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CORAL RECRUITMENT ON ARTIFICIAL PATCH REEFS DEPLOYED IN THE MARGINAL REEFS: EFFECT OF MULTILEVEL SUBSTRATE ON DENSITY OF CORAL RECRUIT

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ABSTRACT

A study of coral recruitment on Artificial Patch Reefs (APR) was performed in the marginal reef of Panjang Island, Central Java (Java Sea) to examine whether multilevel substrates of APR affect the density of coral recruits. Long-term and short-term observations were applied in yearly monitoring 2017-2019 and biweekly observations for 3 months in early 2019. Coral recruitment significantly varied among level substrates of APR ($F_{(a,b),.05}=3.08$; $p\text{-value}<0.05$) and there was a significant difference at the beginning of the year ($F_{(a,b),.05}=5.52$; $p\text{-value}<0.05$). The density of recruits on the substrates after 4 years post-deployment of APRs was 0.2 to 129.2 m^{-2} while the recruitment rate within short-term observations was 0.28-1.28 m^{-2} per month. The highest coral recruitment occurred at the middle to the top level of APR, while the lowest recruitment was found in the lowest level of APR. This is possibly due to high resuspension from the seabed. *Oulastrea* was dominant in both long- and short-term recruitment periods while *Pocillopora* was rare due to post-settlement mortality which trigger the overgrown coral-killing sponges. The results indicated that the adaptation of coral recruitment in the marginal environment is determined by the high recruitment of the small-colony coral species which possessed stress-tolerant for turbidity disturbance, such as *Oulastrea crispata*. This study suggested that the multilevel substrates, Artificial Patch Reefs (APR) are one of the reef rehabilitation methods which can be applied in the marginal environment enhancing coral recruitment.

Keywords: Density of coral recruits, coral recruitment, multilevel substrate, artificial patch reef (APR).

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INTRODUCTION

Coral reefs are important ecosystems for human life, they have provided marine resources for the supply of food and environmental services. Recently, the reef ecosystem has been threatened by global climate change, anthropogenic, destructive fishing practices, and sedimentation (Burke *et al.*, 2011; Ferrigno *et al.*, 2016). Sedimentation is one of the serious problems for coral reef management in several regions in Southeast Asia, mainly in Singapore, the Philippines, Malaysia, and Indonesia (Burke *et al.*, 2011). Strong inflow sediment in a tropical coastal area which cause turbid water are usually referred to as marginal condition (Kleypas *et al.*, 1999; Loiola *et al.*, 2019). Consequently, marginal reefs are characterized by the low in percent cover and diversity of coral species (Otãno-Cruz *et al.*, 2019) due to the reduction of coral reproductive capacity and recruitment. In the eutrophicated waters, coral settlement is primarily affected by water quality and substrate condition (Ritson-William *et al.*, 2009). Low salinity affects to the pre- and post-settlement mortality (Ritson-William *et al.*, 2009), while the sediment layer on the substrate can also prevent coral larval settlement. Furthermore, the heavy nutrient enrichment leads to an overgrowth of algae, result the high space competition (Speare *et al.*, 2019; Ricardo *et al.*, 2017; Randall *et al.*, 2020).

Rehabilitation of coral reefs using artificial reefs in sedimented environments have been applied in several areas (McLean *et al.*, 2015; Ng *et al.*, 2016; Ng *et al.*, 2017). The main objective of coral reef restoration efforts using artificial substrate is to provide a substrate for coral settlement and coral transplantation (Meesters *et al.*, 2015; Boström-Einarsson *et al.*, 2020). However coral recruitment on artificial reefs deployed in the marginal environment waters were not satisfying as indicated by the low density of recruited coral (Chui & Ang 2017; Otãno-Cruz *et al.*, 2019; Subhan *et al.*, 2019). Moreover, many experiments of coral recruitment in the marginal waters using settlement plate also resulted in low recruitment and mostly composed by the pioneer corals i.e., Acroporid and Pocilloporid (Faiz *et al.*, 2017; Purnomo & Afiati 2018; Lubis *et al.*, 2018). However, different result was found on the settlement plate installed in the water column of the reef flat in the marginal reefs of Panjang Island, Java Sea which showed high recruitment of Pocilloporid (Munasik *et al.*, 2014). The reef of Panjang Island is threatened by coastal water pollution due to domestic waste and aquaculture runoff, high turbid water, and high resuspension (Holmes *et al.*, 2000), and therefore need to restore. Randall *et al.* (2020) suggested that the applications of various shapes and rugosity of the artificial reefs increase the success rate of the coral restoration in the coastal environments. In the present study, multilevel of Artificial Patch Reefs (APR), a

combination of concrete substrate installation, and coral transplantation have been applied to eutrophicated waters of Panjang Island (Munasik *et al.*, 2018) in order to increase coral recruitment. The artificial patch reef does not only provide a substrate for coral transplantation but also traps the coral larvae to increase the biodiversity of the shallow water habitat. This paper examines the effect of the multilevel artificial substrates on the juvenile density and population structure of the dominant recruited coral in the marginal environment.

METHODOLOGY

Study area

Reef restoration project in the marginal reef was initiated in 2015 by the deployment of two artificial patch reefs in the northeast of Panjang Island, Central Java (6°34'30"S; 110°37'44"E; Figure 1). Reef of northern Panjang Island is polluted due to domestic waste and aquaculture runoff (Edinger *et al.*, 1998), high turbid water with suspended particulate matter (SPM) 21.83 ± 8.40 mg/l and with high resuspension 26.19 ± 24.42 mg/cm²/day (Holmes *et al.*, 2000). Artificial Patch Reefs (APR) is a multilevel modular concrete block structure with circular form which is deployed at 4-5 m depth. APR provide spaces for both coral transplantation and coral recruitment (Munasik *et al.*, 2018). Branching coral, *Acropora* has been transplanted on the surface of substrate multilevel APR after deployment of the modules in the seabed. In order to observe long-term coral recruitment, two artificial patch reefs APR#1 and APR#2 which were deployed on June 8th, 2015, and September 22nd, 2015 respectively were inspected yearly. Short-term coral recruitment was examined for selected 2 APRs (APR#4 and APR#12) biweekly. Additional long-term coral recruitment observations were examined on two APRs which deployed in December 2016 (APR#5 and APR#7).

Procedures

Long-term (2017-2019) and short-term (2019) coral recruitment observations were performed to assess the density of coral recruits on the multilevel substrate of APR at Panjang Island, Central Java. Annual monitoring of coral density on the multilevel substrate of APR#1 and APR#2 was performed in April 2017, May 2018, and July 2019 while additional observations of coral density were monitored on APR#4 and APR#12 in May 2018 and July 2019. Biweekly monitoring of coral recruitment on the multilevel substrate of APR#4 and APR#12 was also made in the full moon and new moon from 18 January to 11 April 2019.

Coral juveniles were individually recorded on the surface of the multilevel substrate by taking photographs

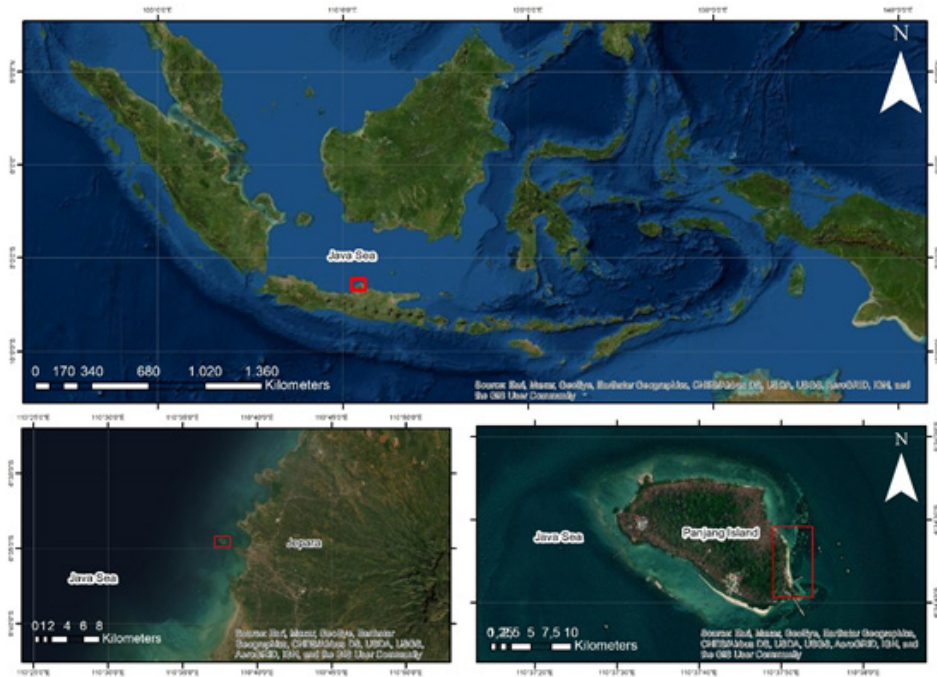


Figure 1. Study site of coral recruitment on multilevel Artificial Patch Reef at Panjang Island, Central Java.

using a 16.5 mega-pixel Nikon (Coolpix 4K UHD) digital camera and putting the scale beside each juvenile. Coral recruits in each APR were photographed initially from modules laid at the low level to the top-level substrates. The multilevel substrate of APR#1 and APR#2 was constructed by 5 levels, level 1 in the low level of APR and level 5 on the top of the APR, while APR#4, APR#5, APR#7, and APR#12 consisted by 4 levels (Munasik *et al.*, 2020; Figure 2). Coral taxa were identified to generic level and diameter length of juveniles were measured using image analyses of computer software, Image J. Density of coral juveniles was calculated by a total number of corals recruits each total surface area of the substrate of the APR in each level per year. The horizontal and vertical surface areas of the multilevel substrates at each level were used to measure the density of coral recruits. Surface area of APR#1 and APR#2 in level 1, 2, 3, 4, and 5 were 4,99 m², 4,05 m², 3,11 m², 2,17 m², and 1,22 m²

respectively, while the surface area of APR#4, APR#5, APR#7 and APR#12 for level 1, 2, 3 and 4 were 4,05 m², 3,11 m², 2,17 m², and 1,22 m², respectively.

Procedures

The density of coral juvenile data from the observation period 2017-2019 was analyzed using two-way variance (ANOVA, at 95% confidence level, $p < 0.05$) to test the significance of the difference in coral recruitment among substrate levels of APR and time (year). Post hoc, pair-wise comparisons were performed using Tukey's Honestly significant Difference (HSD) test. Chi-squared contingency table analysis was used to test for common genus of coral juvenile, the hypothesis that the size-frequency distribution dependent upon levels of substrate. Generic differences were analyzed by t-test from pooled data number of two common species of coral juveniles, *Oulastrea crispata* and *Porites cylindrica* on the substrate of APR

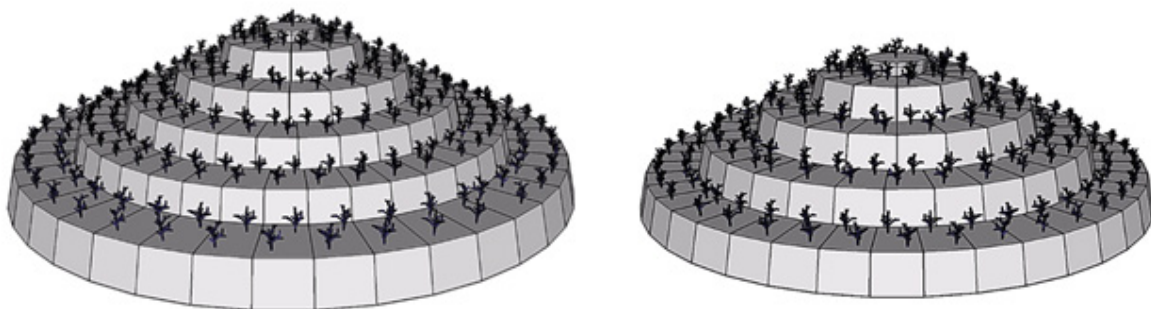


Figure 2. Multilevel substrate of Artificial Patch Reef (APR) deployed in Panjang Island, Central Java made by concrete block which combined in coral transplantation for coral recruitment study (a. APR#1 and #2; b. APR#4, APR#5, APR#7 and APR#12; Munasik *et al.*, 2020) .

after 4 years post-deployment. In order to examine coral juvenile population dynamic, the size (in diameter length) of the dominant recruits *O. crispata* in APR#1 which observed in 2019 was calculated using the frequency distribution parameters skewness and kurtosis (Meester *et al.*, 2001)

RESULTS AND DISCUSSION

Density of Coral Recruits

Densities of coral recruits on artificial patch reefs (APR) for short-term recruitment was 1.2-22.1 m⁻², density increase with time (Table 1), and recruitment rate was 0.28-1.28 m⁻² per month. Within long-term recruitment, densities of coral recruits on artificial patch reefs (APR) after 4 years post-deployment generally varied (0.2 to 129.2 m⁻²) and differed significantly among levels of substrates (Fig 3, F(t, a) .05=3.08 P<0.05). Tukey Post Hoc multiple comparisons test indicated densities of coral recruits varied significantly (1.3 to 33.3 m⁻², P<0.05) in level 1, 3, 4, and 5 of APR#1 substrates during the recruitment period of the studies. Densities of coral recruits varied significantly in levels 3, 4, and 5 of APR#2 substrates (2.8 to 11.9 m⁻², P<0.05) while coral recruits were absent on level-4 and level-5 of the APR#2 substrates (Figure 4). Additional observation of coral recruitment from separate APRs (APR#5 and APR#7) which were examined 3 years after deployment also varied significantly among levels of the substrate (Figure 5). These results indicate that different levels of multilevel APRs significantly affect the variation of juvenile density during the recruitment period and higher densities occur on level 4 of APR substrate. Yearly observation showed that the coral recruit densities on the multilevel substrate of APRs differed significantly (F(t, a) .05=5.52 P<0.05) between 2017 and 2018 during the recruitment period (Figure 4). Interannual recruitment demonstrated a variety of coral recruitment rates in the first year of the recruitment period. First-year recruitment was only found on level 2 and level 3 of the APR while in the second-and third-year coral recruits occurred in all level substrates of APR, indicated a high recruitment rate during 2018-2019.

Generic Composition of Coral Recruits

Annual monitoring of the coral recruitment period (2017-2019) shows that eight genera of coral juvenile i.e., Acropora, Favia, Favites, Goniastrea, Oulastrea, Pocillopora, Porites, and Stylophora were found on the surface of APR substrate. Meanwhile, four coral genera were found during biweekly observations, i.e., Goniastrea, Oulastrea, Pocillopora, and Porites. Two observation periods show that *Oulastrea* was the most dominant and the second one was Porites. Percent occurrence of *Oulastrea* and Porites for biweekly observation were 65-71% and 18.5-20.5%, respectively.

In the last year's observations, *Oulastrea* (n= 500, range density 0.2-129.2 m⁻² and 68.1%) is much more abundant (paired t-test t = 2.28, df = 19, p <0.05) than Porites (n= 179, range of density 0–40.8 m⁻² and 24.4% of the total number coral recruits). Although *Oulastrea*, Porites, Pocillopora, and Goniastrea possessed recruiting every month, only *Oulastrea* and Porites were found in all level substrates of APR with the highest density occurred on level 4 after long-term observation (Figure 6). The density of *Oulastrea* recruits increases with increasing level of APR, while the density of Porites was found relatively consistent in each level, particularly in APR#2 (Figure 7) and the highest density occurred on level 5 of APR#1. The results showed the pioneer species of Acropora and Pocillopora were found in a different pattern of recruitment. Acropora had low density in the lowest substrate level of APR in 2017 and 2019, while Pocillopora was found on the top level of APR in first- and second-year recruitment. The results indicated that the pioneer species of coral Pocillopora have died during post-settlement, and consequently the tolerant-coral *Oulastrea crispata* was predominant on the multilevel substrates of APR in the marginal reef (Figure 8).

Size Frequency Distribution of Coral Recruits

Distribution of coral size classes shows that the common species of coral juveniles, *Oulastrea crispata* was significantly dependent on levels of APR substrate (p <0.05). Size-frequency distribution of the dominant species *O. crispata* showed a normal distribution in all levels of APR substrate, except in level 5 of APR#1 (Figure 9). Kurtosis of the distribution of coral size classes

Table 1. Density of coral recruits (recruits/m²) during the biweekly observation of short-term recruitment on the multilevel substrate of APR#4 and APR#12, January-April 2019

Genera	18 Jan	01 Feb	21 Feb	08 Mar	24 Mar	11 Apr
<i>Oulastrea</i>	18.3 ± 2.7	19.5 ± 2.1	19.5 ± 2.1	20.6 ± 1.9	21.3 ± 2.5	22.1 ± 3.0
<i>Porites</i>	5.1 ± 0.6	5.2 ± 1.0	5.3 ± 0.8	5.8 ± 1.1	6.4 ± 0.7	7.3 ± 0.5
<i>Goniastrea</i>	1.2 ± 0.6	1.4 ± 0.7	1.4 ± 0.7	1.8 ± 0.5	2.1 ± 0.7	2.2 ± 0.7
<i>Pocillopora</i>	1.2 ± 0.3	1.3 ± 0.1	1.4 ± 0.2	1.7 ± 0.1	1.8 ± 0.1	2.0 ± 0.2

Note: All results are expressed as mean ± SD.

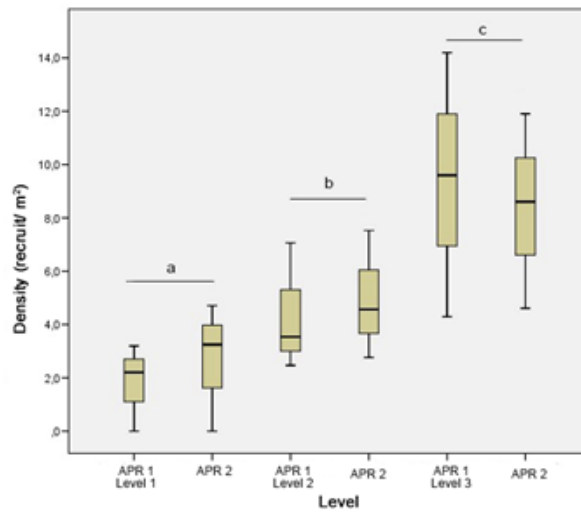


Figure 3. Comparison of coral recruit density in different level of APR for observation period 2017-2019, APR#1 deployed on June 2015 and APR#2 deployed on September 2015 (only level 1, 2 and 3 were analyzed cause of coral juveniles on level 4 and 5 of APR#2 were absent).

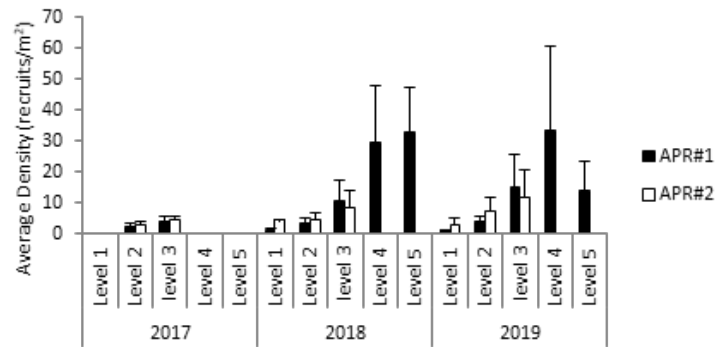


Figure 4. Average Density (\pm SD) of coral juveniles in different level of APR for observation period 2017-2019.

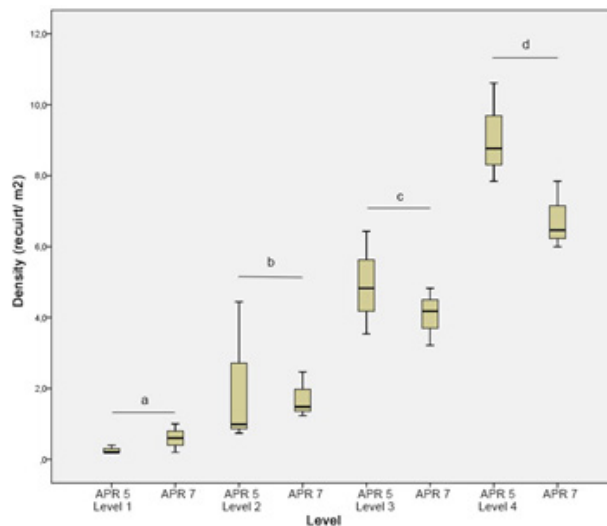


Figure 5. Comparison of coral recruit density in different level of APR for observation period 2018-2019 (APR#5 and APR#7 deployed on December 2016).

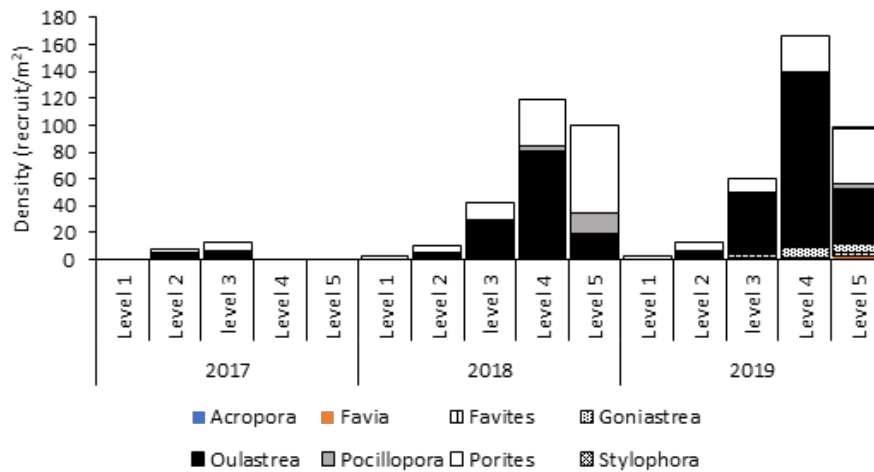


Figure 6. Density of coral juveniles (recruits/m²) in different of generic composition on multilevel substrate of APR#1 deployed on June 2015.

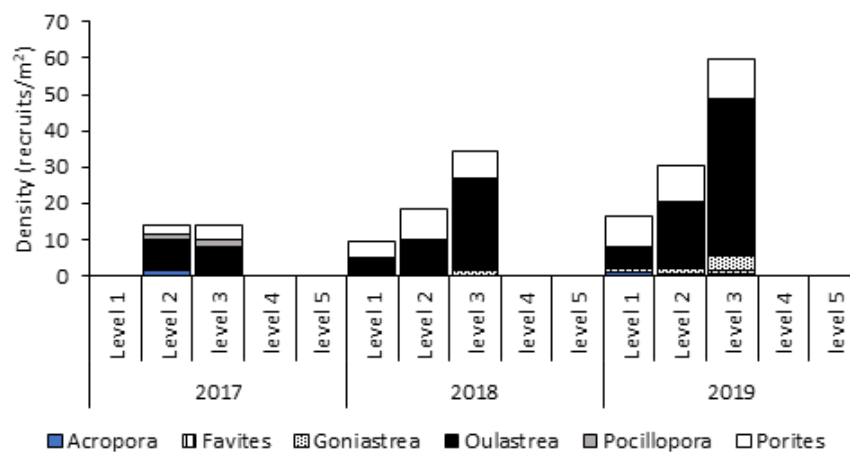


Figure 7. Density of coral juveniles (recruits/m²) in different of generic composition on multilevel of APR#2 deployed on September 2015.

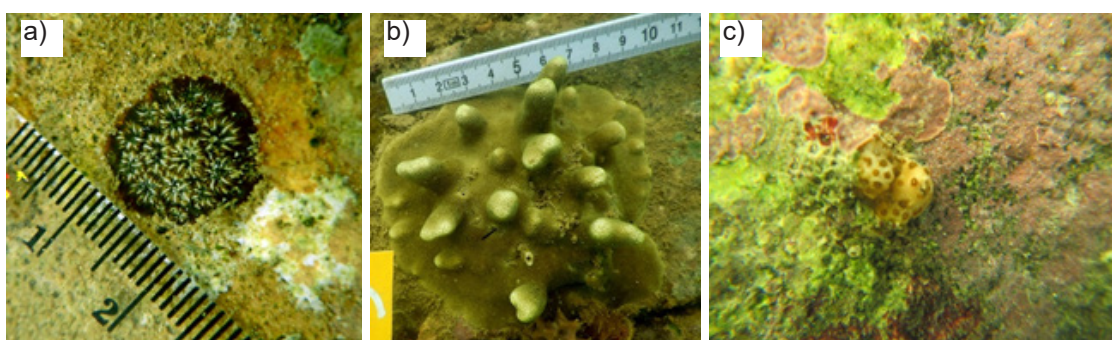


Figure 8. Coral recruits were observed on the surface of multilevel substrate of APR (a. Dominant coral recruits of *Oulastrea crispata*, b. The second dominant coral *Porites cylindrica*, and c. *Pocillopora* competes for space with sponges).

indicated that the population of *O. crispata* displayed a negative distribution (flatter than normal distribution) in the level 2 and 3, while positive distribution (very peaked) occurred in level 4 and 5 of APR#1. This result indicates the size distribution of coral juveniles in a low

level of APR with relatively fewer recruits in the smaller size classes and the preponderance of larger recruits.

The application of multilevel artificial patch reef (APR) is designed for coral reef restoration by utilizing

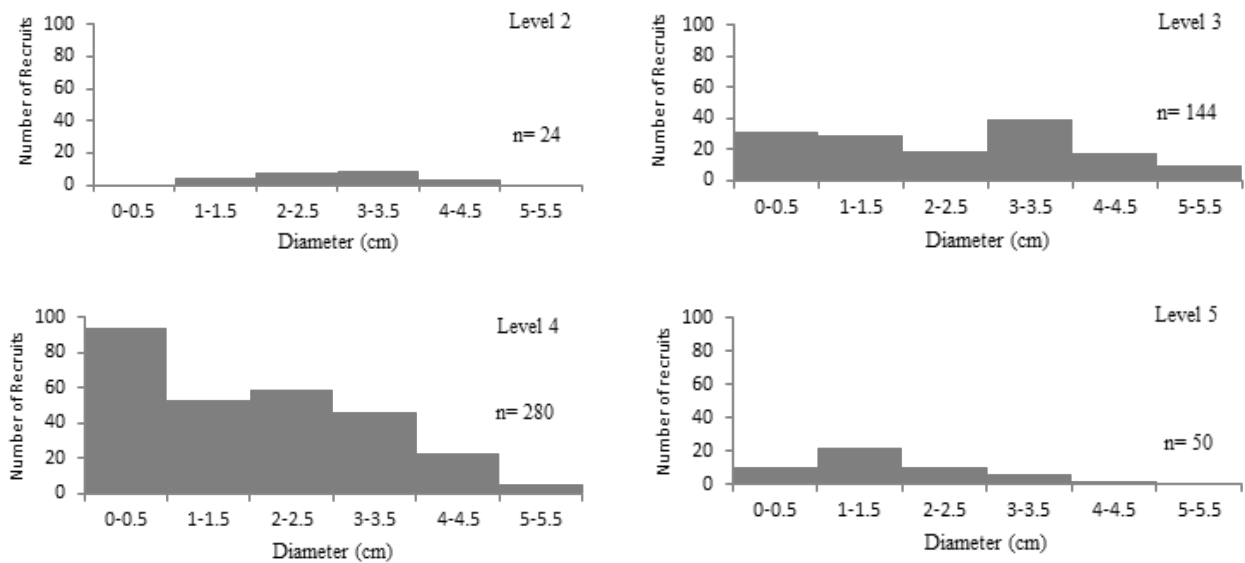


Figure 9. Size frequency distribution of *Oulastrea crispata* on different level of APR#1 observed in 2019.

the combined sexual and asexual reproductive capabilities of corals (Munasik *et al.*, 2018). However, the function of multilevel artificial patch reefs for the growth of coral communities by sexual reproduction, particularly as larval traps has not been revealed. As shown in Figure 3, 4, and 5 the results showed that there had been coral recruitment on the multilevel artificial reef substrate in a marginal environment which was indicated by the increase of the substrate level, the higher the recruitment rate. The juvenile density and diversity increased with higher levels of the substrate, indicating the top level of APR has provided the most suitable substrate to support the survival post-settlement recruits. Thus, a higher recruitment rate in the top-level substrate indicates that the coral larvae have the competence to select site settlement to overcome grazers predation and sedimentation impacts (Humanes *et al.*, 2017; Speare *et al.* 2019; Randall *et al.*, 2020) No recruitment was found at the top level of the substrate at one of the APRs (Figure 3, 4). It was possibly due to the mortality of the transplant corals at that level. Subsequently, the substrate surface was exposed and overgrown with algae. Ferse *et al.*, (2013) has considered that high mortality of the coral transplant is probably to decrease coral recruitment. The results indicated that the increase in coral recruitment rates was determined not only by high levels of the APR substrate but also the possible presence of transplanted corals in the artificial reef structures.

The results showed that the composition genera of the coral recruits on the artificial reef structure were not the same as the genera of the transplanted coral. Single genus of Branching *Acropora* which transplanted on artificial patch reef is broadcast-spawner (Munasik

& Widjatmoko, 2005) possess a low contribute for coral recruits, it probably spawn and disperse their gametes far away from the structure. The results indicate that most of these coral recruits were thought to come from coral larvae sourced from natural coral reefs carried by local currents. Coastal current is generally generated by a coupling between tidal elevation waves and monsoonal winds (Siregar *et al.*, 2017; Bonauli *et al.*, 2016), process of larval dispersal in Karimunjawa, Jepara waters was influenced by currents, tides and monsoonal winds (Indrayanti *et al.*, 2019). Previous studies suggested that tidal current influenced the dispersal of coral larvae in Panjang Island, Jepara (Munasik *et al.*, 2006). During low tide, the current flows to the north and after passing in Panjang Island, the current partly splits to the southeast, flows to the north and west and northwest. The results inferred that short-term recruitment, showed an increasing the density of coral recruit in biweekly (see Table 1), indicates the predominant contribution of tidal currents on coral recruitment to the structures. Thus, the tidal current will be the main variable in determining the selection of artificial reef deployment sites to enhance coral recruitment density and replenish diversity on marginal reefs.

The pattern of coral recruitment in the multilevel artificial patch reef structures in the marginal environment is characterized by the high recruitment rate of stress-tolerant species *Oulastrea crispata*. This is probably related to their reproductive strategy of corals. The predominant species, *O. crispata* was found in all substrate levels of the artificial reefs, from low level to the top-level substrate (Figure 8a, 9), indicating the small pioneer species survived in low to high light in the top level of the substrate (Lam, 2000b; Denis

et al., 2012). The higher density of the species on the substrate may cause a combination of their mode of development as a brooder. The broadcast-spawner has the ability to reproduce out of reproductive season through both sexual and asexual planulae production (Lam, 2000a), and possess wide settlement preference for various substrates conditions (Lam, 2000b). Thus, the species was actively reproducing and recruiting outside the coral reproduction season (Table 1) and able to survive both in pre-settlement and post-settlement in extreme environmental conditions. In contrast to the dominant species strategy, juvenile *Porites* probably originates from the contribution of adult coral populations, *P. cylindrica* near artificial reefs. The tropical *P. cylindrica* corals are known as brooder corals (Abecia et al., 2016) which is assumed to be capable to release planulae and then settle on to substrate surface near their parent colony (Rodríguez-Troncoso et al., 2011).

Low recruitment of the pioneer coral, *Pocillopora* and *Acropora* on the artificial substrate in the marginal environment is probably caused by their reproductive strategy and survival of their post-settlement. Although *Pocillopora* produced larvae every month and were successfully recruited in shallow reef (Munasik et al., 2014), the results show that their recruitment after 4 years of substrate installation was low (Figure 6, 7). Coral recruitment in shallow waters is characterized by the failure of the post-settlement process due to increased mortality (Nozawa et al., 2013). Observations during short-term recruitment indicate that many juveniles *P. damicornis* died during post-settlement which triggered overgrown coral-killing sponges (Figure 8c). The rapid development of sponge outbreaks in environments that have experienced turbidity has recently threatened the health of coral reefs in several Indo-Pacific regions (Fromont et al., 2019), including Indonesia (Maduppa et al., 2017). Presence of sponges negatively affected to the coral recruitment (Brandt et al., 2019), and *Pocillopora* is one of the genera which was infected coral-killing sponges in Indonesia waters (Utami et al., 2018). Meanwhile, the low recruitment of *Acropora* corals may be due to its reproductive strategy. Branching *Acropora* which is known the broadcast-spawner species which has a limited reproductive season, biannual spawning (Munasik & Widjatmoko 2005; Wijayanti et al., 2019) is most likely allocated their reproductive capacities for fragmentation rather than sexual reproduction. The success of the reproductive strategy had the support to previous results the high growth of *Acropora* transplant at APR in turbid water (Munasik et al., 2020). In the future, the application of multilevel artificial patch reefs by transplanting the local *Acropora* and deploying the structure adjacent to natural reefs are recommended for coral reef restoration in the marginal environments.

CONCLUSION

Coral recruitment on the multilevel artificial reefs substrate in a marginal environment was indicated by the increase of the substrate level, the higher the recruitment rate. The juvenile density and diversity increased with higher levels of the substrate of APR while larger size of juvenile was found in vice versa. Pattern of recruitment characterized by the high recruitment rate of stress-tolerant species *Oulastrea crispata* and low recruits of the pioneer coral, *Pocillopora* and *Acropora*.

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