The perspective of high coral growth rate on the artificial reef: what is causing enhancement of coral growth rate on Nyamuk Island, Anambas?

B Prabowo1*, N Rikardi1, M A Setiawan2, P Santoso3, D Arafat3, B Subhan3 and A Afandy1

1Center for Coastal and Marine Resources Studies (CCMRS) Bogor Agricultural University, Jl. Raya Pajajaran No. 1, Baranangsiang, Bogor 16127, Indonesia
2Anambas Marine and Fisheries Agency, Jl. Cekwan Abdul Hayat, Tarempa Barat, Anambas 28791, Indonesia
3Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, IPB University (Bogor Agricultural University), Jl. Agatis Darmaga Bogor, Bogor 16680, Indonesia

Corresponding author: budiprabowo@apps.ipb.ac.id

Abstract. The coral growth rate is affected by several ecological conditions, which could lead to enhancement or deceleration. Good marine habitat and water conditions would escalate coral fragment growth rate on rehabilitation sites. This study was assessed to determine the coral growth rate transplanted on artificial reef-building for rehabilitation purposes and indicated the main driving factors that enhance coral growth rate at Nyamuk Island, Anambas. Benthic communities, coral length, and coral growth rate compared through the year. Analysis of variances and Principal component analysis (PCA) was conducted to indicated differences between variables and analyse driving factors of coral growth rate. Hard coral and sand coverage increasing during observation. Coral length based indicated constant escalation. However, coral growth yearly showed fluctuation with peak growth from 2014 to 2015. PCA exhibited hard coral, dead coral with algae, sponge, and sand played an important role in supporting coral growth on rehabilitation at Anambas. Available niche for other marine faunas built by artificial reef-building could support to preserve of the coral fragments. Acquisitions of hard coral by coral fragments could be supported by good natural hard coral coverage in the habitat. Herbivorous is one factor that could support recent coral reefs.

Keywords: artificial reef-building; benthic communities; coral growth rate; marine habitat condition

1. Introduction

Coral reefs live and grow mutually with other associated marine biotas [1–3]. The major dimension and high reef's rugosity could provide an important ecological function for other marine biotas [4,5]. Complex coral reefs habitats became refuges from various marine species, and even the coral became nourishment for several marine biotas [1,6]. However, the accretion of coral fragments requires much time in the Indonesian seas [7,8]. Coral produce calcium carbonate in the early phase of coral growth for augmented the dimension (wide, length, and width) of coral structure [9,10]. Coral skeletal, which is built on the early phase being covered by zooxanthellae. Thus, growth phase has made coral reefs one of the most fragile biotas in marine habitat.

As a fragile marine biota, coral reefs growth rate is influenced by several global disturbances nor ecological factors [11,12]. Global disturbances generally turn the water quality condition along with the marine habitat life. Global warming that leads to increasing sea surface temperature and seawater levels
indirectly affected coral reefs [13,14]. Ocean acidification poses a global stressor for many marine habitats, including coral reefs [15]. Land-based pollution by the source of riverine runoff [16], sewage [17], and agriculture/aquaculture outcast that lead to eutrophication and sedimentation [18,19].

Furthermore, coral reefs during the survival period, ecologically affected by various factors. The existence of herbivorous fish could suppress the algae on territory competing with coral reefs [20]. Coral-dwelling crab could preserve coral reefs from coral-eater sea stars (*Acanthaster plancii*) [21]. Besides, coral reefs developed using artificial reef-building mostly required support by good marine habitat around the rehabilitation area. Transplanted coral is generally more fragile at the early phase than natural coral reefs.

Degraded marine habitat, which is affected by anthropogenic pressure, is difficult to recover ecologically [22,23]. Marine habitat breakdowns as the impact of destructive fishing gear, abandoning the location with rubble and toxic benthic or water condition. Human intervention is needed to rehabilitate the defective marine habitat caused by destructive fishing gear. Rehabilitation efforts utilising artificial reef-building provide a recent overlay for zooxanthellae to adhere [24,25]. Good artificial reef module design could attract marine biota around rehabilitation sites that could support the survival of the recent coral colony or transplanted coral on artificial reef-building [26–28].

The lack of progress in experimental coral growth and artificial reef studies in Indonesia leads to the low international publication of these studies. Besides, these marine sciences were most applicable to Indonesia, which have several degraded marine habitats. Anambas is one of the coral reef habitats in Indonesia that affected by anthropogenic pressure. Primarily, our study site was affected by not responsible anchor utilization by vessel and utilization of destructive fishing gear. It represents the Anambas, which is denoted as a stopover island for many tourists, and demographically, most Anambas residents worked as a fisher. This study was assessed to determine the coral growth rate transplanted on artificial reef-building for rehabilitation purposes and indicated the main driving factors that enhance coral growth rate at Nyamuk Island, Anambas. Furthermore, this research could be relevant research for developing coral reef rehabilitation in Indonesia.

2. Material and methods

2.1. Study areas and environmental condition

PKSPL-IPB and StarEnergy Ltd. developed a coral rehabilitation program on damaged coral reef ecosystems at Nyamuk Island. Rehabilitation sites located nearly the bay of Nyamuk Island () have calm current and safety for developing coral reef rehabilitation. Artificial reef modules were dropped at 5–6 meters depth and grouped with four modules each. Water quality sampling before dropped the artificial reef module showed (pH = 6.68; Salinity = 35 ‰; Temperature = 25°C; Dissolved Oxygen = 8.8 mg/L) good water condition for coral reefs.

The rehabilitation research was conducted on Nyamuk Island, Anambas archipelagos, Indonesia. Nyamuk island administratively was a village on the coast of Bajau Island. Anambas near Malaysia experienced marine environmental defects caused by destructive fishing gear and coral mining conducted by non-Indonesian regulated fishermen [29]. The degradation and rehabilitation of marine habitats immediately become government concerns.

2.2. Artificial reef-building construction and development

When the module was developed as a coral transplanting medium, artificial reef-building was contained by cement and sand that formed effectively and efficiently for the Anambas sea condition. Artificial reef modules were built in the shape of a furnace, complete with coral transplantation media and a fish shelter model. There was 20 module that will be deployed on the rehabilitation sites which each module has six holes for transplanting the coral fragment (Figure 2). Collecting corals for transplantation donors was carried out on coral reef ecosystems near rehabilitation sites.

The adaptation phase for coral donors would not be necessary if the donors were found near the rehabilitation sites and assumed on the similar water quality condition [30,31]. The corals used as donors
was living coral fragments found around the coral reef ecosystem near rehabilitation sites [32]. Transplantation of donor corals by inserted the fragmented corals into the holes on artificial reef modules then covered with cement. 20 artificial reef-building was dropped on degraded marine habitat with a total of 120 transplanted corals.

2.3. Benthic and coral growth rate observation design
Benthic communities on rehabilitation sites were conducted using Line Intercept Transect (LIT) to assess percent coverage and identify hard coral genera along 50 meters transect parallel to the coastline.
Benthic communities were identified visually whenever a change in benthic cover occurred. Benthic categorisation based on [33] was carried out directly on observation. There are five major benthic communities: algae, dead coral, hard coral, other fauna, and abiotic. However, this study used detailed categories of dead coral, which contained dead coral and dead coral with algae, hard coral, which included hard coral and soft coral, and three abiotic types, including rubble, sand, and silt.

A total of 30 Acropora were selected to be measured every year on rehabilitation sites. Measurement of coral length conducted using roll meter with 0.1 accuracies and take the longest coral growth axis to be recorded [32,34]. Differences between parallel two-year observations become the growth rate of corals. Acropora branching genera has the highest growth rate than the other genera and coral growth types.

2.4. Benthic communities and coral growth rate analysis
Temporal variation of benthic communities was measured every year on the rehabilitation sites. Comparison between year observations could indicate ecological processes around rehabilitation sites [8,32,34]. The same individual corals were compared in each year to perceive coral growth rate through the year observation. Analysis of Variances (ANOVA) two factors without replication was calculated to depict differences in coral length and coral growth rate during seven years of observation. A significant level of p<0.001 was applied to the ANOVA calculation. Multivariate analysis utilising Principal Component Analysis (PCA) based on benthic communities coverage and coral growth rate to assessed linkages between year observation. PCA exhibited driving factors from benthic communities coverage that could influence the acceleration of coral growth rate.

3. Results
3.1. Annually benthic communities condition
The benthic community at the rehabilitation location is dominated by hard coral (HC) and dead coral (DC) (± 30%), rubble (± 15%), and another benthic category (<10%) on the early year observation (Figure 3). The existence of coral reef rehabilitation has gradually increasing hard coral coverage from 26.77% in the first year to 51.88% in the seventh year. Peak replenishment of hard coral cover from silt and algae occurs from 2015 to 2017. As increasing hard coral cover, the dead coral with algae coverage also decreases from 33.85% to 14.78%. Nevertheless, the importance of algae that grow on dead coral for other marine biotas is maintained by another factor of 24.67 to 14.78 percent (Figure 3). Meanwhile, Soft coral cover fluctuates every year observation which no more than eleven percent. Soft coral higher coverage happened in 2015 (10.72%) and 2019 (9.85%). Algae on rehabilitation sites have low coverage through observation. Mostly algae found on rehabilitation sites grow over hard coral that has been dead for a prolonged time. Sponge existence on rehabilitation sites was also lower than 5.00%, with higher coverage in 2018 with 4.13%. Escalation of hard coral coverage leads to increasing hard coral building rugosity, influencing degraded other biota found on rehabilitation sites. Other biotas on rehabilitation sites were higher in 2014 with 6.24%. Abiotic cover from rubble and silt are shifting to sand benthic coverage with abundant coral reef. Rubble covered reduced from 14.52% to 13.96% with slight fluctuations through yearly observation. Silt coverage is higher than sand on early-stage; however, this condition shifting at the end of yearly observation with a higher cover of sand than silt.

Porites were the coral genera that had the highest cover value compared to other genera throughout the year. Figure 4 showed that the porites cover in the first year (2013) was 14.88%, while Diploria 2.05%, Acropora 1.38%, Millepora 1.3%, and others genera below 1%. Acropora escalated directly after coral rehabilitation in 2013. The increase of hard coverage in Figure 1 are mostly contributed by Acropora coverage from the coral reef rehabilitation program. Acropora coverage could reach 31.72% in 2016. 2017 to 2019 exhibit that Acropora and Porites constant coverage each year. These two genera are coral branching types.
Meanwhile, the percent cover of the others genera did not change significantly. Porites represent the coral reef condition in Anambas, which generally could adapt to poor water and ecosystems condition. Mostly on our observation, Porites is found as a massive coral reef form. Pocillopora, Montipora, Lobophyllia, Goniastrea, Fungia, and Diploastrea are included as coral genera that support the coral reef ecosystem through the rehabilitation program Anambas. Millepora, Favia, and Ctenactis were found on

**Figure 3.** Time series plots of each total percent benthic coverage at the rehabilitation sites with nine specific types of benthic coverage.
rehabilitation sites with lower coverage on the 2018 to 2019 observations. Replenishment of coral reef genera occurs after five years of rehabilitation.

3.2. Coral growth rate of coral fragment at artificial reef building

The growth rate of coral reefs in the Anambas Islands based on differences in each coral fragment each year is significantly increasing (Figure 5a). Coral fragment size bottom interval also rising every year and constantly grow each year. Scatter distribution of coral fragments length tends to have a wide distribution verge to the end of the observation year. Averagely more coral fragments have a longer length than average size every year. Our study exhibits coral growth length from seven centimetres in 2013 and could reach 70 cm in 2019. Figure 5b shows that coral fragments' peak growth occurs from 2014 to 2015, which will gradually drop from 2017 to 2018. Even from 2017 to 2018, coral growth rates have wide distribution data—2013 to 2014 inclusively as adaptation year for every coral fragment attached to artificial reef-building. The highest coral growth rate could be found in 2014 to 2015 with 12.2 cm/year and lowest in 2016 to 2018 with 4.7 cm/year. Differences between year observations are indicated a significant difference. Distribution data of coral growth rate indicate out layered on 2016 to 2017 (4.7 cm/year) and 2017 to 2018 (9.6 cm/year), which is far lower on 2016-2017 and way higher on 2017-2018 than usual distribution coral growth rate on that year. The ANOVA showed significant differences between coral fragments on each year observation (Table 1; Figure 5b). Coral growth rate based on data distribution also exhibits significant differences in each year and comparison between years. 2017 to the end observation could be indicated as the stagnant stage of coral growth rate.

Figure 4. Eleven most abundant coral genera at rehabilitation sites. Coral genera percent coverage based on recorded hard coral percent coverage on every observation year.
3.3. Correlation between benthic community structure and coral growth

The early-stage of rehabilitation showed by Figure 3, represented well in figure 6a with year observation 2013 and 2014 grouped mostly directed by dead coral with algae, silt, other, and rubble. Those four variables depict degraded coral reef ecosystems. However, other biotas are abundant because of the low rugosity of coral reef-building that affected increasing exposure for other biotas. In 2015 several variables were shifting and have moderate abundance. On the other hand, 2016 to 2018 is formed by sponge, sand, and hard coral. 2016 to 2018 represented the fully shifting of coral reef ecosystems to a better condition. Coral reefs length is directly grouped, which is in line with the 2019 observation year. Based on the length of the coral fragment, that every coral fragment reached its maximum length in 2019. Algae and soft coral become variables that emergently increase in 2019.

Coral fragment growth rate distributes on the left side of PCA (Figure 6b), unlike the coral reef length analysis (Figure 6a). Generally, those conditions depict the peak growth of coral fragments, which occur from 2013 to 2016. In line with figure 6a, early-stage (2013-2014) is represented by much rubble, other, and silt coverage. 2014 to 2016 affected by peak growth of hard coral cover and sponge. 2016 – 2017

Table 1. Result of non-repeated-measures ANOVA for length of coral fragment and coral growth rate every year observation (*p<0.05, **p<0.01, ***p<0.001, n.s. not significant).

| Variable                  | Factor           | F     | Df | P   |
|---------------------------|------------------|-------|----|-----|
| Length of Coral Fragment  | Coral Fragment   | 75.817| 29 | *** |
|                           | Year Observation | 5408.02| 6  | *** |
| Coral Growth Rate         | Coral Fragment   | 87.251| 29 | *** |
|                           | Year Observation | 4615.58| 5  | *** |
4. Discussion

4.1. Benthic community structure

Anambas has good marine habitat quality to support the recent rehabilitation coral reefs ecosystem. That condition is simply visible by gradually increasing hard coral coverage on the rehabilitation sites. Hard coral could expand widely with the availability of vacant hard substrate or structure provided by artificial reef [35]. Acropora and Porites are the most abundant genera on rehabilitation sites, besides those are
genera that we choose for this rehabilitation program. Moreover, the rehabilitation of Acropora and Porites could trigger the growth of other coral genera that occurs on other coral reef ecosystems near rehabilitation sites [36,37]. Sexual breeding of coral reefs produced planula/coral larvae that could disperse widely depends on water current direction and velocity [38,39].

Well-designed artificial reef attracted many coral reef-associated marine biota, especially reef fishes [27]. Our field observation showed some herbivorous fish aggregating around rehabilitation sites after deployment of the artificial reef. The existence of herbivorous fish suppresses algae coverage and indirectly supports coral reef recruitment—our study exhibits low coverage of algae and gradual degradation of dead coral with algae. Moreover, corallivore fish as bioindicator occurs on rehabilitation sites after two to three years of observation. Besides, the sponge is competing for space to grow with coral and algae. Nevertheless, a good support system for corals around the rehabilitated area could control sponge growth to avoid becoming sponge blooming [40].

Soft coral presence on the recent developed coral reef ecosystem signifies the good quality of marine habitat for coral reefs to grow [41]. On rehabilitation sites, soft coral has not covered over ten percent yearly, which denotes the slight possibility of soft coral blooming. Several studies show soft-bodied coral could grow massively overrun above hard-living coral [42,43]. Sarcophyton and Alcyonacea are soft corals that grow around rehabilitation sites. Those soft coral orders are axial growth soft coral, which can spread widely [44].

Silt gradually decreases, replace by sand coverage which increasing yearly. Silt mostly comes from river runoff which transport sedimentation from the mainland. Moreover, siltation could happen on the coral reef ecosystem wherefore of fishing vessel operation [45]. Most of the Anambas communities are fishermen, even though fishing only to fulfil daily needs. Coral reef defect on study sites before rehabilitation was caused by siltation or sedimentation, besides destructive fishing activities is a most contributing factor which defects Anambas coral reef ecosystems. At the same time, sand is ecologically produced by the symbiosis process on coral reef ecosystems [46]. Scaridae is a reef fish family that produced sand from its excretion after consuming algae attached to a coral reef-building surface. Scaridae have unique oris like bird rostrum that could ram and shattered stony coral as its feeding mechanism [47]. Rehabilitation sites exhibit ecology improvement through the year by derivation of siltation that shifts to an ecological process-based substrate.

High hard coral coverage on rehabilitation sites is mostly contributed by Acropora genera which generally have branching structures. Based on [48], a coral ecosystem mainly covered with branching structure is characterised as rapid growth and high fragility coral ecosystems. Fisheries activity and vessel anchoring causing coral fracture, which leads to escalation of rubble coverage. Ecologically, high water current and catastrophic could lead to increasing dead of coral and rubble coverage [42,49]. Anambas as remotely islands which located on open seas areas somewhat occurs bad water condition with high current. However, with a rapid growth rate and Montipora with strong durability hard coral genera, Acropora became a pioneer that could trigger the paster of other hard coral genera on rehabilitation sites.

4.2. Reciprocal coral reef habitat variable to escalation of coral growth rate
Coral growth rates, measures as vertical expansion, habitually consider reef health indicators in marine habitat assessment of coral reefs, assuming that low physiological stress and environmental degradation should lead to increased growth rates—Anambas marine habitat mostly on a good condition which could support coral reef rehabilitation in several sites. Based on observation, the seawater condition of the Anambas Islands has clear seawater and good current rotation. Coral reefs could sustain growth preferable on clear water so that the photosynthesis process will continually occur [50]. Another factor that influences coral growth is sedimentation, which does not occur on Anambas Islands cause Anambas Island possess less riverine. Based on water conditions, Anambas Islands have good water conditions to assist the recent develop coral habitat.

Our coral growth rate research is based on Acroporidae, which has a lower difficulty finding Acroporidae fragments in its natural habitat. Several studies reveal Acroporidae growth rate in Indonesia
in non-Coral Triangle zone only around 30-40 mm/year on rehabilitation program [11]. Whilst on natural habitat could reach 150 mm/year [11]. However, our research exhibit Acroporidae on rehabilitation sites could grow to 100 mm/year. Planted coral fragments on coral reef-building could be extended to 600 mm at the end of 2019. Fluctuation occurs on coral growth rate each year with a maximum growth rate from 2014 to 2015 and gradually declines after 2015. 2014 to 2015 is peak coral growth on Anambas Island that biologically certain biota also has peak growth rate at the juvenile stage and gradually decline after the adult stage. Growth in the adult stage will be indicated by a stagnant growth rate each year of that biota, including coral reefs [51]. Anambas Islands coral growth rate that generally higher than other coral reef rehabilitation sites indicated several variables, especially benthic communities, which support resiliences and growth of coral reefs.

Yearly, coral reef ecosystems are affected by different benthic community changes—high silt coverage and abundant other biotas that withstand degraded ecosystems. High silt deposition on coral reef ecosystems would be an inclement impact on coral reefs and other biotas which live on coral reef ecosystems [45]. Sea urchins and anemone included in other biota groups is observed in the early year stage of the rehabilitation program. Sea urchins are identified as one indicator of the degradation of their ecosystems [52]. Sea urchins could be outbreaks if there are no sea urchins’ predators, mostly from the Scaridae reef fish family. Low coverage of coral reefs on the early stage of rehabilitation leads to loss of refuges for several territorial reef fish, including Scaridae. Several studies exhibited that sea urchins blooming could alter the coral reef ecosystems into algae ecosystems [52,53].

Next two years of the rehabilitation program, hard coral become significant recovery the ecosystems. Good water condition and support systems around rehabilitation sites provide a good niche for hard coral to grow significantly. Artificial reef-building functionally becoming a grazing area for reef fish, especially herbivorous. Herbivore reef fish ecologically suppress the algae growth around rehabilitation sites. Most studies indicated algae as an adversary for recent coral colonies in the early stage of rehabilitation [54]. Sea urchins’ existence is controlled by the predators, which are mostly from the Scaridae reef fish family. At this stage, rehabilitation sites are ecologically restored to the food chain from the lower class. Mostly, herbivorous, benthic invertivorous, and planktivorous are filled on the early-stage food chain. Hard coral on early year progress only reaches functionally as a nourishment area for herbivorous, benthic invertivorous, and planktivorous biota. Hard coral complexity growth is still low, which could not give refuges or shelter to nektonic biotas.

The last two years observation exhibit good coral reef ecosystems based on biotic as well as abiotic. Based on biotic, hard coral has developed an ecosystem of coral reefs as refuges for many biotas. Contexture of coral reef-building growth widely could become a niche for various biotas. Soft coral significantly grows following shifting algae community to coral reef ecosystems. Most research on coral reef ecosystems shows that soft coral growth indicates the early development of coral reef ecosystems at rehabilitation on degraded ecosystems. Soft coral growth on ready-made coral reef ecosystems will deduct the possibility of soft coral outgrowth. Soft coral blooming could slowly depress hard coral growth by cover its surfaces. Abiotic exhibit shifting from silt coverage to sandy benthic cover. Sand ecologically produce by the excretion process of the Scaridae reef fish family [46,47]. Sand benthic coverage indicates the ecological process of healthy coral reef ecosystems functionally decent. Large-bodied nektonic are observed around rehabilitation sites which from herbivore and carnivore trophic classes. The existence of top predators on coral reef ecosystems represents the completeness of trophic levels and stable reef fish community structure. Precipitate hard coral growth will ecologically escalate coverage of dead coral with algae. However, in Anambas, the growth rate of dead coral with algae is controlled well by herbivorous biota. Complex rugosity of coral reef-building gave a shelter for other biotas with small-bodied or cryptic fauna, with the result that difficult Bentos observation.

5. Conclusion
Available niche for other marine fauna built by artificial reef-building could preserve the coral fragments, especially in the early stage. Acropora and Montipora genera become a pioneer on rehabilitation sites. Silt existence on early-stage rehabilitation indicated defects of coral reef ecosystems, which emphasis from mainlands. Acquisitions of hard coral by coral fragments could be supported by good coverage of natural
hard coral in habitats around rehabilitation sites. Herbivorous is one factor that could support recent coral reefs ecosystems. Good coral reef ecosystems in 2019 are indicated by a rapid growth rate of hard coral, the existence of top predators on the ecosystems, complex rugosity of coral reef-building, which could lead to the existence niche for many biotas.

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