Enhancing reef fish diversity using artificial reef-building: A case study of coral reef rehabilitation on Nyamuk Island, Anambas Islands

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Abstract. CCMRS-IPB conducted coral reef rehabilitation at damaged coral reefs around Nyamuk Island. Those artificial reef buildings for rehabilitation gave shelter spaces for reef fish. This research aims to calculate the effect of coral reef-building, which enhances rugosity to the reef fish diversity around the rehabilitation sites. The study was conducted on Nyamuk Island in the Anambas Islands. Reef fish were sampled annually from 2014 to 2019 using the underwater visual census. The Diversity index and non-Metric Multidimensional Scaling were built to discover reef fish diversity, and reef fish species were affected the most. Yearly data shows an escalation number of reef fish abundance and richness at the end of 2019. The major reef fish group is found to have constant diversity throughout the year compared to other functional groups. The target reef fish group came to this rehabilitation ecosystem primarily attracted by nourishment availability. There is a shift in the reef fish diversity from the early year to the project end. Generally, major reef fish groups will be refuged first around the rehabilitation sites, especially territorial types. Target fish groups from herbivorous and carnivorous types will mostly come along after their food availability and location to get around.

Keywords: Artificial habitat; Community shifting; Reef-building rugosity; Reef fish diversity.

1. Introduction
Coral reefs have become one of the most fragile ecosystems in the underwater environment throughout the year [1-2]. Anambas Islands reefs have encountered some acute declination of coral reef-building, mainly affected by anthropogenic pressure, inclement fisheries management. However, due to a scant number of coral reefs ecosystem publications, detailed information is still fairly deficient [3–6]. Certain coral reef rehabilitation activities around Anambas Islands have been conducted to recover the acute losses of coral coverage [4-5, 7]. CCMRS-IPB (Centre of Coastal and Marine Resources Study – IPB University) came to be one study center that contributed to coral reefs rehabilitation with sustainable monitoring. Recovery of coral reefs using artificial reef-building is considered the major tool to revive the reef ecosystem function for reef fishes by restoring the coral reef coverage and recreating high rugosity reef-building and ensuring food availability [8–10]. The selection for coral reef rehabilitation sites was considered moderate open seas with frequent water flushing but still convenient for monitoring the artificial reef modules.
Artificial reef-building, designed as the coral reef rehabilitation tool, has been assumed to increase the local fish population by enhancing and imitating rocky areas [11–13]. In this context, artificial reef-building could escalate the local production by providing additional critical habitat, increasing the carrying capacity of the marine environment around rehabilitation sites [11, 14]. Therefore, it could attract juveniles to refuge and increase the abundance and biomass of reef fishes. The presence of imitated rocky areas by artificial reef-building allows the budding of a coral colony, algae, and larvae of benthic invertebrates [12-13, 15]. Local trophic efficiency could be improved by the survival of embedded organisms on the hard surface of artificial reef-building [16-17], mainly on degraded productivity areas covered by rubble and sandy bottom that are impoverished of nutrients [18-19]. These phenomena assumed that habitat built by artificial reef-building determines the composition of reef fish assemblages through leverage on food availability and refugees [13-14].

Artificial reefs have long been utilized to increase the ecosystems’ rugosity, mainly in areas with low coverage of coral reef-building [11, 14, 20]. The complex design of artificial reef-building could help to restore degraded habitats and perform approximately similar ecological functions as natural reefs [21–23]. Shelter, refuge, and migration are the ecological functions that come closest to the natural reef function when artificial reef-building is dropped to the underwater ecosystems for the first time. A large-scale module of artificial reef-building with a more complex habitat could support higher reef fish species richness and evenness [14, 24-25]. Furthermore, the artificial reef structure, scale, and placement play an essential role in determining their level of influence on the reef fish communities [23-24, 26]. Although, a different method of coral reef rehabilitation could give different results, not only about artificial reef design but also coral fragment type, location selection, and coral fragment adaptation periods [11, 14, 21].

Utilizing artificial reef as a rehabilitation program by CCMRS-IPB at Nyamuk Island with sustainable annual monitoring became a significant improvement of rehabilitation activities around the Anambas Islands. This study aims to define the yearly shifting of the reef fish community around rehabilitation sites with artificial reef-building as the primary habitat and identify the influence factor that affects the fluctuation of fish community at rehabilitation sites yearly. The study is expected to affix reliable research information about successful rehabilitation programs around Anambas Islands. Furthermore, we hope to contribute to a more detailed understanding of coral reef conditions and the marine environment surrounding the Anambas Islands, which is still poorly documented in the global scientific community.

2. Materials and methods

2.1. Study sites

The study was conducted in Nyamuk Island, Anambas Islands, one of the outer islands in Indonesia adjacent to the territory of Malaysia. Nyamuk Island is a coastal village located on the coast of Bajau Island. For quite a long time, the marine environment surrounding Anambas island has been deeply impacted by the illegal fishers from adjacent countries. Anambas coral reefs are also damaged by coral mining and destructive fishing activities (e.g., potassium and bomb) [4].

In 2013, CCMRS-IPB with StarEnergy constructed an artificial reef-building module for the coral reefs rehabilitation program. This module was dropped at 5-6 meters depth on a low coral cover, which is now covered with rubble and sand with a low productivity level (Figure 1). Artificial reef-building was deployed at the south side of Nyamuk Island and near the low current level’s cape, which is considered safe and sustainable for module placement and monitoring.
2.2. Artificial reef-building construction
The establishment of the module as a transplanting medium used a mixture of cement and sand, which then formed into an effective and efficient shape for Anambas water conditions. Artificial reef-building is designed like a furnace, with coral transplantation media and a fish shelter model. A total of 20 artificial reef-building modules were deployed, with each has six holes to transplant the living coral fragment (Figure 2). These coral transplantation modules were built like a furnace to increase effectiveness when the modules were being deployed.

2.3. Sampling design
The reef fish community assessment used underwater visual census (UVCs) to quantify the fluctuation in abundance, species richness, and diversity around the rehabilitation sites [27]. Reef fish assessment at Nyamuk Island was surveyed annually after establishment from 2013 to 2019. However, for the analyses, we used the data from 2014 to 2019 to avoid discrepancies in reef fish data, assuming that the fish community is still in the adaptation phase after deploying the rehabilitation module underwater. The reef fish observation included counting, identification, and estimating the length size of all mobile and territorial species associated with the habitat of rehabilitation sites.
Collecting data on reef fish was then continued by identifying groups of reef fish based on trophic levels and functional groups. There are six trophic levels based on FishBase [28], including planktivorous, omnivorous, herbivorous, detritivorous, coralivorous, and carnivorous. Three functional groups include major, indicator, and target reef fishes. Both groups were built to perceive interaction development between category levels every year. Besides, food availability is considered to affect the reef fish community structure around rehabilitation sites.

2.4. Reef fish diversity analyses
Shannon-Wiener diversity index was calculated to assess biodiversity, evenness, and dominance of reef fish communities on rehabilitation sites every year [27, 29]. Primary time-series data of reef fish biodiversity was calculated to determine the diversity fluctuation of reef fish communities around rehabilitation sites, log-transformed for abundance and biomass ratios of reef fish species. The logarithmic transformation was conducted to minimize the leverage of much data as schooling reef fish and considered small, abundant reef fish species [25].

Multivariate analysis non-Metric Multidimensional Scaling (nMDS) was built based on a functional group of reef fish, which have been reduced to only prioritize species based on Similarity Percentage (SIMPER) analysis [15,24,30]. nMDS was calculated to specify the driving species on the rehabilitation sites all year and determine the value of those groups or species of reef fishes. Multivariate analyses were conducted using Primer V7 with log-transformed and Bray-Curtis similarity index [31-32].

3. Results
A total of 686 individual reef fishes included in 68 species and 14 families. Based on the analyses of coral reef rehabilitation carried out from 2014 to 2019, there is an escalation of the reef fish assemblages in artificial coral reef ecosystems. Generally, the abundance and species richness of the reef fish community increased slowly yet significantly enhanced at the end of 2019. Those general overall conditions exhibit an excellent marine habitat ecosystem that could support the growth of the recent development ecosystem in Anambas. The reef fish community quality has tended to increase in the last six-year monitoring period (Figure 3). Reef fish diversity index from 2014 to 2018 fell in the moderate category diversity, which then escalated to high category diversity. The gradual change is significantly indicated on the diversity and evenness index, while there is no significant change on the dominance index. Besides, alteration of each index consistently exhibits of stable reef fish community.

The abundance of reef fish after deployment of artificial reef-building on degraded habitat has occurred in 0.60 log(ind/250 m²) or 4 ind/250 m² indicator fish groups, 112 (2.05) ind/250 m² mayor fish groups, and target fish as much as 36 (1.56) ind/250 m² (Figure 4). Between 2015 to 2017, there was a decrease in the indicator and target reef fish, while the major reef fish was stable during the observation period. The abundance of reef fish increased during observation from 2018 to 2019. The

![Figure 3. Reef fish diversity index based on Shannon-Wiener diversity index (H), Evenness (E), and dominance (C) on the rehabilitation sites.](image-url)
indicator fish group is found to be 6 (0.78) ind/250 m², target reef fish is 36 (1.56) ind/250 m², and major reef fish is 147 (2.17) ind/250 m². Based on observation during the monitoring, abundant major fish species are generally affected by branching coral and shelter availability.

On the other hand, there is an enhancement in abundance based on the trophic level category from 2014 to 2019. Significant fluctuation obtained on carnivore reef fish group with 38 (1.58) ind/250 m² in 2014, 2 (0.30) ind/250 m² between 2016 to 2017, and reverted to 36 (1.34) ind/250 m² in 2019. Omnivorous and planktivorous are found stable throughout the observation, in which both groups mostly contained major functional groups. Significant abundance enhancement occurs between 2018-2019 in each trophic category—corallivore and herbivore reef fish experiencing abundance fluctuation from 2016 to 2018; nevertheless, those are escalated in 2019. Benthic invertivore experienced a significant change than other groups with a total of 36 (1.56) ind/250 m² at the end of 2019. Other than that, as many as 22 (1.34) ind/250 m², 9 (0.95) ind/250 m², 24 (1.38) ind/250 m², 41 (1.61) ind/250 m², and 57 (1.75) ind/250 m² are found for the carnivorous, corallivorous, herbivorous, omnivorous, and planktivorous group respectively.

**Figure 4.** Annual observation of reef fish abundances on coral reef rehabilitation sites based on (a) functional group and (b) trophic level.

Generally, reef fish species richness is enhanced at rehabilitation sites based on the functional group throughout the observation phase. However, the indicator and target reef fish slightly declined from 2014 to 2016 until they reached 1-3 species/250 m² (Figure 5). Observation after the deployment of artificial reef module on the sites counted several aggregating target fish. On the other sites, major groups experienced derivation from 2016 to 2018 with only 19 species/250 m² found. Trophic reef fish groups exhibit similar upward trends during the observation phase around the artificial reef-building habitat, even with fluctuation during the half period of the observation. Planktivorous, omnivorous, and corallivorous slightly increase from 2014 with replenishment of around 1-3 species/250 m². The fluctuation was recorded from 2016 to 2018 for those groups, even though it is not significantly changed. Herbivorous reef fish constantly increase from 2 to 8 species on rehabilitation sites. Carnivorous is decreasing until 2017, then increased from 2017 to 2019. Other than that, benthic invertivore reef fish enhanced gradually after the deployment of artificial reef-building from 2 to 5 species but suddenly dropped in 2018 to 2 species/250 m². However, further observation indicated that benthic invertivorous is the most significantly increased trophic group from 2018 to 2019.
The observation from 2014 to 2019 shows the greatest biomass owned by groups of size 6-10 cm in 2014 to 2016, 11-15 cm in 2017 to 2018, and 26-30 cm in 2019 (Figure 6). The significant alteration occurred in 2016 to 2017 with a group size of 21-25 cm, which even reached 25.04 (1.39) kg/250 m², and the gap decreased on small-bodied reef fish group (0-5 cm) until reach 0.12 (-0.89) kg/250 m² and become the minor biomass interval of overall groups. Reef fish groups with size intervals 0-5, 26-30, 21-25, and >40 cm are significantly altered during the 2018 to 2019 observation. The body size of 6-10, 11-15, and 16-20 are indicated to inhabit artificial reef habitats with consistently high biomass throughout the observation time. Small to moderate-bodied reef fish maintain food web and coral reef resilience in the rehabilitation module.
Neoglyphidodon nigroris, Pomacentrus moluccensis, and Halichoeres leucurus. However, early recorded target species Caesio cuning and Lutjanus monostigma are found aggregating on considerable schooling around the observation area after the deployment of the artificial reef module.

![Figure 7. The nMDS of the 30 highest contributed reef fish species sorted by SIMPER analysis.](image)

4. Discussion
This study observes good recovery of reef fish community with stable community structure in the rehabilitation sites. High diversity occurs at the end of 2019, with less dominant species in every observation. Caesio cuning schooling is observed in 2017, but it did not affect community structure dominance significantly. The pace of reef fish recovery would be faster than the recovery of its habitat [33-34]. Artificial reef-building is valued as a reasonable settlement for reef fish around the damaged sites, mainly from the first-time deployment in 2014 to 2015, reef fish community consists of primarily territorial type. The family of Pomacentridae and Labridae are found to be the most abundant that live around artificial reef-building from early 2014. Several species from those families with small-bodied fish were usually found in every marine environment in Indonesia, even though there is low coverage on coral [35-36]. Affix research determines that besides attraction from nourishment, they mainly look for shelter to hide from predators, especially for the early reef fish species. Thus, it indicates that the design of artificial reef-building could immediately provide habitat for early reef fish species. Except for Pomacentridae and Labridae, observation shows Caesionidae and Lutjanidae, categorized as mobile necton, came around the rehabilitation sites. In a certain sense, an excellent marine environment around rehabilitation sites gives a support system to the degraded environment rehabilitated [37-38].

Well-designed artificial reef-building could attract major reef fish from the first time of deployment [22, 35]. Escalation in the abundance of major reef fish around recent habitats by well-designed artificial reef-building could vitalize food chain occurrence [28, 39]. The abundance and richness of the major group are slightly increased, even though it was constantly higher than the other groups. Besides food availability on habitat coverage, major reef fish also play an essential role in alluring big-sized fish either from pelagic or reef fishes. Those fish are categorized into target fish, which mainly occupy the rehabilitation sites at the end of 2018. Richness came to be advanced yearly, but the abundance is slightly dropped at the end of 2019 for the target group. As mentioned before, target fish mainly consists of high mobility fish, which could eventually occur at the rehabilitation.

Habitat rugosity in the marine environment was notable in affecting the existence of reef fish [20, 26, 40]. Furthermore, artificial reef-building on this research was built to enhance topographic...
complexity, various size in the refuges hole, fluctuation of substratum height building, percentage of hard coverage, and percentage of living coverage, including corals. Those marine ecosystem services could enhance reef fish diversity annually, besides the assistance from existing seagrass beds and mangroves forest as coastal marine ecosystems [37-38]. Anambas provides a healthy marine coastal ecosystem that could support the recently developed marine environment [3-4]. From the first deployment of artificial reef-building, most marine ecosystem functions are directly replaceable, mainly functioning to enhance the rugosity of the habitat. Major reef fish categorized as planktivore, omnivore, and benthic invertivore with small-bodied fishes first inhabit rehabilitation sites to take shelter. Several planktivores, carnivores, and herbivores from the target functional group are mostly only passed around the rehabilitation sites. Some large-bodied reef fish are generally more attracted to the nourishment than the shelter function from their habitat.

Moreover, they have a high capability of mobility to avoid predators, such as Caesionidae, Lutjanidae, and Dasyatidae, which are recorded in our research. This research shows a complete trophic structure in 2019 with an escalation of large-bodied fish, which indicated the artificial reef structure could resettle larger fish. For example, Taeniura lymma, which was found burrowed under the artificial reef structure in 2019, and Lutjanus boulton which was discovered going around under the artificial reef-building. In the end, this artificial reef-building can also function well as the fish aggregating device. It is indicated that the rehabilitation activities of artificial reef building and the coral reef have provided a niche for big-bodied fish. This coral reef rehabilitation ecosystem could provide nourishment for those big-bodied fish, and there is enough space to be sheltered between coral reef ramifications.

Nourishment came as a key for enhancing the reef fish diversity near a low carrying capacity environment [10, 41]. Food availability becomes the next important factor in improving reef fish diversity around recently rehabilitated areas after more than one year of deployment. Our research indicated the enhancement of abundance and species richness from each trophic group. Herbivorous smoothly increases every year, constantly exhibited algae growth rate on the artificial reef-building surfaces. Thus, herbivorous reef fish could assist coral in overcoming algae growth in the recently flourished coral reef ecosystems [36, 42]. Planktivorous, omnivorous, and benthic invertivorous have constant abundance through the early deployment. Those groups are classified as early-stage species found on recent habitats because of the higher food availability than the other trophic groups [15,43]. Moreover, large-bodied carnivorous occurs in the first year but decreases each year and only renounces the small-bodied carnivore. Carnivorous regain abundance and richness from 2017 to 2019, dominated by moderate to large-bodied fishes. Other trophic groups mainly decrease around 2017 or 2018 and re-increase at the end of 2019 because of ecological shifting.

Ecological shifting occurs at our coral reef habitat rehabilitation sites. Ecological shifting is mainly marked by alternated of reef fish species, the composition of reef fish trophic structure, and reef fish size that inhabit the rehabilitation sites [25, 44]. Fluctuation data in 2017 and 2018 indicates an alteration in the composition of reef fish trophic structure. Predation and adaptation would happen from 2017 to 2018. Large-bodied fish increase significantly throughout 2018 to 2019, even though small-bodied reef fish are constantly abundant. As mentioned before, this recent marine habitat has a stable reef fish community, resulting in maintaining even ecological pressure by shifting the community. The nMDS represents major reef species that exist from the beginning until the end of 2019 observation. Indicator reef fish from the corallivore group also withstand inhabited the rehabilitation sites by relying on recent coral coverage. Whereas the large-bodied target fish generally seize the rehabilitation habitat during the last two years of observations. This habitat is predicted to withstand and continually enhance the reef fish diversity to a saturated point, which is the same as the other coral reef ecosystem surrounding this rehabilitation site.

5. Conclusion
This study shows that a well-designed artificial reef module can substitute several marine environment functions (e.g., shelter, refuges, and ecological food providers) by providing advantages to the broad scale of reef fish during rehabilitation. It is shown by the enhancement of reef fish abundance and diversity every year. Also, reef fish that occur on coral reef rehabilitation habitat is several target fish with big-bodied size and several recent species of small-bodied size reef fish. Small to moderate-bodied major groups inhabited the earlier stage and shifted to large-bodied fish with several target reef fish groups. Early trophic groups on rehabilitation sites consist of planktivore, omnivore, and benthic
invertivore reef fishes, which then shifted by escalating herbivorous and carnivorous mainly of large-bodied fishes. Eventually, we can say that the overall abundance and species richness are gradually enhanced by the deployment of artificial reef-building at the degraded marine habitat of Nyamuk Island.

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