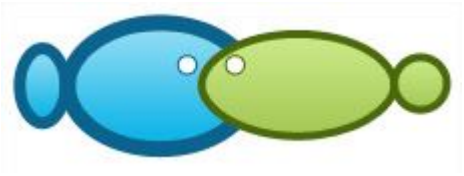

Faviidae coral colonization living and growing on agricultural waste-materialized artificial substrate

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Abstract. A study on colonization of Faviidae corals on the agricultural waste-materialized artificial substrate was conducted in Selat Besar, Ratatotok district, southeast Minahasa regency, North Sulawesi. Nine artificial substrates modules made of mixture of cement, sand, padi husk, and bamboo were placed for about 5 years on the sea bottom of Selat Besar waters. All corals of family Faviidae found on the artificial substrate were collected. Results showed that Faviidae corals could live and develop on those substrates. Fifteen species of 8 genera of family Faviidae were recorded in the present study, *Dipsastraea pallida, D. laxa, D. matthaii, Favites pentagona, F. complanata, Paragoniastrea russelli, Oulophyllia bennettae, Echinopora gemmacea, E. lamellosa, Goniastrea stelligera, G. favulus, G. pectinata, Coelastrea aspera, Platygyra daedalea,* and *P. sinensis*. Mean number of colonies of Faviidae corals was 3 col mod^{-1}, while mean diameter of the corals attached on the artificial substrate was 2.35 cm long. The distribution pattern of Faviidae corals was uniform. The diversity of Faviidae corals on the artificial substrate was low (H' = 2.568). The dominance index showed no dominant species (D = 0.089). In addition, the artificial substrate module in this study could become an alternative technique to rehabilitate the degraded coral reefs.
Key Words: diversity, dominance, distribution pattern, Selat Besar.

Introduction. Corals are animals belonging to phyllum Cnidaria (Reid et al 2009), while coral reef is an ecosystem built by calcium carbonate-producing marine biota, especially coral animals, together with other biota living on the sea bottom or water column, such as mollusks, crustaceans, echinoderms, porifera, tunicates, and other biota free-living in surrounding waters including plankton and fishes (Lalamentik 1995; Giyanto et al 2017). According to Barus et al (2018), coral reef is one of the unique communities that are entirely formed from biological activities. It is one of the main coastal and marine ecosystems that possess the highest productivity and biodiversity so that it is often called as tropical marine forest.

Coral Triangle (CTI) is known as center of world marine biodiversity with the highest coral diversity, 76% of total coral species. The region inside the ecological boundary of CTI covers nearly 73,000 km^2 of coral reefs (29% of total world coral reef area) distributed in six countries, Indonesia, Malaysia, Philippines, Timor Leste, Papua New Guinea and Solomon Islands (Burke et al 2012). As part of the CTI, Indonesia is an archipelagic country with 16,056 islands, 1,922,570 km^2 terrestrial area and 3,257,483 km^2 water in the west Indo-Pacific (Briney 2020). Indonesia that is located in the CTI area is recognized as one of the countries with high biodiversity consisting of more than 80 coral genera and 596 species, particularly in North Sulawesi waters where have been recorded more than 80 genera (Suharsono 2008).

Coral taxonomic and distribution studies in North Sulawesi were carried out by several scientists (Lalamentik 1998; Halidu et al 2016; Nasaru et al 2017; Suleman et al 2017; Reskiwati et al 2018). So far, there is no study on corals of family Faviidae living and growing on the artificial substrate, especially in North Sulawesi waters. Hence, the

present study focuses on Faviidae coral colonies on the artificial substrate with the objectives of identifying the coral species, analysing the density and the diameter of the coral colony, the ecological index, and assessing the distribution patterns. This finding is expected to be one of the references in coral development studies, concerning Faviidae coral colonization on the artificial substrate. Besides, it could provide alternative artificial substrates in coral reef rehabilitation program.

Material and Method

Study site. This work was accomplished in Selat Besar waters, Ratatotok district, southeast Minahasa regency (Figure 1), North Sulawesi. Selat Besar is flanked by Totok bay and Moluccas Sea. The study site was laid on 0°51'34.945''S and 124°44'14.416'' E (Figure 1) using Global Position System (GPS).

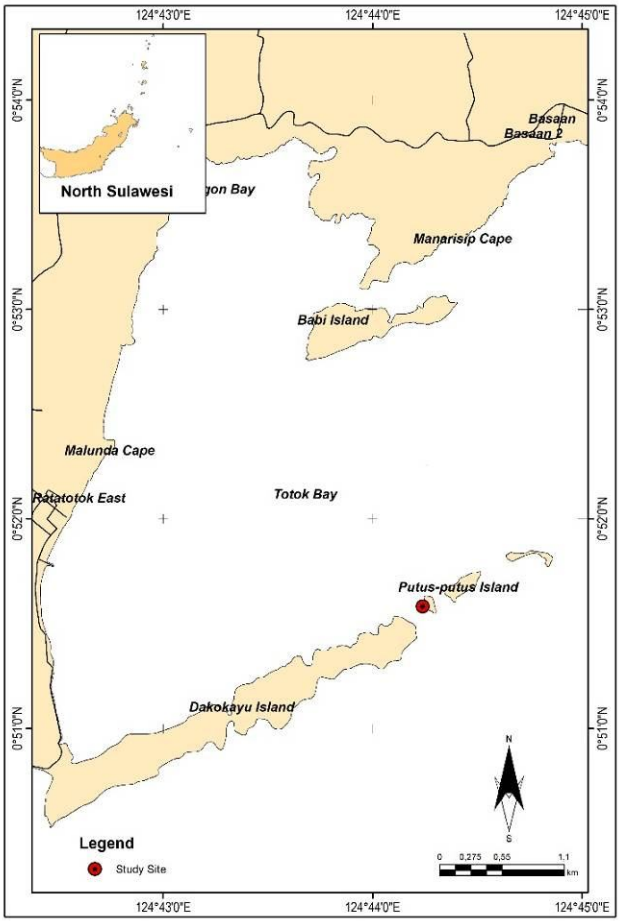

Figure 1. Sampling locality.

Artificial substrate construction. In this study, 9 artificial substrate modules were set on the sea bottom, approximately 7-8 m depth (Figure 2). Sheehy (1986) stated that one of the major roles of artificial substrate placement in the water is to create new habitats similar to natural reefs to be inhabited by target species. The use of artificial substrate as coral new habitat had been conducted in Singaporean waters in order to restore the coral reefs (Ng & Chou 2017). Each module consists of 10 concrete blocks made of mixture of padi husk, sand, and cement. The block frames were made of bamboo. The use of bamboo in concrete construction has been done before as mentioned in Glenn (1950) and Mehra & Ghosh (1965). One of the properties that would make bamboo a good substitute to steel in reinforced concrete is its strength (Varma 2017). The block had a dimension of 100 cm length, 15 cm width, and 15 cm height. The blocks were set in such a manner to yield a module. Each module is estimated to have an area of 4.5 m^2. These 9 modules

were placed since June 2014. Sample collections were carried out in July 2019 (after 5 years of deployment). The period of 5 years is determined because the massive coral growth is slow. This duration is considered enough to see whether there is Faviidae coral capable of adhering and growing on the artificial substrate.

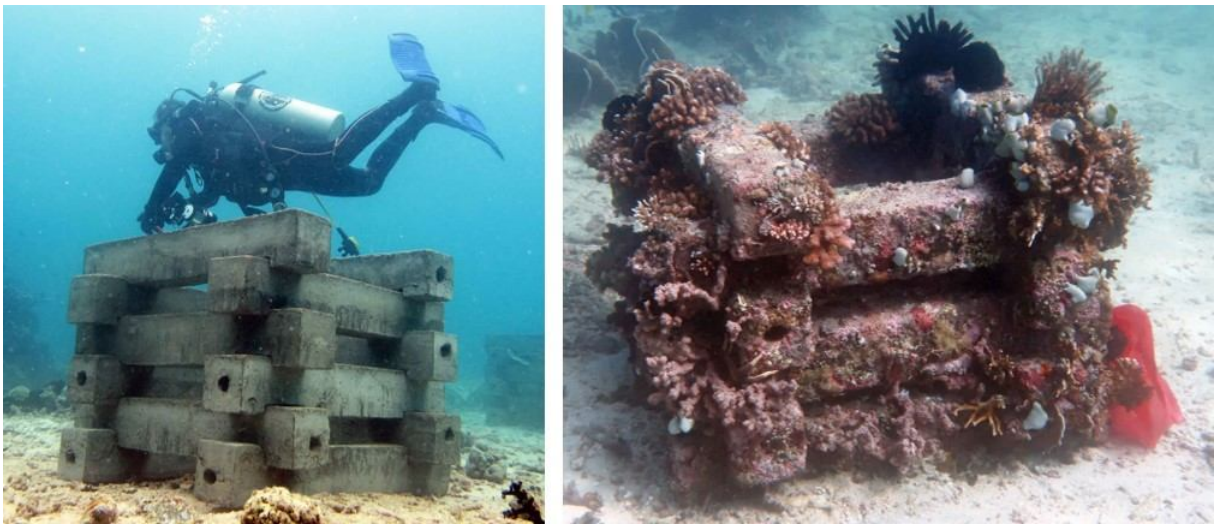

Figure 2. Artificial substrate modules. Left: new module; Right: colonized module.

Sample collection and handling procedures. All massive coral species found to attach on the module substrate were taken using a chisel and hammer. The samples were then put into labelled bag as the module number. All corals were collected by using SCUBA equipments. All activities were documented by using an underwater camera.

Before species identification, the coral specimens were soaked in bleach-containing freshwater for 24 h in order to kill the coral and to prevent the presence of fungi. The corals were then cleaned under the running water to remove the attached dirt so that the clean coral and the bleaching coral skeleton were obtained. The corals were placed under direct sunlight to get dry to ease the identification.

Species identification. Coral identification was done following Veron (1986), Veron & Stafford-Smith (2000), Suharsono (2008), and Veron et al (1977). The specimens of Faviidae corals were examined through morphological observations under the SZ51 Olympus microscope on the characteristics of paliform lobe, septa cleats, coralite type, number of first septa, second septa, and third septa. The measurements of width of paliform lobe, coralite size, and calix size used an LCD electronic digital gauge stainless Vernier caliper 150 mm. World Register database of Marine Species (WoRMS) was utilized for scientific name validation (Hoeksema & Cairns 2020).

Data analysis. Faviidae coral colonization data were directed to ecological index analyses as follows:

Dominance index. This index was employed to know the dominant species in data sampling boundary. The present study applied Simpson dominance index (Krebs 1989):

$$D = \sum_{i=1}^{s} \left[\frac{ni}{N}\right]^2 \quad \text{..... (1)}$$

Where D = dominance index, ni = number of *i* individuals, and N = total number of individuals.

Dominance index ranges between 0 and 1, if D approaches to 0, it indicates no dominance and the community structure is in stable condition, and if D approaches to 1, it indicates the presence of species dominance.

Density. The population density was calculated using Krebs (1989) as follows:

$$K = \frac{Ni}{A} \quad \text{..... (2)}$$

Where, K = density (ind module^{-1}), Ni = number of individuals, and A = number of modules where samples were collected.

Diversity. The diversity index of genus *Favia* Oken, 1815 was calculated using Shannon-Wiener equation (Krebs 1989):

$$H = \sum_{t=1}^{s} \frac{ni}{N} \left(\frac{\ln ni}{N}\right) \quad \text{..... (3)}$$

Where H = Shannon-Wiener diversity index, ni = number of individuals *i*, N = total number of individuals, and s = number of genera.

Distribution pattern. The distribution pattern of Faviidae corals was estimated using Morisita index (Krebs 1989):

$$Id = {}^{q}\frac{\Sigma_{i=1}^{q} ni\ (ni-1)}{N\ (N-1)} \quad \text{..... (4)}$$

Where Id = Morisita index, ni = number of individuals in each plot, and N = total number of individuals in all plots, in which Id = 1 is categorized as random distribution, Id > 1 as clumped, and Id < 1 as uniform.

Results and Discussion

Water conditions of Selat Besar. Water quality is crucial for colonization of macroinvertebrates (Orwa et al 2018). Water temperature is one of the limiting factors for aquatic organisms to live, one of which is coral. Field measurements found that water temperature in the study site ranged from 29 to 30ºC. This range is still suitable for coral development. According to Reid et al (2009), corals, in general, can live at water temperature from 18 to 30^{o}C, while for growth, they require an ideal water temperature from 27 to 29ºC (Giyanto et al 2017). Most coral reefs exist where salinity is stable, and average salinity of normal seawater is 34-36°/$_{oo}$ (Sheppard et al 2017). Water salinity in the study site was in the range of 30-31°/$_{oo}$. Guntur (2011) found that water salinity for ideal coral growth in Indonesia ranged from 29 to 36°/$_{oo}$. Therefore, water salinity in Selat Besar highly supports the coral to grow well. Light intensity does not influence larval settlement, and their response to light intensity may be species-specific (Mundy & Babcock 1998).

Corals of family Faviidae recorded on the artificial substrate. Physical and biological factors are important for recruitment success (Doropoulos et al 2016). As many as 15 coral species of 8 genera were recorded in this study (Table 1). *Dipsastraea* and *Goniastrea* had the highest number of species, each with 3 species, followed by genus *Favites, Echinopora,* and *Platygyra* with 2 species each, while *Oulophyllia*, *Paragoniastrea*, and *Coelastrea* were only represented by one species. Mean density of Faviidae corals on the module substrate was 3.00 col mod^{-1}. Even though these numbers are less than those reported by Kilfoyle et al (2008), 13 col mod^{-1}, the colonies comprised several coral genera. The coral genera of Faviidae inhabiting the artificial substrate apparently come from the coral reef around Selat Besar waters. It is reasonable, since Faviidae is coral family generally found in Selat Besar waters (Lalamentik 1996, 1997, 1998).

Oulophyllia bennettae recorded in the present study is the first record found in the coral reef of Central Indonesian waters. This species was previously mostly found in the northeast of Australian waters (Veron et al 1977). Moreover, genus *Dipsastraea* was found having the highest mean number of colonies, 0.889 col mod^{-1}, followed by *Goniastrea*, 0.667 col mod^{-1}, and the lowest was found in *Oulophyllia* and *Paragoniastrea*, 0.111 col mod^{-1} (Figure 3).

Table 1

Faviidae coral species encountered living on the artificial substrate module

No	*Species*	*Mean diameter (cm)*
1	*Echinopora gemmacea* (Lamarck, 1816)	1.361
2	*E. lamellosa* (Esper, 1795)	0.556
3	*Dipsastraea laxa* (Klunzinger, 1879)	2.389
4	*D. matthaii* (Vaughan, 1918)	1.056
5	*D. pallida* (Dana, 1846)	2.000
6	**Oulophyllia bennettae* (Veron, Pichon & Wijsman-Best, 1977)	0.778
7	*Favites complanata* (Ehrenberg, 1834)	1.056
8	*F. pentagona* (Esper, 1795)	0.694
9	*Paragoniastrea russelli* (Wells, 1954)	0.944
10	*Coelastrea aspera* (Verrill, 1866)	1.556
11	*Goniastrea favulus* (Dana, 1846)	0.556
12	*G. pectinata* (Ehrenberg, 1834)	0.972
13	*G. stelligera* (Dana, 1846)	0.667
14	*Platygyra daedalea* (Elis & Solander,1786)	1.222
15	*P. sinensis* (Milne Edwards & Haime, 1849)	0.667

* The first record for Central Indonesia.

Variations in number of Faviidae colonies per module are dependent upon the abundance of larvae that survive and settle on the substrate. Faviidae tends to have good adaptability to occupying the available artificial substrates. Bachtiar & Prayogo (2010) found that Faviidae is one of the coral families capable of surviving in the reef ball deployed on the sea bottom as well.

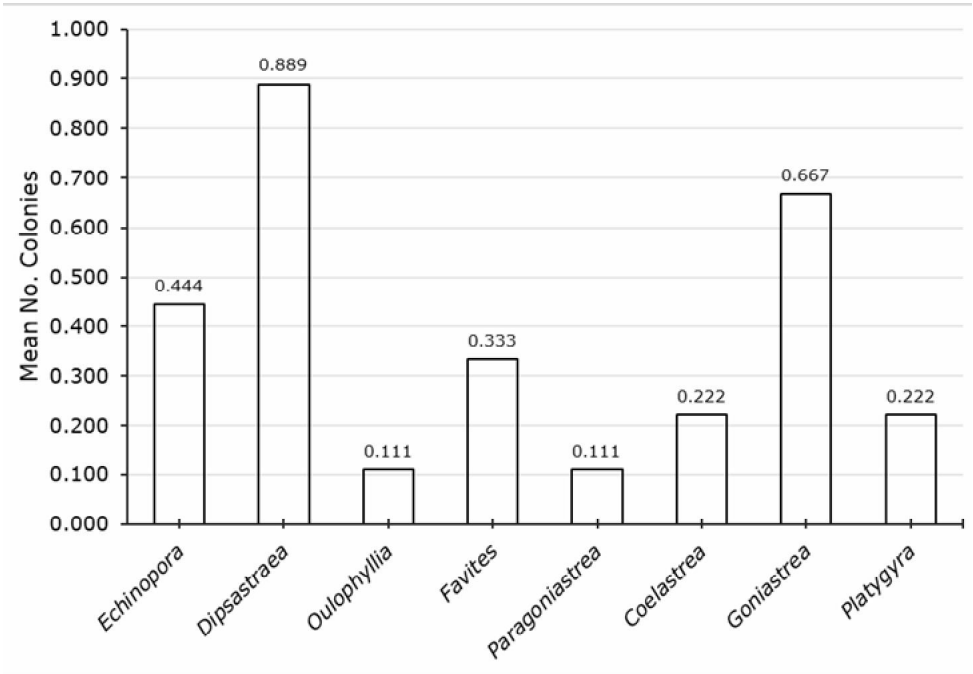

Figure 3. Mean number of colonies of *Faviidae* per module.

Mean diameter of the coral colony on the artificial substrate was 2.35 cm with the largest recorded in *Dipsastrea,* 5.444 cm, and the smallest in *Oulophyllia,* 0.778 cm (Figure 4). In species level, the largest mean diameter was recorded in *D. laxa* and the lowest in *E. lamellosa* and *G. favulus*, respectively (Table 1). Variations in colony size could result from different sequence of planula settlements and available space on the module. This condition, according to Bachtiar & Prayogo (2010), indicates that coral colonization on the artificial substrate sustainably occurs.

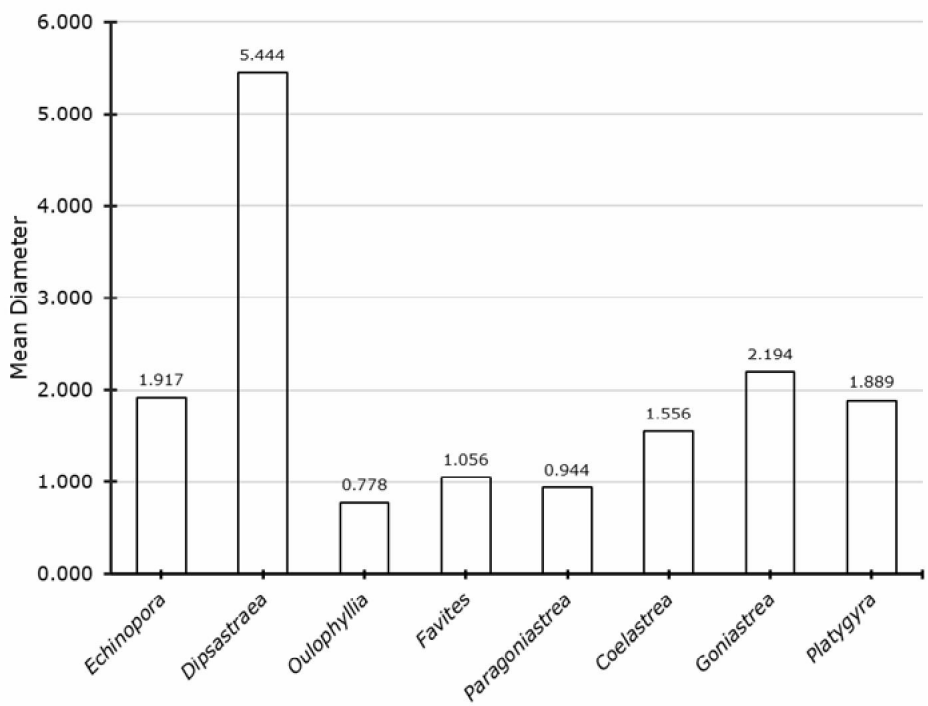

Figure 4. Mean diameter of Faviidae corals living on the artificial substrate.

Ecological index. The present study measured dominance index (D) and diversity index (H') of Faviidae corals thriving on the artificial substrate. The data are given in Table 2.

Table 2

Ecological index of Faviidae corals

No	*Ecological index*	*Value*	*Remarks*
1	Dominance Index (D)	0.089	No dominance
2	Distribution pattern (Id)	0.49	uniform
3	Diversity index (H')	2.568	high

The dominance index of Faviidae corals is 0.089 (Table 2). It means that no species outnumbers the others. Selat Besar waters is still capable of supporting the coral life, and there is no competition that could make certain species be dominant (Muqsit et al 2016). The diversity index is 2.568. This value is higher than that in all study sites of natural coral reefs reported by Akbar et al (2020) in Bangka Belitung Islands reflecting that Selat Besar waters is potential for coral development. This high diversity index is also supported by low species dominance index, in which there were 15 Faviidae species found. These numbers are high enough due to small study area cover. This finding is in agreement with Rondo et al (2014) that high diversity will cause low species dominance.

Distribution pattern analysis found that Faviidae in the study site had unform distribution (Id = 0.49 > 1). This pattern could result from the fact that there were four modules not occupied by Faviidae corals. In Indonesia, studies on coral colonization was also done by Razak (2008) using eco-reef module in Manado bay waters, North Sulawesi, and found that the artificial substrate used are, in fact, inhabited by hard corals. Hence, the artificial substrate could be recommended as an alternative in coral reef rehabilitation program.

Conclusions. Fifteen coral species were found settling on the agricultural waste-materialized artificial substrate, *Dipsastraea pallida, D. laxa, D. matthaii, Favites pentagona, F. complanata, Oulophyllia bennettae, Echinopora gemmacea, E. lamellosa, Coelastrea aspera, Goniastrea stelligera G. favulus, G. pectinata, Paragoniastrea russelli, Platygyra daedalea,* and *P. sinensis.* They had mean 3.00 col mod^{-1} with mean diameter

of 2.35 cm. The ecological index also indicated that the available artificial substrate could support various coral species to grow. In this study, Faviidae corals growing on the available artificial substrate have reflected uniform distribution. Thus, this type of module could be used for coral reef rehabilitation. In addition, water conditions in Selat Besar are important factors supporting the coral development.

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