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ORIGINAL ARTICLE

Spatial and Temporal Variation of Scleractinian Coral Recruitment in Balok Coastal Waters and Bidong Island, Malaysia

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Abstract

Understanding coral recruitment is important as increasing of regional decline of coral reef worldwide. This study aimed to investigate the spatial and temporal coral recruitment patterns around reef sites in Balok coastal waters and Bidong Island, Malaysia. Recruitment density was determined by quantifying number of coral recruits settled on the terra-cotta tiles and artificial reef settlement plates. In Balok coastal waters, a total of 159 coral recruits were counted with 0.09 ± 0.03 n/m^2 mean recruitment density per plate, while in Bidong Island, a total of 319 coral recruits were counted with 0.19 ± 0.02 n/m^2 mean recruitment density per plate. Coral recruits were dominated by genus *Pocillopora* followed by *Stylopora* and *Seriatopora* in Bidong. Meanwhile in Balok, genus *Platygyra* was dominant coral recruits followed by *Porites* and *Fungia.* Additionally, minor spawning event was predicted in Balok coastal waters in September due to increase number of *Platygyra* coral. Recruitment density varied significantly between locations, types of settlement plates and plate's orientation at both study areas. Current findings highlighted the significant use of artificial reef plates to increase the chances of larval settlement. This research also provides important information in assessing coral resilience towards different environmental conditions between coastal and sheltered reef areas.

Keywords: Scleractinian coral, coral recruitment, coral spat, terracotta tile, artificial reef plate

Introduction

Malaysia's coral reefs cover approximately 4,000 km^2 areas (Wilkinson, 2008) and contain an estimated 500 hermatypic coral species, which equivalent to more than 60% of the worlds described hermatypic corals (Veron *et al*., 2011). However, reefs are increasingly threatened due to a multiple of anthropogenic stressors such as coastal development, sedimentation, nutrient pollution and tourism related activities (Praveena *et al*., 2012). It is estimated over 40% of Malaysian reefs are exposed to high and very high threat levels (Burke *et al*., 2011). The coral condition has become worsened by the effects of natural bleaching phenomenon recorded in 1998 and 2010 due to the El Niño event, which caused from mild to severe bleaching impacts of hard corals around islands in Peninsular Malaysia (Tan and Heron, 2011).

The increasing frequency and intensity of these coral threats are significantly reducing the coral population sizes in the near future. Therefore, knowledge of coral recruitment is crucial for measuring population density and understanding resilience recovery capacity especially in the area that exposed to various human disturbances (Salinas-de-León *et al*., 2013). Coral recruitment has been widely investigated around the Indo-Pacific reefs. It has been reported that the different in latitudinal regions might affect the relative abundance of coral recruits (Adjeroud *et al*., 2010). Previous studies indicated that the broadcast spawner of acroporids recruit in abundant at low latitude (Ho *et al*., 2014) while the brooder spawner of pocilloporids, dominated at high latitude regions (Tioho *et al*., 2001).

Besides, the artificial settlement plate is widely used to estimate the relative abundance of coral recruits over both time and space (Perkol-Finkel *et al*., 2007). Many research studies have been done to describe the characteristics of settlement plate in terms of material composition (Saliu and Ovuorie, 2006), size of artificial substrate (Field *et al*., 2007), angle of settlement panel (Salinas-de-León *et al*., 2013) and surface structure (Nozawa, 2008). However, the different of surface structure and position of settlement plate that might give effect on coral recruitment pattern have not been well documented.

Therefore, the present study contributes to fill in the gap in information regarding coral recruitment pattern in Bidong Island and Balok coastal waters. The spatial and temporal variations of scleractinian coral recruitment density were assessed in multi-dynamic scales of plate orientation and different types of substrate (artificial reef plate and terracotta tile) between both study areas. The outcome of this study provides reliable scientific data and information on scleractinian coral recruitment and factors influencing their recruitment processes between Bidong Island and coastal waters of Balok.

Materials and Methods

Description of Study Area

Sampling was carried out at Bidong Island, Terengganu and Balok coastal waters, Pahang off the east coast of Peninsular Malaysia. Both areas have different environmental conditions, where Bidong Island is situated in sheltered reef area with less coastal development activities while Balok coastal water, situated in exposed reef area with high human pressures since located near to Gebeng industrial area and Kuantan Port.

Besides, Bidong Island is characterized as well-developed reef ecosystem with high diversity and distribution of corals. Whereas, Balok coastal water consist of coral patches lined the reef slopes and mostly dominated with stone rock. Three sampling stations per study area were selected for coral recruitment study (Figure 1).

Settlement Plates Used for Density Measurement of Coral Recruit

Two types of settlement plates were used to observe the density of coral recruits namely terracotta tile (20 x 20 x 0.5 cm) and artificial reef plate (20.5 x 20.5 x 4 cm). The surface area of terracotta tile and artificial reef plate was approximately 8.4 m2 and 11.7 m2, respectively.

Terracotta tile has smooth surface structure (Figure 2), while artificial reef plates have rough, various grooves and larger pore size (Figure 3). Both settlement plates have different in terms of surface structure, mineral composition and apparent porosity (Table 1).

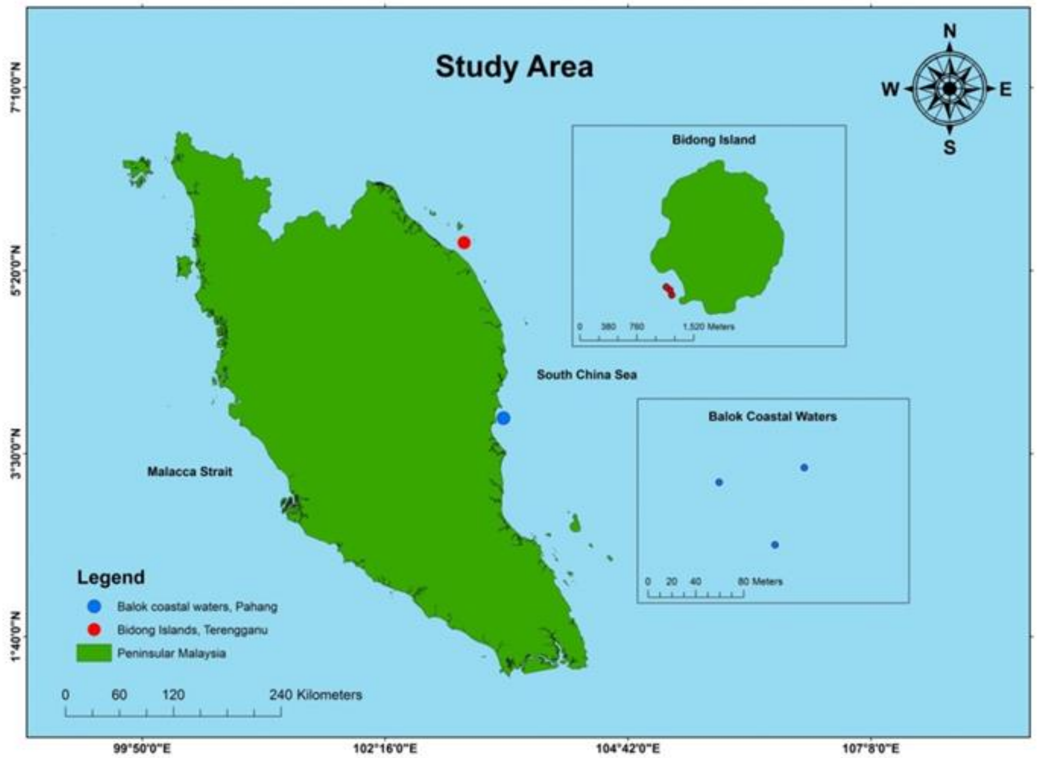

Figure 1: Sampling stations for coral recruitment studies in (a) Bidong Island and (b) Balok coastal water.

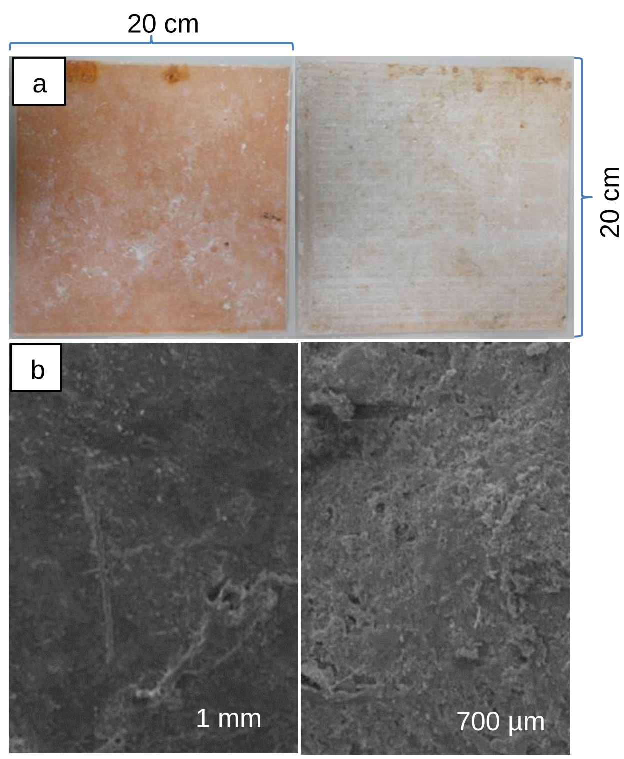

Figure 2: Images of smooth surface structure of terracotta tiles at front and back positions captured using (a) digital camera and (b) Scanning Electron Micrograph (SEM)

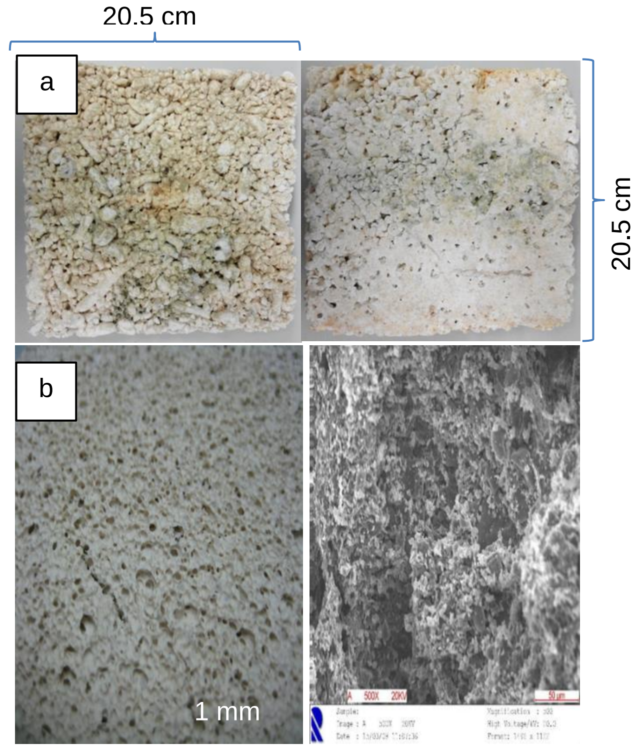

Figure 3: Image of rough surface structure of artificial reef plates at front and back positions captured using (a) digital camera and (b) Scanning Electron Micrograph (SEM)

Table 1: Comparison of apparent porosity test between artificial reef plates and terracotta tiles

No	Weight dry (D)	Weight suspended (S)	Weight saturated (W)	Volume (V) (W-S)	Apparent Porosity (W-D/V) x 100	Water Absorption (W-D/D) x 100	Density (D/V)
Artificial Reef	15.4365	9.5827	16.9005	7.32	20.01	9.48	2.11
Terracotta	7.3423	4.3416	7.7670	3.43	12.40	5.78	2.14

Deployment and Retrieval Methods of Settlement Plates

Settlement plates were attached to triangular steel frames approximately 1 m depth above the seabed (Figure 4). Each frame consists of 20 settlement plates (8 at left side, 8 at right side and 4 at upper side). Two sets of frames consist of different types of settlement plates (terracotta tile and artificial reef plate) were deployed side by side at different depth (Bidong Island: 6 m depth, Balok coastal waters: 7-15 m depth) which give a total of 240 settlement plates used in this study. Settlement plates were submerged in water column within 15 months (July 2013 to September 2014).

Throughout this study, a total of 108 plates were retrieved and analysed while 10 plates were lost due to wave and current actions. In Balok, three plates from each frame were retrieved in 3-month interval starting from March 2014. Meanwhile in Bidong, three plates also were retrieved from each frame in 2-month interval starting from April 2014 (Table 2).

The difference of retrieval interval was due to the environmental condition of the study areas. Sampling stations in Balok located near to shoreline about 5 nautical miles and experience strong current and unpredictable tidal fluctuation. The visibility is low ranging from 1 to 2 m depth depending on whether condition. In comparison to Balok, sampling stations in Bidong Island was easy to access and sheltered from strong current and wave actions.

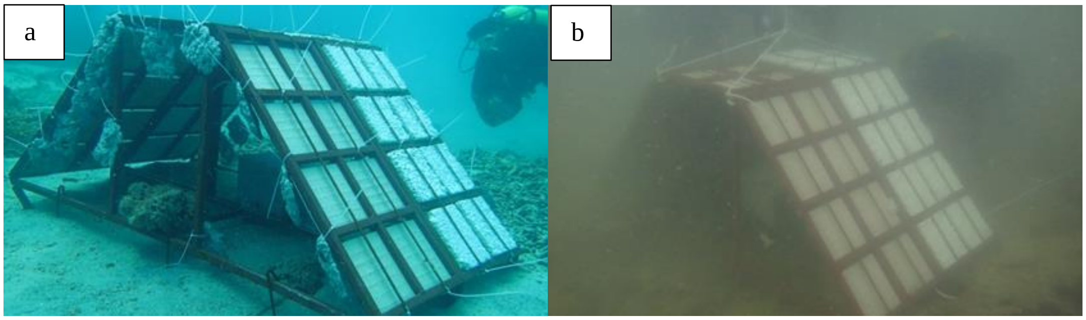

Figure 4: Settlement plates were arranged onto designated racks which placed close to each other; (a) Bidong Island and (b) Balok coastal waters

Table 2: Number of settlement plates retrieved throughout study period in Bidong Island and Balok coastal water

Sites	**Balok coastal water**			**Bidong Island**			
	03/2014	06/2014	09/2014	04/2014	06/2014	08/2014	Total
Station 1	6	6	6	6	6	5	35
Station 2	6	6	6	6	4	3	31
Station 3	6	6	6	6	5	3	32
Total	18	18	18	18	15	11	98

Analysis for Larvae Settlement Pattern and Identification of Coral Skeleton

The retrieval settlement plates were bleached in 10% sodium hypochlorite to remove soft tissue organisms and reveal the coral spat skeleton. Settlement plates were then rinsed with fresh water and dried in oven at 60°C for 2 days. The specimens were examined under Zeiss Stemi DV4 stereomicroscope at 40x magnification. The number of coral recruits was counted and classified based on reference from Babcock *et al*. (2013).

The identification method was applied based on review from Babcock *et al*. (2013) and Baird and Babcock (2000). The representative skeletons were photographed using Dino Lite Premier 2.0 digital microscope and coated with gold with Scanning Electron Micrograph (SEM) model Hitachi S-2500.

Statistical Analysis

One sample t-test was done to analyse the normal distributed data while the Kolmogorov Simonov test was used to analyse the non-normal distributed data. In terms of the variation of recruitment density, data of coral recruits between locations, plate's orientation and types of settlement plates were significantly non-normal. Thus, non-parametric Kruskal-Wallis was used for significant test of recruitment density. All analyses were done using SPSS software version 20.

Results and Discussion

Morphology and Development of Coral Recruits

In Bidong, three genera (*Pocillopora*, *Stylopora* and *Seriatopora*) from family Pocilloporidae were identified (Figure 5). Juvenile pocilloporids has a solid coenosteum, prominent septa and columella at early stage of development. After subsequent months, coral juvenile grow laterally as secondary corallite wall were developed upward. Then, coral juveniles have similar features of the adults after 12 months immersion (approximately 9 months after first coral spat observed).

Meanwhile in Balok, three coral families were identified namely Poritidae, Fungiidae and Faviidae (Figure 6). Juvenile poritids has 6 primary septa, and each has a single prominent vertical tooth. The corallite has grown by an extension of the basal plate beyond the epitheca. The primary septa has also grown beyond the epitheca and extended to the perimeter of the new boundary of the basal plate.

The development of family Faviidae is clearly seen after 11 months of settlement. Epitheca was observed in all faviids examined. Corallum observed as an extension of the basal disc across the surrounding substratum. For Fungiidae recruits, second wall had formed beyond the epitheca, presumably as a result of fusion of the synapticulae between the outer edges of the primary and secondary septa. The primary septa extended into the center of the corallite and obscured the columella.

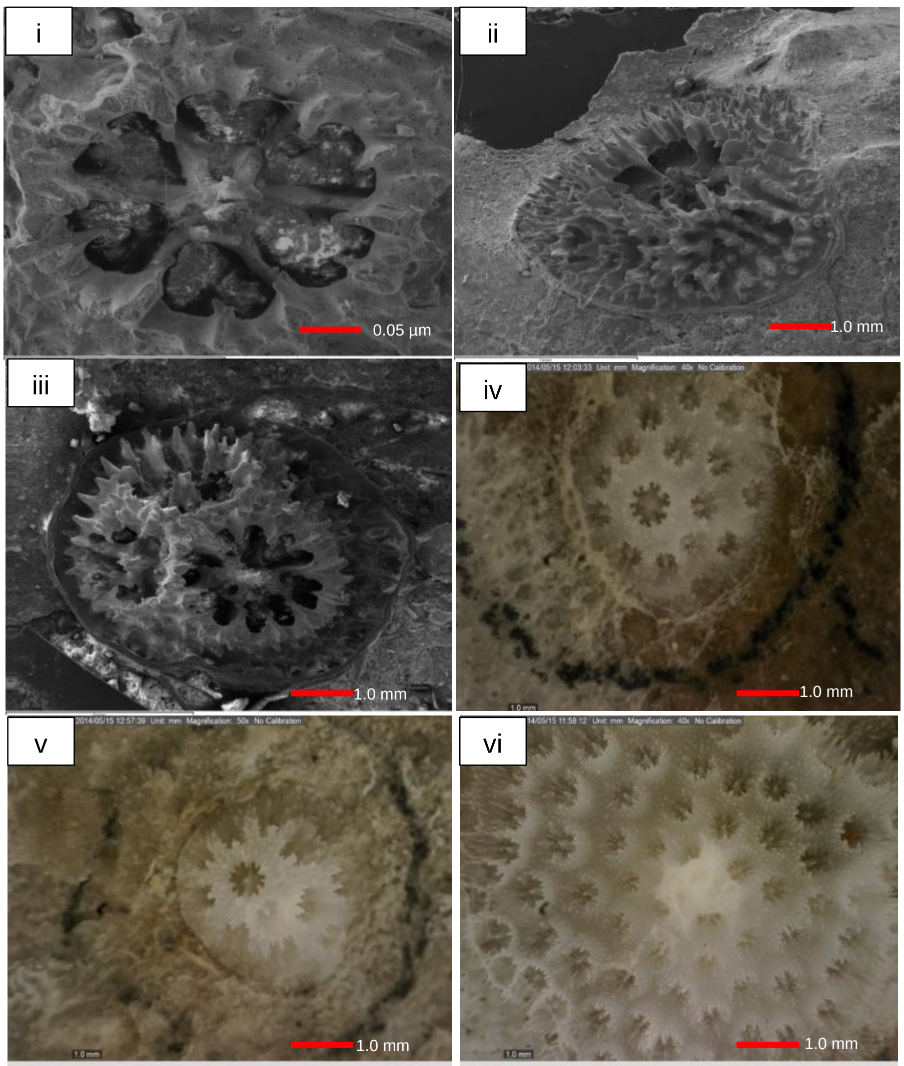

Figure 5: Pocilloporidae recruits development observed after i) 6 months; ii) 6 months; iii) 8 months; iv) 8 months; v) 10 months and vi) 10 months

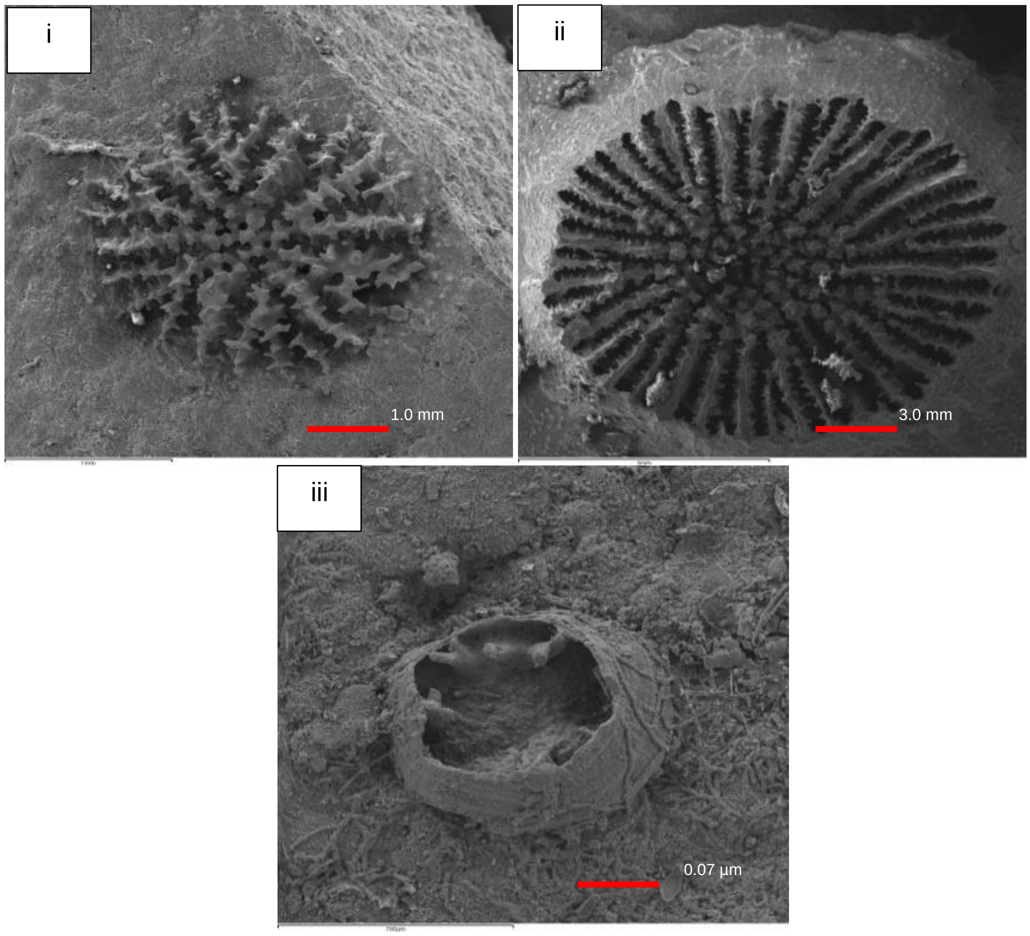

Figure 6: Coral recruits observed throughout the study for i) Poritidae (after 11 months), ii) Faviidae (after 14 months) and iii) Fungiidae (after 8 months)

Spatial and Temporal Variations of Scleractinian Coral Recruitment

In Bidong, a total of 319 coral recruits were recorded on both settlement plates with mean recruitment density of 0.19 ± 0.02 n/m2 per plate. Coral recruits were dominated by genera *Pocillopora* (297), *Stylopora* (14), *Seriatopora* (7) and *Porites* (1). Whereas in Balok, a total of 159 coral recruits were recorded on both settlement plates with mean recruitment density of 0.09 ± 0.03 n/m2 per plate. Genus *Platygyra* (58) was found dominant coral recruit followed by *Porites* (51) and *Fungia* (28). Other genera *Echinophyllia*, *Favites*, *Leptoria* and *Montipora* were found in low recruitment with only 1 recruit (Figure 7).

In terms of the recruitment density (Table 3), genus *Pacillopora* recorded the highest mean value at all stations in Bidong. Whereas in Balok, genus *Platygyra* was recorded the highest mean value at Station 1 and 3. Besides, genera *Porites* and *Fungia* were recorded the higher recruitment density at Station 2. Based on the spatio-temporal variations of scleractinian coral recruitment between study areas, station 1 recorded the highest mean coral recruitment on April in Bidong while the highest mean value was recorded in September at Station 2 in Balok.

Overall, the trend showed that the recruitment densities were relatively high in April at all stations and decreased gradually in June and August in Bidong while in Balok, coral recruitment densities were relatively low in March at all stations and increased gradually in June and September (Fig 8). Kruskal Wallis test indicated that the mean coral recruitment density varied significantly ($p < 0.05$) between stations in Bidong but not in Balok.

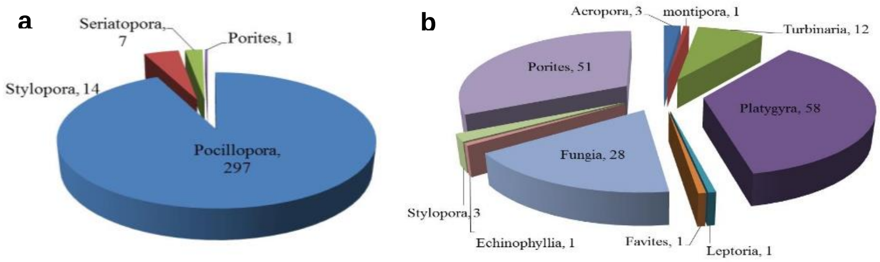

Figure 7: Distribution of coral genera in (a) Bidong Island, (b) Balok coastal water

Table 3: Comparison of mean coral recruitment densities between stations among coral genera in Bidong Island and Balok coastal water

No	Genera	Station		
		1	2	3
Bidong Island				
1	*Pocillopora*	16.4 ± 0.076	7.15 ± 0.063	4.71 ± 0.045
2	*Stylopora*	0.68 ± 0.009	0.29 ± 0.005	0.26 ± 0.005
3	*Seriatopora*	0.61 ± 0.010	0.09 ± 0.003	0.00 ± 0.000
4	*Porites*	0.00 ± 0.000	0.00 ± 0.000	0.12 ± 0.004
Balok coastal water				
1	*Acropora*	0.00 ± 0.000	0.12 ± 0.007	0.20 ± 0.008
2	*Montipora*	0.00 ± 0.000	0.12 ± 0.007	0.00 ± 0.000
3	*Turbinaria*	0.00 ± 0.000	0.00 ± 0.000	1.06 ± 0.053
4	*Platygyra*	0.26 ± 0.008	1.49 ± 0.048	3.48 ± 0.075
5	*Leptoria*	0.00 ± 0.000	0.00 ± 0.000	0.12 ± 0.007
6	*Favites*	0.00 ± 0.000	0.09 ± 0.005	0.00 ± 0.000
7	*Fungia*	0.20 ± 0.008	2.13 ± 0.078	0.36 ± 0.015
8	*Echinophyllia*	0.12 ± 0.007	0.00 ± 0.000	0.00 ± 0.000
9	*Stylophora*	0.24 ± 0.009	0.12 ± 0.007	0.00 ± 0.000
10	*Porites*	0.09 ± 0.005	4.61 ± 0.159	0.17 ± 0.007

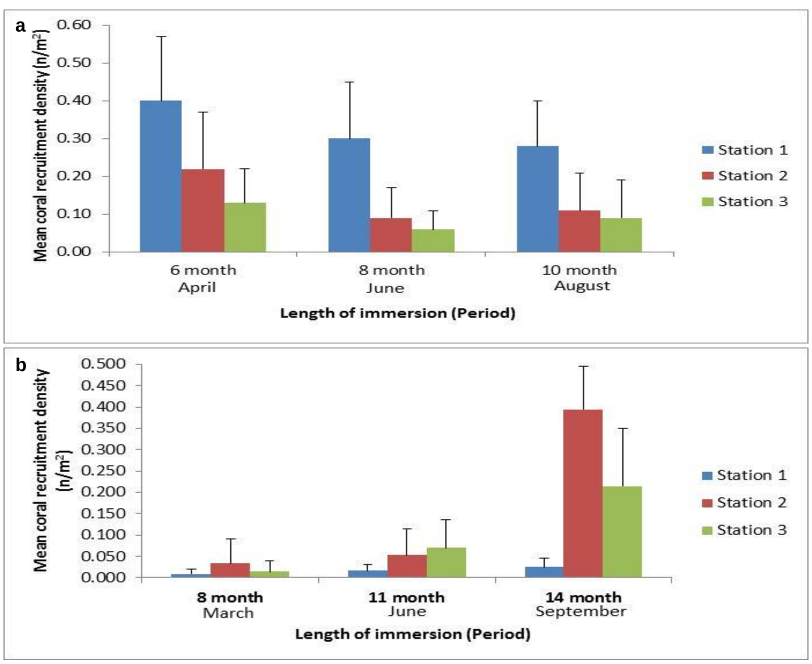

Figure 8. Spatio-temporal variation of scleractinian coral recruitment in (a) Bidong Island and (b) Balok coastal waters

Coral Recruitment Variations Between Different Substrate and Plate's Orientation

Results showed that the artificial reef plates recorded higher mean coral recruitment density compared to the terracotta tiles in both study areas. In Bidong, the highest mean coral recruitment of artificial reef plates and terracotta tiles was recorded in April. Whereas in Balok, the highest mean coral recruitment of artificial reef plates and terracotta tiles was recorded in September (Figure 9).

In terms of the difference in plate's orientations, front position recorded higher coral recruitment compared to back position in Bidong. The highest mean coral recruitment for front and back positions in Bidong was recorded in April. Meanwhile in Balok, back position recorded higher coral recruitment compared to front position (Figure 10). The highest mean coral recruitment for front and back positions in Balok was recorded in September. Kruskal Wallis test indicated that the mean coral recruitment density varied significantly ($p < 0.05$) between types of substrate in Bidong but not in Balok. However, the mean coral recruitment density varied significantly ($p < 0.05$) between plate's orientations in Balok but not in Bidong.

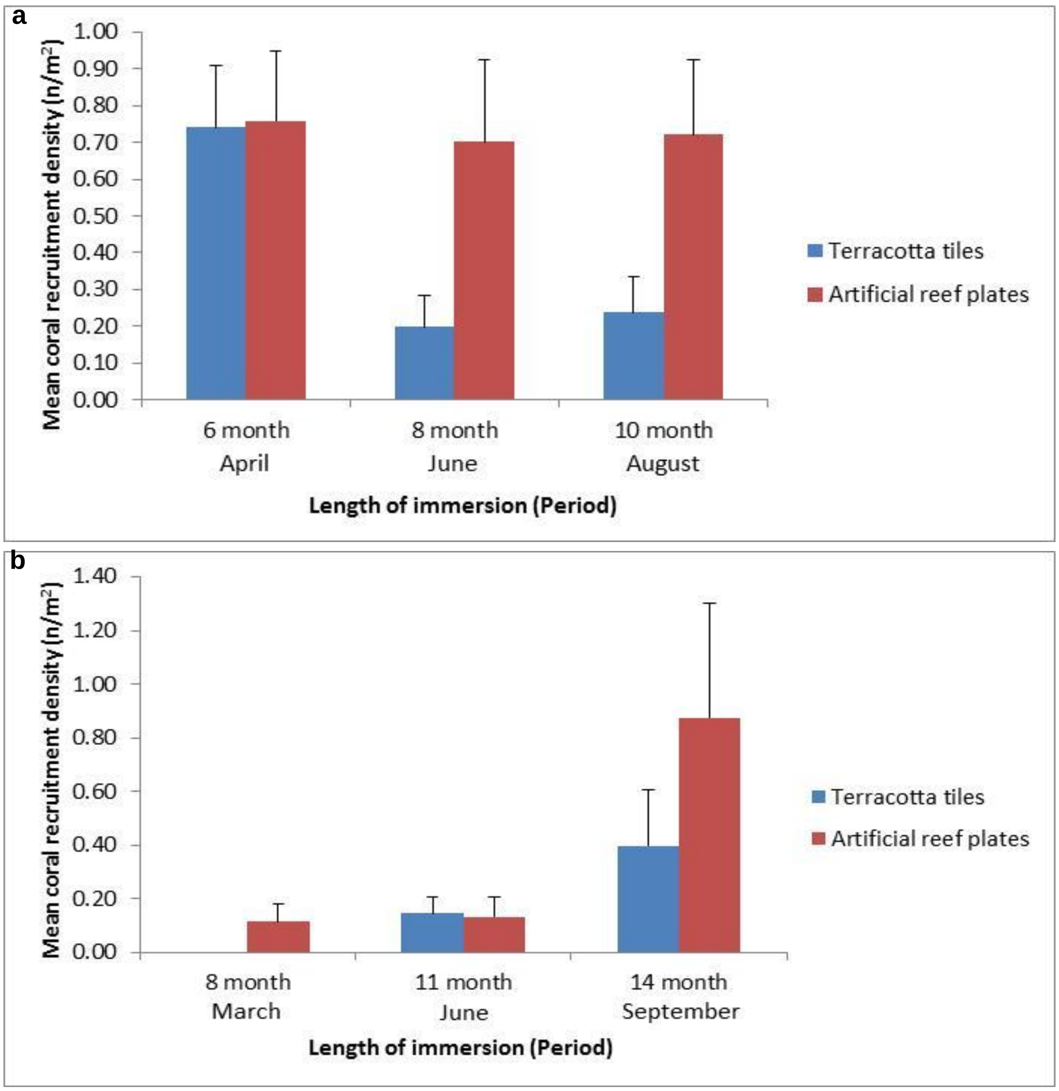

Figure 9. Comparison of recruitment densities on type of substrata at (a) Bidong Island and (b) Balok coastal waters

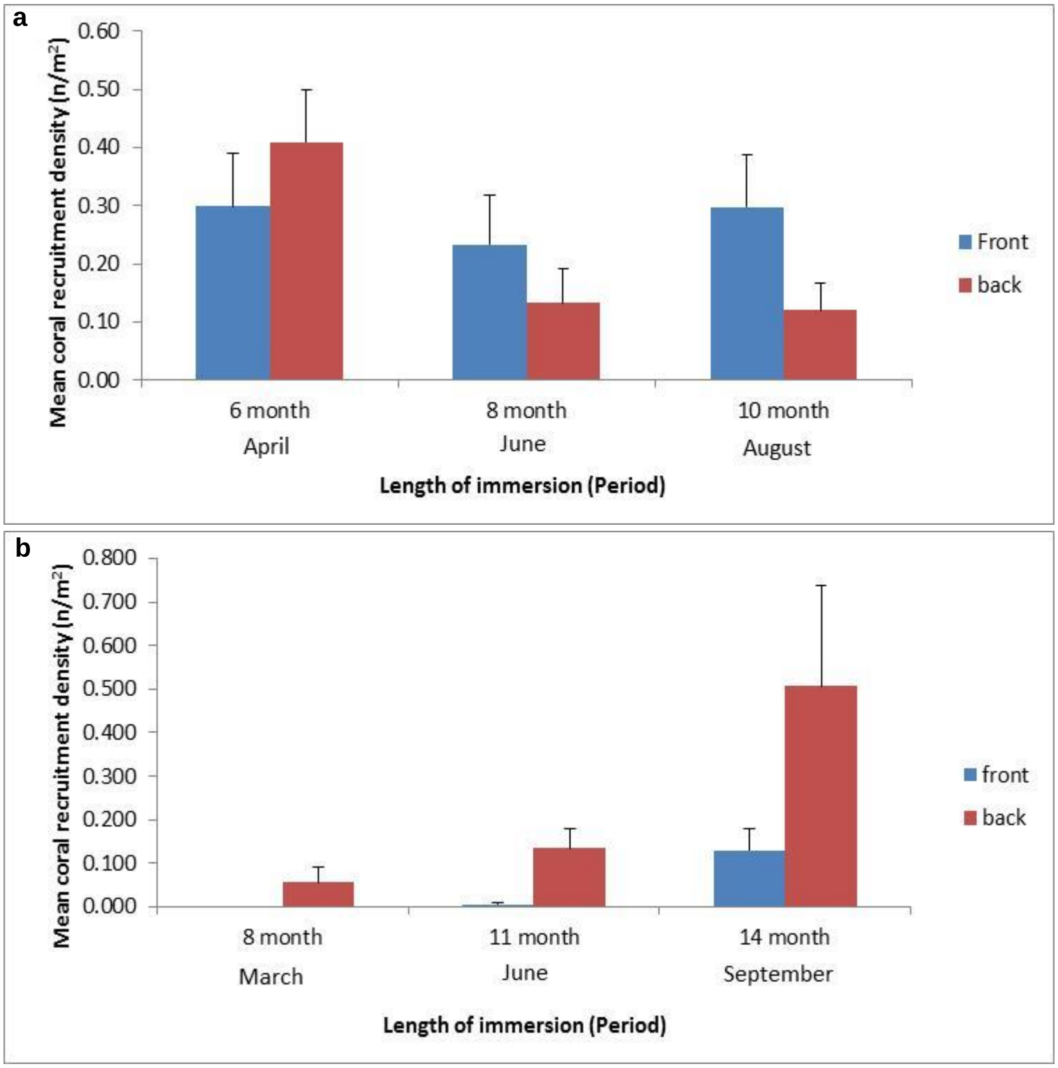

Figure 10. Comparison of recruitment densities on different plate's orientation at (a) Bidong Island and (b) Balok coastal waters

Spatial and Temporal Variations of Scleractinian Coral Recruitment

The scleractinian coral recruitment varied in spatio-temporal scales, where Bidong (0.19 ± 0.02 n/m^2 per plate) recorded a higher recruitment density compared to Balok (0.09 ± 0.03 n/m^2 per plate). Low recruitment density in Balok may be due to turbid water condition from high suspended sediment concentration. On site surveys, it is estimated that the water visibility in Balok was ranged between 1 to 2 m. High water turbidity could suppress larval settlement due to early post mortality (Jokiel et al., 2014). Meanwhile, high recruitment density in Bidong may be due to low turbidity and good clarity of the water column (ranged between 10 to 20 m) which enhance recruitment process of coral larvae.

In Bidong, coral recruits were dominated by brooder type of pocilloporid species particularly *Pocillopora* species. Meanwhile, broadcast type of corals such as *Platygyra* (family Faviidae), *Porites* (family Poritidae) and *Fungia* (family Fungiidae) are among the most abundant coral recruits in Balok. The results indicate that the modes of reproduction either broadcast spawning or brooding have significant influenced in shaping the distribution of coral recruits as outline from previous researches done by Harii and Kayanne (2003) and Nakamura and Sakai (2009). The dominant of *Pocillopora* planula larvae at all sampling stations in Bidong might be due the ability of adult *Pocillopora* coral to release competent planule larvae into the water column before attach to any suitable substrates. Besides, rapid settlement of *Pocillopora* planula larvae within 0 to 2 days are highly contribute to their survivability (Baird and Babcock, 2000).

In comparison to Bidong, the abundant of adult colonies from broadcast spawners such as *Platygyra*, *Porites* and *Fungia* result in high density of their larval pool which in turns influenced the dominant coral recruits of these types of genera in Balok. Additionally, results showed that the recruitment densities of genera *Platygyra*, *Porites* and *Fungia* were higher after 14 months compared to 8 and 11 months deployment at all stations, suggesting mild spawning event occurred during September 2014.

Variations of Coral Recruitment Between Different Substrate and Plate's Orientation

Different types of settlement plate and plate's orientation could have significant effect on coral recruitment density. Findings showed that the rough surface of artificial reef plates were recorded higher coral recruitment density compared to the plain surface of terracotta tiles at both study areas. It is consistent with the previous study indicated that higher recruitment densities were observed in micro crevice plates compared to plain tile-surfaces (Nozawa, 2008).

The rough surface structure with various grooves and pores could trap a selective marine bacteria and algae that act as the chemical cue to enhance settlement and recruitment of competent coral larval (Nozawa, 2008). Besides, rough surface of the artificial reef plates could protect coral larvae from strong currents and maximize the chances of newly recruit larvae (Edmunds *et al*., 2014). In addition, higher number of larval settlement and recruitment on artificial reef plates are due to its specific substratum which made up by mixture of coral rubbles and different types of cement compared to the terracotta tiles which made up by clay. Previous researches indicated that the coral larval preferably of species *Pocillopora damicornis* has a positive response to substrata containing coral rubble with an aid by the present of crustose coralline algae (Lee *et al*., 2009).

In terms of the variation between plate's orientations, the highest recruitment densities of coral larvae were recorded at back position in Balok while still receiving adequate light penetration. It might be due to the siltation and sedimentation in Balok as well as the scouring effect on the seafloor which engulf the front position of settlement plates. Besides, less space competition with other fast growing sessile benthic organisms is another factor that governs high recruitment of coral larvae on back position as outlined by Nozawa *et al*. (2011). In comparison to Balok, the highest recruitment densities of coral larvae preferably pocilloporids were recorded at front position due to less siltation and sedimentation problems in Bidong. It has been reported by that pocilloporids and acroporids were found dominant on front position of settlement plates in the area of less sedimentation and good water visibility (Jokiel et al., 2014).

Conclusion

Overall, the spatial and temporal variations of coral recruitment densities were higher in Bidong compared to Balok. Brooder spawned of *Pocillopora* colonies were found dominant in Bidong while broadcast spawned of *Platygyra* in Balok. Current findings indicate that the environmental stresses such as siltation and sedimentation as well as the effects from human induced disturbances are the most influential factors in determining the distribution of adult coral community structure and recruitment of coral larvae in both study areas.

Present study also highlighted the significant use of artificial reef plates to increase the chances of larval settlement. Furthermore, the information on different coral recruits and their modes of reproduction provide baseline data for future research and management support on recruitment study that is important for reef resilience and natural recovery.

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