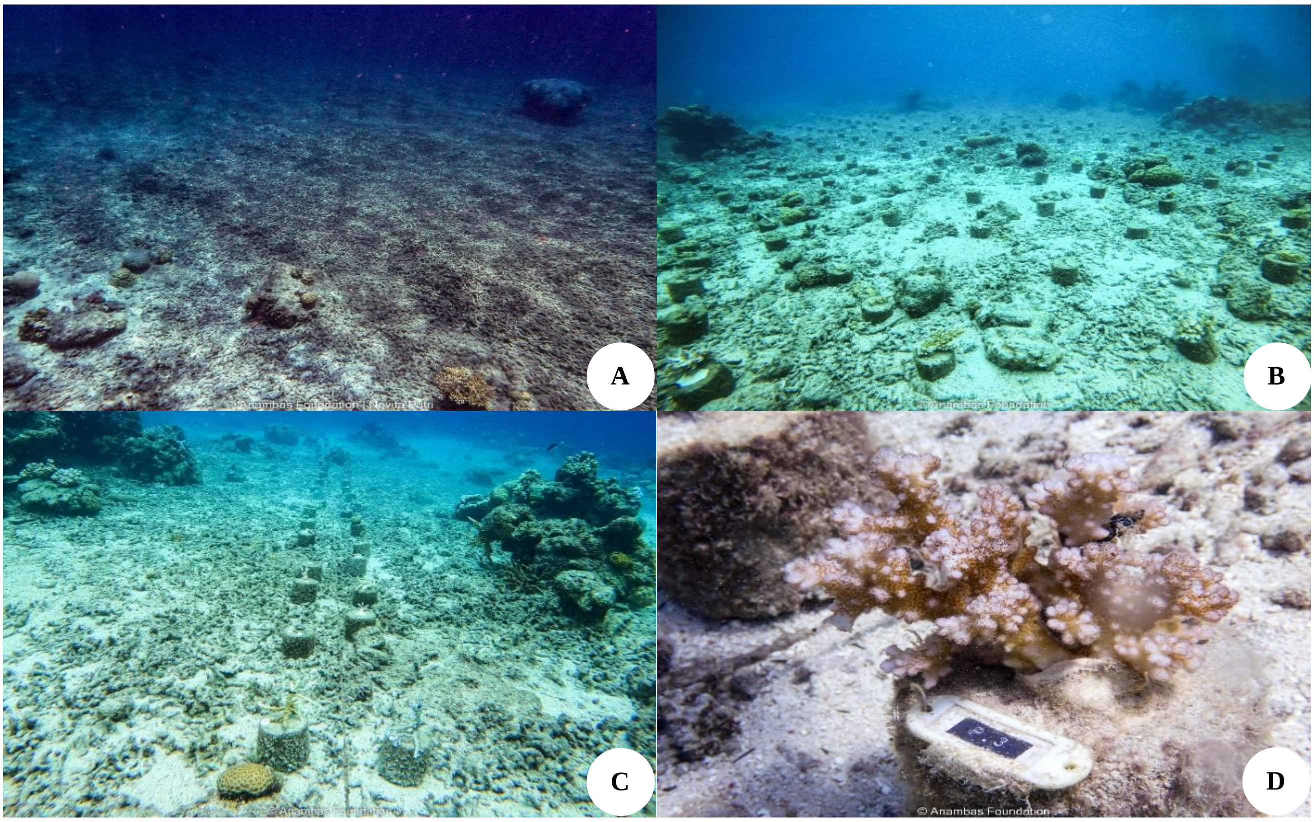

Figure 3. A. Coral reef condition in degraded area before BPC deployment, B. Coral reef condition in degraded area after BPC deployment, C. Research area along 50 m belt transect, D. BPC tag for growth rate monitoring

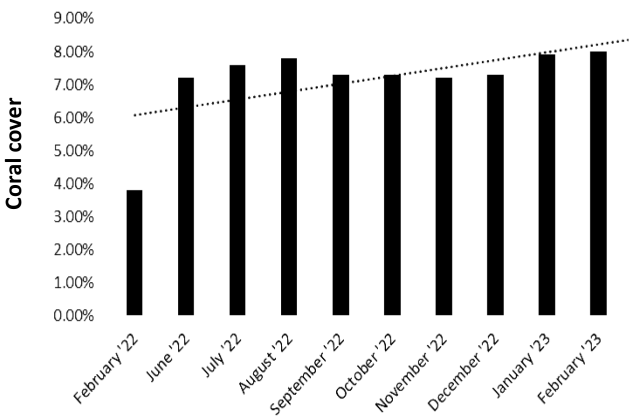

Figure 4. Coral cover percentage from February 2022 to February 2023

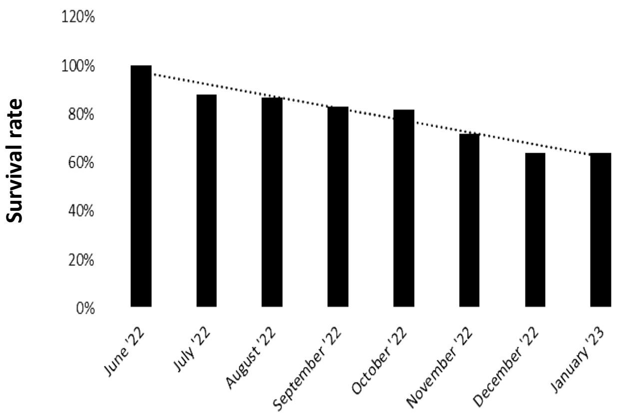

Figure 5. Survival rate percentage from June 2022 to February 2023

Fish biomass and diversity

A total of 26 fish species from 7 families were found on this site. Fish biomass data showed the number of biomass (kg/ha) in February 2022, June 2022, September 2022, and January 2023 were 146 kg/ha, 485 kg/ha, 502 kg/ha, and 576 kg/ha, respectively. Figure 8 shows that the fish biomass significantly increased about 3.9 times from the first installment. From Table 2, fish biomass from each family showed that family Scaridae had the highest biomass from other family.

Control site

According to our annual reef health monitoring in the control site (Table 3), the fish biomass in March 2021, 2022 and March 2023 measured 158 kg/ha, 146 kg/ha and 237 kg/ha, respectively. While coral cover percentage in March 2021, 2022 and March 2023 was 18.1%, 18.6% and 19.8%.

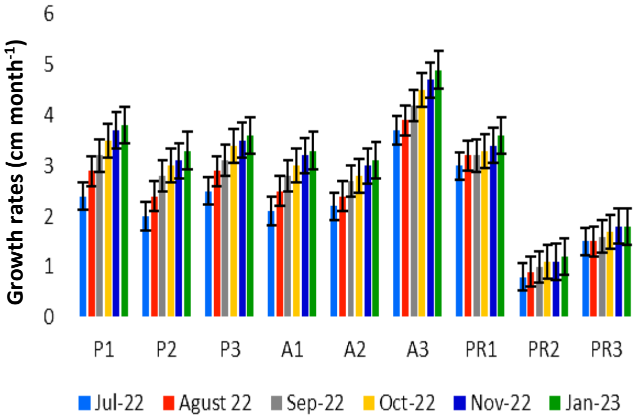

Figure 6. Growth rates (cm month^{-1}) of the three different genera over six months of monitoring (P: *Pocillopora* sp.; A: *Acropora* sp.; PR: *Porites* sp.). The error bars are the Standard Error (SE)

Table 2. Fish Biomass from February 2022 to February January 2023

No	Family	Feb-22	Jun-22	Sep-22	Jan-23	Mean biomass (kg/350 m²)	Mean biomass (kg/Ha)
1	Acanthuridae					0.00	0.0
2	Haemulidae	0.52		0.26	0.87	0.41	11.9
3	Lethrinidae		0.37	0.65		0.26	7.3
4	Lutjanidae	0.33	1.52	1.36	1.17	1.09	31.2
5	Scaridae	4.25	14.10	11.68	15.55	11.39	325.5
6	Serranidae	0.03		0.54	0.54	0.28	7.9
7	Siganidae		1.00	3.09	2.04	1.53	43.7
Biomass (Kg/350 m²)		5	17	18	20	15	
Herbivore Biomass (kg/ha)		121	432	422	502	13	369
Carnivore Biomass (kg/ha)		25	54	80	74	2	58
Biomass (kg/ha)		146	486	502	576		428

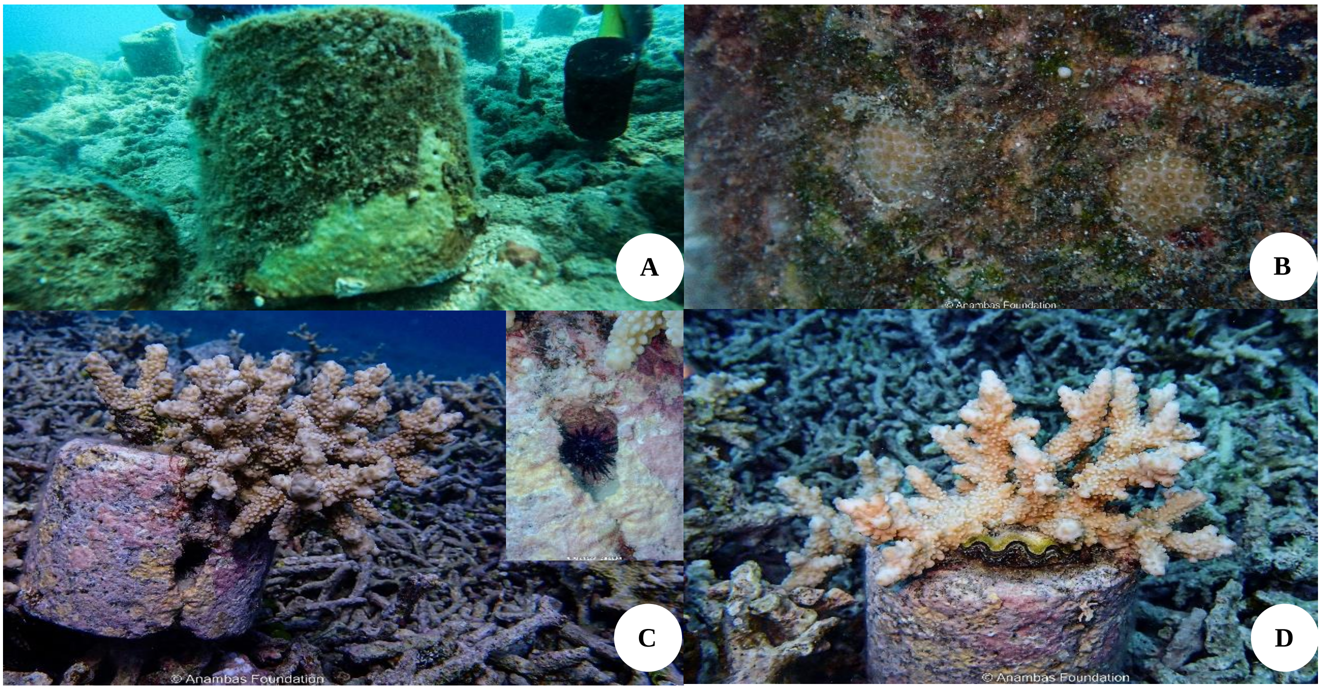

Figure 7. Coral recruits and megabenthos found in BPC: A. Coral recruit of the genus *Porites* sp. attached on the BPC in Semut Island, Indonesia (7 cm x 8.5 cm); B. Coral recruit of genus porites attached on the BPC in Semut Island, Indonesia (3 mm to 5 mm); C. Sea urchin hiding inside the BPC in Gembili Island, Indonesia; D. Giant clam settling on the BPC in Gembili Island, Indonesia

Table 3. Coral cover percentage and fish biomass at control site

Month	Coral Cover (%)	Fish Biomass (Kg/ha)
March 2021	18.1	158
March 2022	18.6	146
March 2023	19.8	237

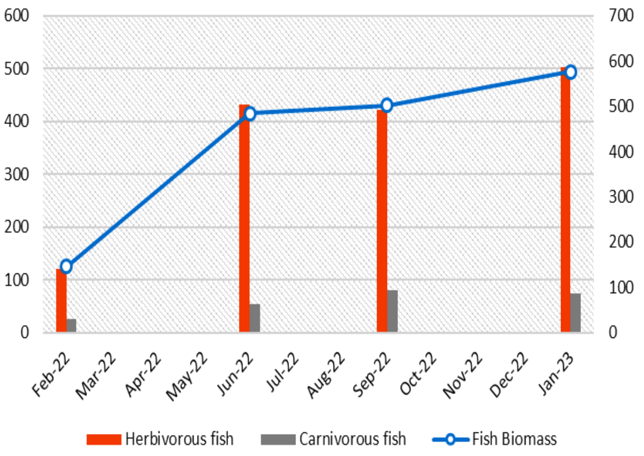

Figure 8. Fish biomass (kg/ha) over 11 months of monitoring

Discussion

BPC advantage

There have been few coral restoration efforts in Anambas Islands to help replenish depleted coral reefs using different techniques. Compared to other artificial reef methods, BPC is low-cost, easily deployable, and can be constructed in areas with minimum accommodation; therefore, it requires less significant manpower and expenses, and each BPC only costs IDR 9,000. The number was derived from making 100 BPCs, including the costs of concrete mix, marine epoxy, 3-inch steel rebar, boat rental, logistics, and hiring one person to make the BPCs. Therefore, this method is suitable for coastal communities and can be utilized as an educational tool to promote local resources and community-based management (Reguero et al. 2018). Lastly, planning on artificial reefs must be evaluated based on their needs and feasibility.

Coral survivorship

The coral cover percentage increased by 4.2% following the rehabilitation process, surpassing the initial deployment figures. Compared to the control site (Table 3), there was an average annual increase in coral cover of 0.85%. In contrast, at the rehabilitation site where the BPCs were deployed, there was a noticeable growth up to 4.2% after one year. These findings indicate that deploying BPC helps to accelerate coral reef recovery through artificial reef use. Coral restoration research in the Indo-Pacific stated that coral cover was higher in restored plots after ten years than at control reference treatments. This indicates coral rehabilitation effectively increases reef complexity (Hein et al. 2020). The percentage of coral cover on artificial reef structures in Wasini Island, Kenya, rose significantly from 17% one year after fragments were first attached to 41% after two years (Mwaura et al. 2022).

Results showed the survival rate was 64%, which is still considered effective from a biological point of view. Generally, 50-100% survival rates are effective (Mompala et al. 2017). A study in the Red Sea showed the survival rate of coral after 12 months was 67.2% and increased to 68.3% after 24 months (Mahmoud et al. 2019). A survival rate of 70.2% was recorded after one year of monitoring in Maldives (Pancrazi et al. 2023).

Semut Island is under the tropical monsoon climate influences; from November to January, this site experiences the northwest monsoon. Most BPCs in the pilot project site and Semut Island could provide stable substrates during big waves. However, minor movements and fragment breakage were recorded during disturbances such as strong waves and currents. The location of the deployment of the BPCs must be selected carefully; therefore, deploying at a depth of 3-6 meters on the rubble area where wave impacts lower is recommended.

Increased wave movements and heavy rainfall in Kiabu Islands during the northwest monsoon might have impacted the high mortality of corals, especially *Acropora* genera. This may cause a localized shift in salinity, nutrients, and sediments. Based on research by Hernández-Delgado et al. (2014), a wild and cultured *Acropora cervicornis* (Lamarck, 1816) experienced a long period of bottom swell and sediment runoff, resulting in tissue loss and Shutdown Reaction (SDR) during heavy rainfall that might cause high concentrations of dissolved organic and inorganic carbon into the body of water. Competition and disease did not affect the transplant, though predation by a crown of thorns was recorded on many occasions.

Species with a higher chance of survival are *Porites* sp. and *Pocillopora* sp. compared to *Acropora* sp. with lower coral survivorship. Out of ten fragments from each genera, seven fragments from *Porites* sp. and *Pocillopora* sp. are still growing, whereas only five fragments *Acropora* sp. have survived. Although *Acropora* sp. is a fast-growing coral, the structure of *Acropora* sp. is vulnerable to environmental and physical disturbances such as waves and gravity (Dao-Ru et al. 2013). Many studies support the conclusion that the genera *Pocillopora* sp. and *Porites* sp. have higher survival rates than the genus *Acropora* sp., as *Pocillopora* sp. is regarded as a pioneer due to their high survival rate (Jouval et al. 2021). Many studies have shown that *Acropora* sp. is more resistant than other genera (Mahmoud et al. 2019). Only coral species that responded favorably to natural conditions in Semut Island would be selected. The combination of physically complex corals will be better for the ecosystem to recover from disturbances (Rogers 2013; Carturan et al. 2022). Therefore, all species need to be considered to maximize coral generic richness.

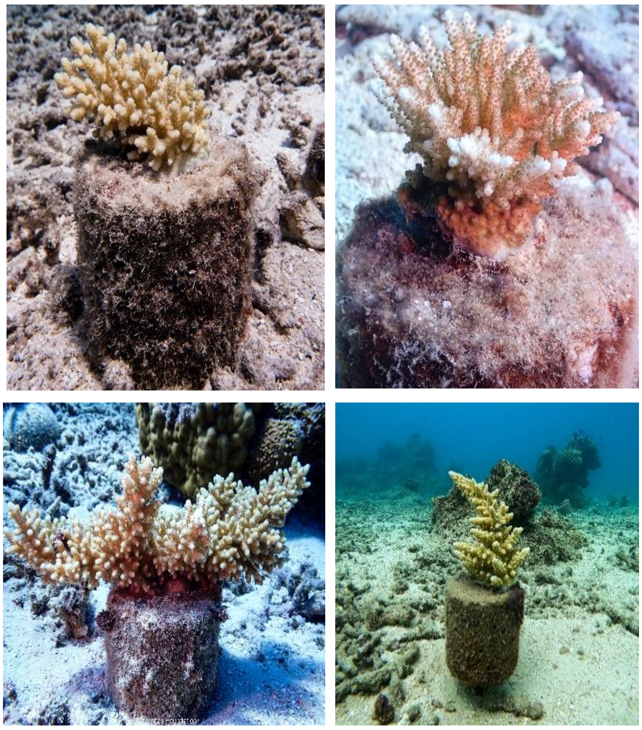

Figure 9. Coral growth after 5 months of deployment

Growth rates

Moreover, each fragment showed similar growth enhancement every month after six months of monitoring, with *Pocillipora* sp. (0.23 cm month^{-1}) having the highest survival rate than *Acropora* sp. (0.22 cm month^{-1}) and *Porites* sp. (0.08 cm month^{-1}). This data further supports previous studies from Mahmoud et al. (2019) that found the family Pocilliporidae (1.2±0.07 cm yr^{-1}) to have higher growth rates compared to the family Acroporidae (0.98±0.03 cm yr^{-1}). Other studies have reported the growth rate of *Pocillopora* sp. was 0.34±0.03 cm month^{-1} (Pancrazi et al. 2023) and 4,1 cm month^{-1} (Adi et al. 2016), which are higher values than what we observed in this study.

Previous studies on the genus *Acropora* sp. revealed that its growth rate is higher than other hermatypic corals (Munasik et al. 2020; Nozawa et al. 2021). *Acropora* sp. transplanted onto an artificial dome-shaped reef exhibited growth rates of 1.07 cm month^{-1} (Muzaki et al. 2019), 7.8 cm year^{-1} (Nithyanandan et al. 2018), 2.27-3.37 cm month^{-1} (Adi et al. 2016), 1.03 cm week^{-1} (Putra et al. 2020). However, compared to many other *Acropora* studies, the low growth rate of *Acropora* sp. could be potentially caused by algae growth, where coral will spend more energy cleaning the mucus produced by the algae rather than growing its tissue (Tuttle and Donahue 2022).

The invasion of fouling organisms such as bryozoans and ascidians will naturally be attached to any natural or man-made structures (Salimi et al. 2021). Algae growth on the BPC influences the survival of attached coral fragments due to competition with algae and other competitors (i.e., sponges, bryozoans, tunicates) (Meesters et al. 2015). Thus, the BPC requires regular maintenance during the first three months by brushing the surface to remove algae or recruit other sessile life. Based on our routine monitoring, the growth rates of transplanted fragments were similar to those planted on our coral spiders and nurseries at the same site. This shows that these fragments on different artificial reefs also respond to the same environmental factors (Figure 9). Growth and survival rates of corals may differ in different species, locations, and environmental conditions.

Coral recruitment

Coral recruits on Semut Island are mostly found attached to rubbles, which are unstable. Therefore, these recruits are at a higher risk of death during extreme weather events. Coral larvae survival and reef recovery are negatively impacted by frequent movement (Ceccarelli et al. 2020). Compared to other artificial reef methods like Coral Spiders (steel rebar base materials), the coral recruitment rate by BPC (concrete base material) is slower; only 15 coral recruits grew on 200 BPCs. This could be due to many factors, including competition of algae or ascidian encrusted in BPC, low supply and settlement of larvae, and low post-settlement survival or a mix of factors that could not determined (Meesters et al. 2015; Swierts and Ja Vermeij 2016). In contrast, other studies showed 26 colonies of hard coral recruits were found in 400 modules (Adi et al. 2016). Although the result could not provide the total coral recruitment rates from 1,500 BPCs and in the control site, the level of recruitment on BPCs is considered low.

Fish biomass

Artificial reef effectiveness is generally associated with fish diversity, richness, and biomass (Gulayan 2017; Cresson et al. 2019; Higgins et al. 2022). During the initial observation in February 2022, the rehabilitation site exhibited lower fish abundance. According to our analysis of trophic level categories (Table 2), fish biomass increased about 3.9 times from 146 kg/ha to 576 kg/ha especially for herbivore fish due to the abundance of algae on Semut Island. The algae easily attached to the BPC's surface, leading to more frequent grazing activities by a group of herbivore fish (Graham and Nash 2013; Knoester et al. 2019; Wilson et al. 2021). A previous study showed reef fish also quickly populated the artificial reef structures, which was three times greater than those observed on natural reefs after two years in Kenya (Mwaura et al. 2022). Carnivorous fish slowly increased, albeit not too significantly, from 25 Kg/Ha in February 2022 to 74 Kg/Ha in January 2023. According to our annual reef health monitoring in the control site (Table 3), the fish biomass was only 1.5 greater since March 2021 (158 Kg/ha) to March 2023 (237 kg/ha).

Based on research in the Philippines, they are stated that rehabilitated areas inside a no-take zone successfully increased fish abundance from poor to high (Gulayan et al. 2017). The presence of artificial reefs has likely attracted diverse fish species. Over time, the overall reef fish population has increased, indicating successful rehabilitation efforts (Williams et al. 2019).

Herbivore fish are crucial to influencing the rehabilitation project's success since turf and macroalgae can be controlled largely by herbivores, and they help the coral recruitment process (Robinson et al. 2019). The data indicate an increase in fish abundance in this restoration site.

Therefore, to increase the carnivorous fish population, rehabilitation efforts need to develop a 3-dimensional structure with more chambers, void spaces, and volumes to provide shelter from predators and habitat for predatory fish that have more economic value and can be consumed by the community. Artificial reefs with chambers are more effective at attracting fish.

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