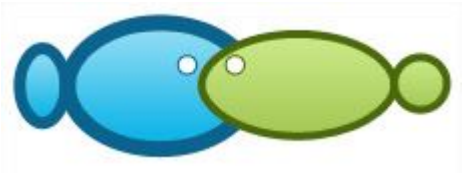

# Effect of *Kappaphycus alvarezii* mariculture on the recruitment of scleractinian corals

[1]Sri Mulyani, [2]Ambo Tuwo, [2]Rajuddin Syamsuddin, [2]Jamaluddin Jompa, [3]Indra Cahyono

[1] Department of Fisheries, Faculty of Agriculture, Bosowa University, Makassar, 90231, South Sulawesi, Indonesia; [2] Faculty of Fisheries and Marine Science, Hasanuddin University, Makassar, 90245, South Sulawesi, Indonesia; [3] Marine Technology College of Balik Diwa, Makassar, 90245, South Sulawesi, Indonesia. Corresponding author: S. Mulyani, smjournal45@gmail.com

**Abstract**. Currently, the red alga *Kappaphycus alvarezii* is the species most commonly cultivated by seaweed farmers in the tropical Indo-Pacific. Seaweed farming over coral reefs is thought to have a negative impact on scleractinian corals. This study aims to determine the effect of *K. alvarezii* aquaculture over coral reefs on the recruitment of scleractinian corals. The study site was in Laikang Bay, Jeneponto Regency, South Sulawesi Province, Indonesia. This study used a grouped two level factorial design. The two factors were seaweed seed/clump spacing with 3 treatments (10, 20 and 30 cm) and controls with no seaweed; and substrate depth, with 2 levels (2 and 5 m). Grouping was based on planting period with replicates at 3 stations. The *K. alvarezii* cultivation media were bamboo rafts (2m x 2m) with polyethylene planting ropes. The rafts were moored at each site in the coral reef ecosystem for two planting periods. The 20 x 20 cm collector plates for coral settlement (total 72 per period) were placed on the substrate (sea bed) under the seaweed farming units and in the control areas (3 per raft or control area). The results showed that recruitment differed with substrate depth, seaweed spacing and planting period. The results indicate that at 30 cm spacing the seaweed farming did not have a significant effect on coral recruitment

**Key Words**: coral recruitment, seaweed culture, planting spacing, depth.

**Introduction**. Countries around the word are faced with tensions between environmental sustainability and development (Romeo et al 2013). Coral reefs have many biological, ecological and economic functions, including the provision of food, as fishing grounds, serving as spawning grounds, nursery grounds, feeding grounds and providing shelter for a wide variety of marine organisms including species with high economic values (Nybakken & Eidman 1988; Moberg & Folke 1999; Pascal et al 2016; Nikijuluw 2017; Cabral & Geronimo 2018). Global warming, human activities, coastal development and pollution can damage coral reef ecosystems (Westmacott et al 2000; Cinner et al 2012, 2018; Pendleton et al 2016; Giyanto et al 2017) and the ecosystem services they provide (Woodhead et al 2019). Tropical seaweed culture is an important livelihood activity for many coastal communities, and often takes place in coral reef areas (Sievanen et al 2005; Mariño et al 2019; Kelly et al 2020). Seaweed culture is increasingly viewed as an alternative or complement to terrestrial biomass production (Barbot et al 2016; Stevant et al 2017). Globally, the cultivation of aquatic plants is a large industry with a total production of 29.4 million tons in 2015 (FAO 2018).

Different perceptions of economic, social and environmental consequences from various aquaculture development trajectories may lead to controversies (Baulcomb 2013). Such controversies may impede or even prevent a sustainable future expansion of the sector (Krause-Jensen et al 2015). Furthermore, emerging industries can result in unforeseen ecological and societal consequences (Cottier-Cook et al 2016). The potential loss of coastal ecosystem health, integrity and resilience could pose a direct threat to coastal populations (Waite et al 2015). Seaweed culture on coral reefs is thought to have potentially negative impacts on coral reefs including loss of coral cover through increased

siltation, trampling and shading, and could cause a reduction in coral recruitment ability (Sievanen et al 2005; Hehre & Meeuwig 2015). People farm seaweed over coral reefs at various depths, which could potentially result in different levels of negative impacts on certain biological aspects of these reefs. For example, Mulyani et al (2018) found a negative effect on the growth of the coral *Acropora muricatum* from seaweed farming. The impact was significantly greater at 2 m depth than at 5 m. With respect to possible adverse effects from shading, one potential driver could be seaweed farmers trying to increase production by reducing plant spacing, which could increase interference with light penetration to the substrate, i.e. the coral habitat. Reduction in the growth of *A. muricatum* under farmed seaweeds is reported to be more severe at closer planting distances (Mulyani et al 2018).

According to Nontji (2004) in 2003, approximately 61% of Indonesian coral reefs had been significantly degraded, and of these about 36% were in poor condition. The most recently published monitoring of 1067 reefs across Indonesia by the Indonesian Institute for Science (LIPI) found similar results (Hadi et al 2018). Just 70 sites (6.56%) qualified for the Very Good condition category (hard coral cover over 75%), with 22.96% sites in the Good category (50-75% HC cover), 34.3% in the Average category (25-50% HC cover) and 36.18% in the Poor category less than 25% HC cover). Recruitment is an important part of the process of forming and developing communities in a natural coral reef ecosystem (Lukoschek et al 2013). Successful recruitment ensures the coral community is maintained, replenishing the population after the occurrence of natural or anthropogenic mortality (Erwin et al 2008; Graham et al 2011; Sawall et al 2013; Lukoschek et al 2013; Bramanti & Edmunds 2016). Coral recruitment is important in both natural recovery and assisted recovery under coral rehabilitation programs. However, there is a lack of data on the effects of seaweed farming over coral reefs on coral recruitment.

Based on the above considerations, this study aimed to evaluate the effect of seaweed culture when conducted in a coral reef ecosystem, specifically the farming of *Kappaphycus alvarezii* with different planting distances on the recruitment of scleractinian corals on reefs at different depths. It was anticipated that the results would be of use to inform the regulation and management of seaweed culture in coral reef areas.

## Material and Method

***Site and study location***. The experiment was conducted in Laikang Bay, Garassikang village, Bangkala Barat District, Jeneponto Regency in South Sulawesi Province, Indonesia (Figure 1). The research was designed using a complete randomized design (CRD) with a 3 x 2 x 4 factorial pattern. The depth treatments (2 m and 5 m) and seaweed seed spacing treatments (10 cm, 20 cm, 30 cm and controls) were applied at three stations (spatial replicates) in coral reef ecosystems at the site (Figure 1). This resulted in a total of 24 research units (18 seaweed farming units and 6 coral reef areas without seaweed farming as controls) (Table 1). There were two seaweed planting periods (temporal replicates), October-December 2014 and January-March 2015. Collector plates for the settlement of coral larvae were placed on the substrate under the rafts at each seaweed farming treatment site, as well as at the control sites, with three collectors per experimental unit, giving a total of 72 collectors per period.

Table 1

Coordinates and layout of the rafts and collectors by treatment

| *Station* | *Treatments** | *Approximate coordinates* | |
|---|---|---|---|
| I | B1 (A1 & A2); B2 (A1 & A2); B3 (A1 & A2); C 1 & C2 | 05°35.532' S | 119°31.212' E |
| II | B1 (A1 & A2); B2 (A1 & A2); B3 (A1 & A2); C 1 & C2 | 05°35.616' S | 119°31.014' E |
| III | B1 (A1 & A2); B2 (A1 & A2); B3 (A1 & A2); C 1 & C2 | 05°35.284'' S | 119°31.299' E |

* Planting spacing: B1 = 10 cm, B2 = 20 cm, B3 = 30 cm; Depth: A1 = 2 m, A2 = 5 m; C1 = control at 2 m; C2 = control at 5 m.

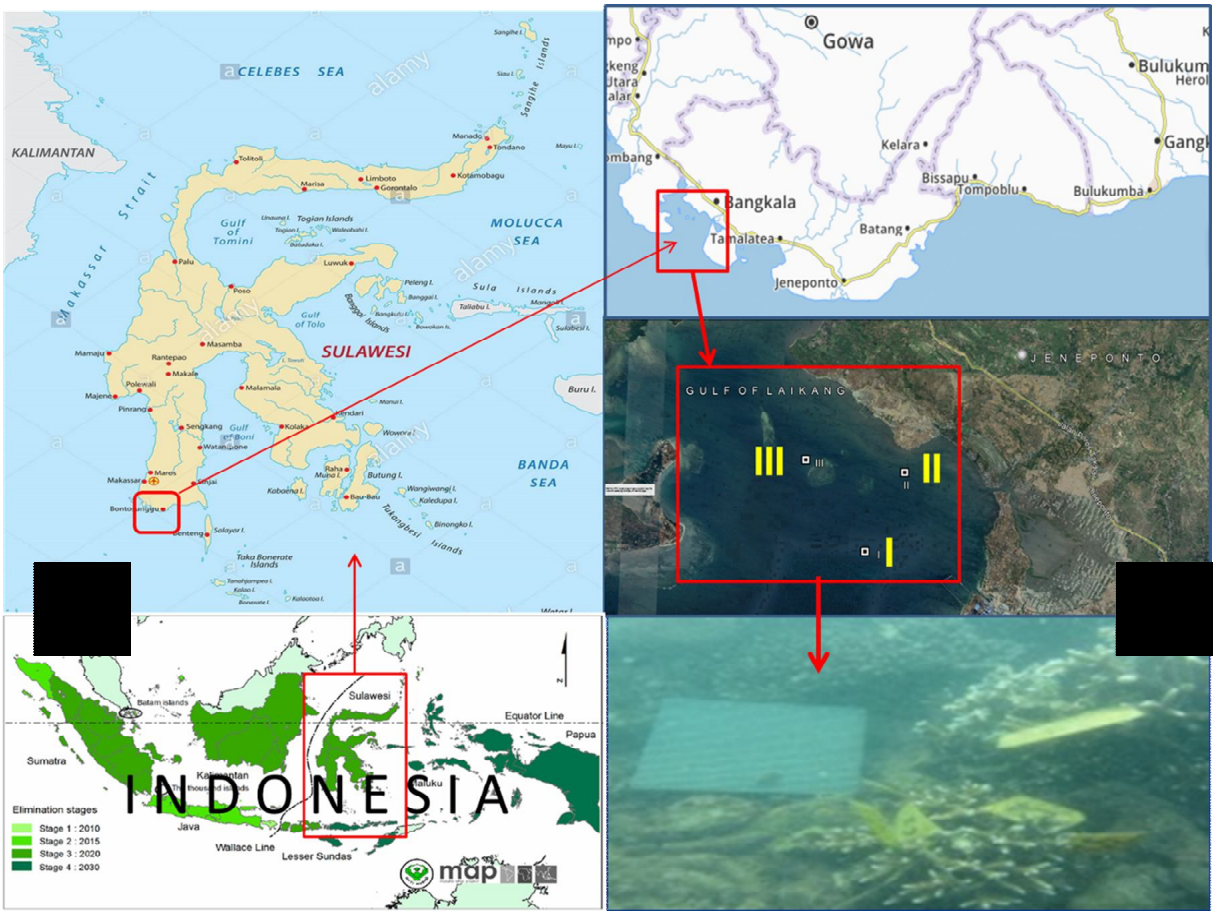


Figure 1. Map of the study area showing the experimental layout; a. The Roman numerals indicate the three stations (I, II, III); b. A collector plate in place.

***Research material and equipment***. This research used a brown variety of the seaweed *K. alvarezii*. The culture media were floating rafts with a bamboo frame (2 m x 2m). The 20 cm x 20 cm collector plates used for coral settlement were made of natural stone following Rudi et al (2005). Bleach (NaClO 5.25%, make: Bayclin) was used for cleaning and sterilisation of the collector plates before placement. Other equipments used are shown in Table 2.

Table 2

Equipment used for collecting data on coral recruitment

| *No* | *Equipment* | *Description* |
|---|---|---|
| 1 | Plastic tray | To clean and bleach collector plates |
| 2 | Gloves | To protect hands from bleach solution |
| 3 | Flashlight | To help identify juvenile coral colonies |
| 4 | Microscope (Wild Heerbrugg type 211070208) | To identify juvenile coral colonies |
| 5 | Handy counter | To count juvenile coral colonies |
| 6 | Snowman OPF permanent marker | To mark juvenile coral colonies |
| 7 | Camera (Canon Power Shot SX 260 HS) | To document juvenile coral colonies |
| 8 | SCUBA sets (2) | To install and retrieve the collector plates |

***Field methods***. Preliminary activities included field observations to determine the research stations within the coral reef ecosystem at the study site. Hard corals growing on the substrate in the seaweed farming and control areas at 2 m and 5 m depth were dominated by the coral *Acropora formosa*.

The floating raft culture system (Neish 2008) was used, with 18 of the 2 m x 2 m bamboo rafts deployed at each of the 3 stations. The rafts were kept in place using wooden stakes. Polyethylene floating monoline planting ropes (No. 6 and 1.5) were attached to the bamboo frames at a distance of 30 cm from each other. Each rope within each frame was planted with *K. alvarezii* seedlings (initial weight 50 grams) at the appropriate spacing for each treatment.

Collector plates were installed and retrieved using SCUBA diving equipment. Three collectors were placed at each replicate unit (18 seaweed farming rafts and 6 control areas) resulting in a total of 72 collectors. The collector plates were left in place for two months before being retrieved and replaced with new collector plates. Each collector plate was carefully removed from its position and brought to the boat where it was carefully wrapped in newspaper and placed in a plastic container. The plates were then taken to the Marine Ecology Laboratory at the Hasanuddin University, Centre for Research Activities in Makassar for scleractinian coral recruit counting and identification.

The density of juvenile scleractinian coral colonies was counted using a collector bleaching method according to Babcock et al (2003). Each collector plate was first rinsed and washed with fresh water. The plate was then bleached by immersion in a Bayclin solution (5.25% NaClO) for 10 minutes, in order to remove the soft tissue and other organic matter (biofouling) covering the entire surface of the collector plates. This bleaching process revealed the structure of attached coral corallites to facilitate observation and identification. After bleaching, the collector plate was rinsed with fresh water and air dried at room temperature.

Juvenile coral colonies were observed under a microscope (Wild Heerbrugg type 211070208), and all coral colonies present over the entire surface of collector plate were marked with a red marker, and counted. They were then identified to the genus level using a coral identification guide (Veron & Stafford-Smith 2000) with reference to Babcock et al (2003). The coral recruits were photographed through the microscope ocular using a digital camera (Canon Power Shot SX 260 HS).

***Statistical analysis***. To evaluate the effect of treatment (plant spacing and substrate depth) on the recruitment of scleractinian corals the parameters measured were compared using analysis of variance (ANOVA) with a grouped factorial design. Two factors were observed: plant spacing and substrate (sea bed) depth. Grouping was based on the planting period. To evaluate the consistency of the effect of plant spacing and depth, analysis of variance (ANOVA) was performed separately for planting period 1 and planting period 2 using a CRD factorial design similar to that described above, but without a group effect for planting period.

Data were tested for normality. If the data did not pass the normal distribution test, transformations were applied; if the transformed data still deviated significantly from a normal distribution, non-parametric analyses were used. The Kruskal-Wallis test was used to analyse the effect of plant spacing while the Mann-Whitney test was applied to evaluate the differences related to depth and planting period.

## Results

***Coral recruit density***. The observations of coral recruitment on the 72 collectors placed on the reef during two periods of planting (2 months each) revealed an average of 2.66 colonies collector$^{-1}$ with a range of 0-12 colonies collector$^{-1}$. This is equivalent to a mean density of 66.5 recruits m$^{-2}$ and a maximum density of 300 recruits m$^{-2}$, while some collectors had no scleractinian coral recruits attached. The average number of scleractinian coral recruits per collector for each factor (seaweed spacing and substrate depth) combination (Table 3) shows that recruitment varied with both depth and seaweed planting method. This high variability in recruitment resulted in a non-normal data distribution. The data distribution remained non-normal after transformation; therefore, non-parametric analyses were used.

Table 3

Mean density of scleractinian coral recruits by seaweed spacing and substrate depth

| *Seaweed planting spacing treatment* | *Density by substrate depth* | | | |
|---|---|---|---|---|
| | *Recruits collector$^{-1}$* * | | *Recruits m$^{-2}$* | |
| | *2 m* | *5 m* | *2 m* | *5 m* |
| 10 cm | $1.39^{a1}$ | $2.39^{a2}$ | 34.75 | 59.75 |
| 20 cm | $1.61^{a1}$ | $2.78^{a2}$ | 40.25 | 69.5 |
| 30 cm | $2.17^{ab1}$ | $3.44^{ab2}$ | 54.25 | 86 |
| Control | $4.94^{b1}$ | $3.0^{b2}$ | 123.5 | 75 |

* Superscript letters indicate significant differences based on seaweed planting distance/control (Kruskal-Wallis test); superscript numbers indicate significant differences based on depth (Mann-Whitney test).

Despite the large difference in mean values (Table 3), the Kruskal-Wallis analysis did not show a significant difference in the number of recruits between the three seaweed seed spacing treatments. There was a significant difference between the number of recruits settling on collectors in the control areas compared to the seaweed farming plots with seaweed planting distances of 10 cm and 20 cm, but not between the controls and seaweed farming with a planting distance of 30 cm.

The fractional Kruskal-Wallis analysis applied to the two planting periods showed that during planting period 1, the effect of seaweed spacing on recruitment was not significant, however in period 2 there was a significant difference in recruitment between the seaweed spacing treatments. During the second planting period, the scleractinian coral recruitment was significantly higher for the 30 cm seaweed spacing compared to the 10 and 20 cm planting spacing treatments.

The Mann-Whitney analysis of the two planting period groups combined showed a significant difference in the number of coral recruits between the 2 m and 5 m depths. The mean scleractinian coral recruit density was higher at the 5 m depth compared to the 2 m depth. However the single period Mann-Whitney test results differed between the two planting periods. In period 1 (October to December 2014), the difference in mean recruit density with depth was not significant; however in period 2 (January to March 2015), the mean recruit density was significantly higher at the 5 m depth than at the 2 m depth.

***Coral recruit identification***. The observation of juvenile coral recruits based on the known characteristics for each genus enabled the identification of four coral genera from three families: *Seriatopora* and *Pocillopora* (family Pocilloporidae), *Porites* (family Poritidae) and *Platygyra* (family Merulinidae). The remaining recruits could not be identified due to their small size and imperfect correlate development. Examples are presented in Figures 2 to 6.

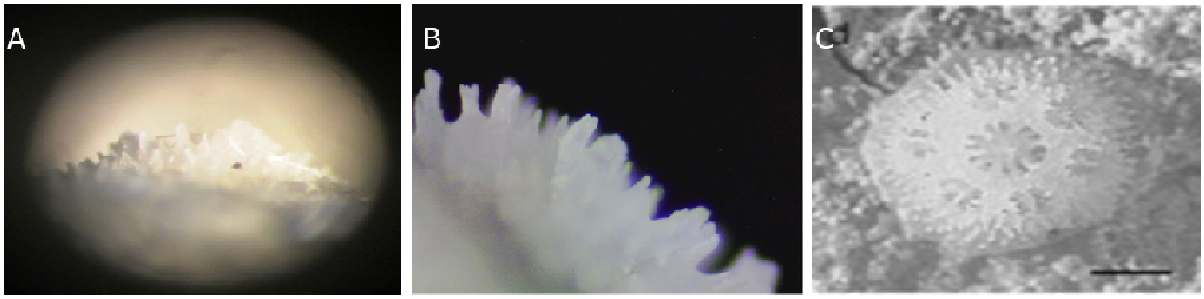


Figure 2. Genus *Seriatopora.* (A) Recruit aged 4-5 weeks, 40x magnification; (B) at 100x magnification; (C) Genus *Seriatopora* identified based on Babcock et al (2003).

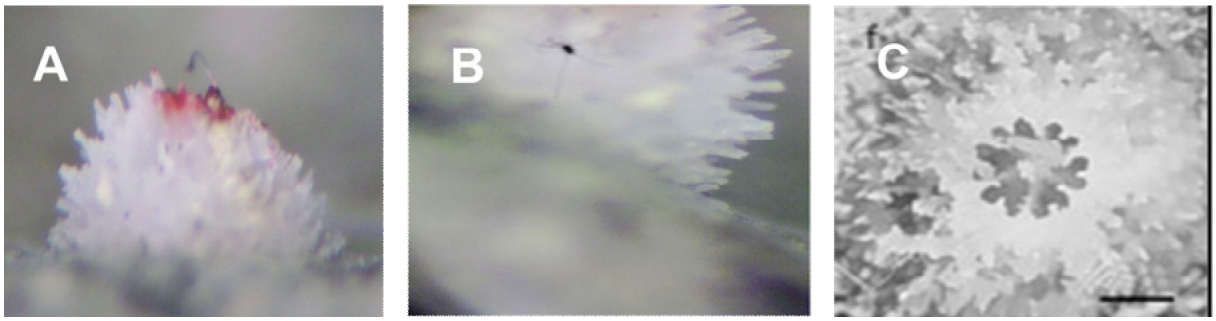

Figure 3. Genus *Pocillopora.* (A) recruit aged 3-4 weeks 40x magnification; (B) at 100x magnification; (C) *Pocillopora* identification based on Babcock et al (2003).

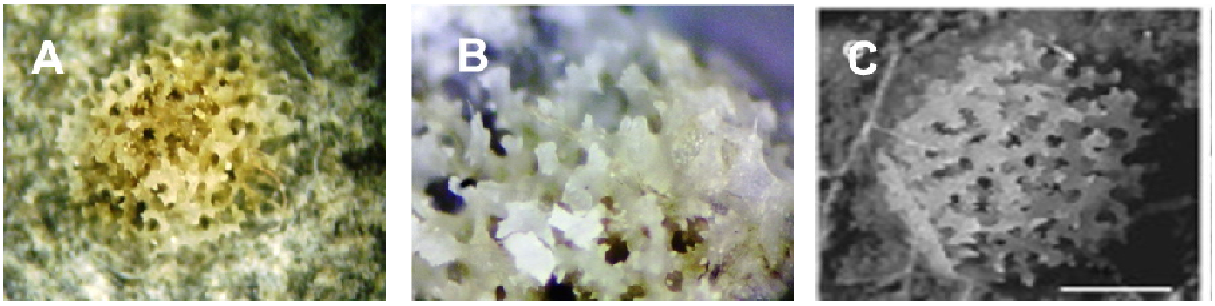

Figure 4. Genus *Porites*. (A) recruit aged 8 weeks, 40x magnification; (B) at 100x magnification; (C) *Porites* identification based on Babcock et al (2003).

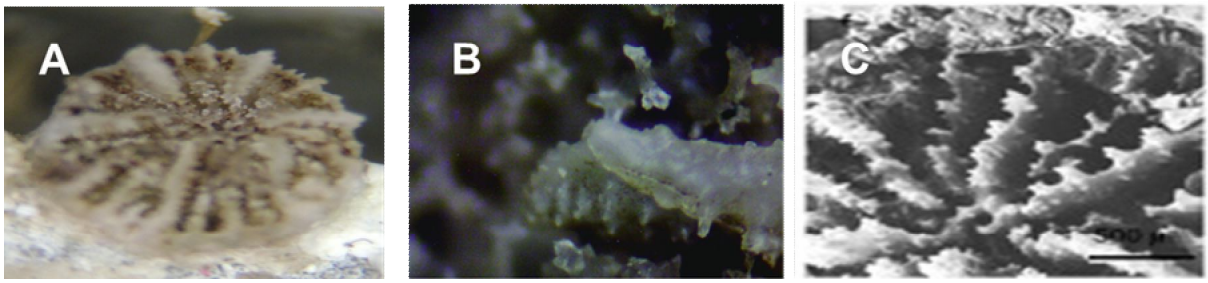

Figure 5. Genus *Platygyra*. (A) recruit aged 8 weeks, 40x magnification; (B) at 100x magnification; (C) *Platygyra* identification based on Babcock et al (2003).

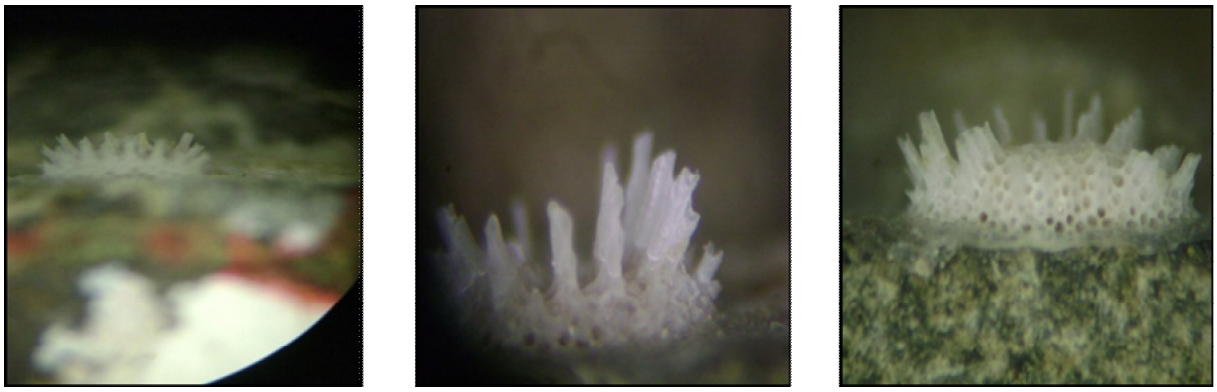
Figure 6. Three scleractinian coral recruits of unidentified genera, 40x magnification.

Only one coral family (Pocilloporidae) and genus (*Seriatopora*) was found attached to the collector plates during the October to December period. During the January to March period, at least four families of juvenile coral corals attached to the collector plates: Pocilloporidae, Poritidae, Merulinidae and a group that could not be identified. The genus level composition of coral recruits during planting period 2 (January to March) was similar at each station. At station I the genus *Seriatopora* dominated (42 individuals), followed by *Pocillopora* (34 individuals), *Porites* (18 individuals) and other taxa (18 individuals). At

station II, the genus *Seriatopora* also dominated (37 individuals) followed by *Pocillopora* (34 individuals), *Porites* (10 individuals) and other taxa (3 individuals). At station III, *Seriatopora* was also the dominant genus (45 individual) followed by *Pocillopora* (39 individuals).

**Discussion**. Recruitment of coral planula larvae is influenced by several parameters including the timing of spawning, the competency period of planulae, current patterns and velocity, substrate availability, predator density and competition (Richmond & Hunter 1990). In turn, coral spawning periods are thought to be influenced by environmental factors including absolute and relative water temperature, wind strength, and lunar phase (van Woesik 2009; Wijayanti et al 2019). Broadcast spawners typically release their gametes just after the full moon, while brooding corals tend to release planulae during the new moon or full moon phases (Munasik 2002).

In this study, coral recruitment during planting period 1 (October to December 2014) was dominated by the genus *Seriatopora*, while the genus *Pocillopora*, another member of the family Pocilloporidae, also recruited during the second period. Other coral recruitment studies from Indonesia also report the presence of Pocilloporidae, as well as a variety of other families and genera. Tuhumena et al (2019) identified the pocilloporid genera *Pocillopora, Seriatopora* and *Stylophora* as well as *Porites, Montipora*, and *Goniastrea* from the Saleo Beach Area, Dampier Strait, Raja Ampat. Fadli et al (2013), observing coral recruits settled on the substrate in the Seribu Islands at depths of 6 and 10 m identified the families Acroporidae, Pocilloporidae, Oculinidae, Fungiidae and Poritidae. Purnomo & Afiati (2018) recorded the genera *Porites, Acropora, Pocillopora* and *Platygyra* around Panjang Island. In the Wakatobi Archipelago, Southeast Sulawesi, coral recruits identified over two years (2008-2009) belonged to the taxa Faviidae, Acroporidae, Pocilloporidae, Agariciidae and Poritidae, with a substantial proportion of recruits classified as 'others' (Salinas-de-Leon et al 2013).

Veron (2000) in Rahman et al (2014) state that the Pocilloporidae are pioneering corals in coral reef ecosystems and their presence can play an important role in promoting and determining the recruitment success of other coral taxa. In Laikang Bay, corals of the genus *Seriatopora* dominate the coral community. It is therefore not surprising that this genus recruited to the collectors. In addition, this pioneer coral is fragile and readily reproduces asexually through fragmentation of existing colonies. Coral recruitment patterns in the study area appear to be dominated by asexual recruitment with the genus *Seriatopora* as the prime pioneer coral taxon. The *Seriatopora* coral fragments also have a structure which enables them to become easily embedded in or associated with the substrate so that they can grow to become new colonies. There are indications that in certain taxa (in particular acroporid corals), such fragments can grow into colonies contributing significantly to sexual reproduction and thus potentially to coral recruitment (Ferse et al 2013).

The dominance of *Seriatopora* during planting period 1 (October to December) and continued settlement of this genus during the second period indicates an extended spawning season covering (and possibly extending beyond) the period October to March. Diaz-Pulido & McCook (2002) state that bare substrate in the coral reef environment will be colonized rapidly by algal filaments, but the succession process culminating in crustose coralline algae (CCA) can take weeks or even years. However, according to Glynn et al (1991), corals of the Pocilloporidae are able to colonize the bare substrate at an early stage, which is one reason why members of this family are often pioneer species in the colonization of new substrates. Furthermore, Pocilloporidae have the ability to spawn all year round, so they can often maintain a steady dominance of the adult coral community. In addition to the local abundance of potential broodstock, these traits could help explain the predominance of pocilloporids on our settlement tile collectors.

According to Munasik (2000), the timing of coral spawning in Indonesia can be grouped into three types of seasonal patterns: spawning before the rainy season (October-November), spawning during or after the rainy season (January-April) and spawning or planula release throughout the year. However, more recent research indicates that these three patterns may be an over-simplification, and the spawning

patterns of equatorial corals may be more varied. For the Family Acroporidae (genera *Acropora* and *Isopora*), two spawning peaks are reported from Manado, in North Sulawesi (Okamoto et al 2012); these were between February and June, and around October. A similar pattern is reported from Karimunjawa with two spawning peaks: March-April and September-October (Permata et al 2012). In contrast, the spawning peak for corals in the Wakatobi (Southeast Sulawesi) was from November to March, corresponding to higher seawater temperatures (Salinas-de-Leon et al 2013), was similar to the period of our study. The taxa recorded in the Wakatobi include the Acroporidae as well as two of the families identified in this study (Pocilloporidae and Poritidae).

The abundance of coral recruits in treatment and control areas was relatively low compared to some other studies, for example a multi-year recruitment study in the Wakatobi, Southeast Sulawesi (Salinas-de-Leon et al 2013). The Wakatobi study found a significant difference in recruit abundance between a reef in relatively good condition and a highly degraded reef. Salinas-de-Leon et al (2013) proposed sedimentation and associated turbidity as probable key influencing factors. Reduction in the penetration of sunlight (e.g. due to sedimentation) will affect the photosynthesis process, and therefore the production of carbohydrates that contribute to the reproduction process (Abrar 2011). The attachment of larval planulae can be impeded or even prevented if the substrate is covered by sediment. Sedimentation cover of 95% can completely prevent the attachment of *Pocillopora damicornis* larvae, while a decrease from 90 to 50% did not significantly increase larval attachment (Hodgson 1990). Babcock & Davies (1991) also report that a high sedimentation rate (3.1 mg $cm^{-2}$ $day^{-1}$) can reduce the number of *Acropora millepora* planulae attaching to the substrate. Purnomo & Afiati (2018) state that severe sedimentation loads are a major driver in the drastic decline of live coral cover around Panjang Island, Indonesia.

At the study site, in addition to sedimentation associated with the seaweed *K. alvarezii* farming, turf algae cover was high (> 50%). This likely resulted in limited suitable larval settlement space and therefore high competition for the suitable spaces available. The presence of macroalgae, barnacles and other organisms could create habitat niches that are unsuitable for scleractinian coral settlement (Ritson-Williams et al 2009). Purnomo & Afiati (2018) found that dissolved organic materials in the sediment can support a wide diversity of bacteria, floral and faunal periphyton, and may also contribute to increased nitrate concentrations to cause macroalgal blooms. In turn, these blooms may completely cover the coral recruits and promote the spread of pathogenic bacteria such as *Pseudomonas* sp. and *Phormidium coralyticum* amongst settled planulae and juvenile colonies. Conversely, a positive role of certain bacteria in triggering the attachment of coral larvae has been reported by Samidjan (2005). In particular, the bacterium *Micrococcus luteus* was found to trigger attachment of the pocilloporid coral *Pocillopora damicornis* recruits and the *Macrozamia communis* bacterium functioned as a pioneer to encourage settlement by *Acropora tenuis*.

The differences with depth and seaweed planting spacing during the second period but not the first indicate that these effects can be influenced by seasonal or other variable environmental parameters. The differences in coral recruit taxa settling on the collectors in period 1 and period 2 also indicate seasonal differences in the coral planulae present, likely related to differences in spawning periods between coral taxa. Although data are not available for April to September, it is not improbable that coral reproduction in Laikang Bay occurs (albeit at fluctuating levels) throughout the year. For the taxa found only in period 2, the results indicate peak spawning may occur after the rainy season (January-April). However, the recruitment of corals onto the collector plate can be expected to reflect not only the timing of coral reproduction, but also a number of other factors such as the duration of larval competence and environmental conditions. Ompi & Svane (2018) state that local conditions, larval availability in the water column, substrate availability, survival and growth of new settlement might determine variation in coral recruit abundance. Babcock (1988) estimated that for more than a month after settlement coral planulae can still release themselves from the substrate originally chosen. During this period planulae can drift to another location and resettle. This could

result in the arrival of previously settled planulae from an earlier spawning period or the departure of temporarily settled planulae before the plates were collected.

The season of observation can influence the density of coral recruits attached to the substrate. Gleason (1996) who observed the recruitment of coral in Moorea, Polynesia-French with observation once every four months found the highest recruitment during the period from December to April, closely associated with the periods of highest water temperature which he suspected to be a trigger of mass coral reproduction. The majority of coral larvae require chemical stimulants such as microalgae and certain bacteria in order to initiate settlement. According to Baird & Morse (2004), coral planulae will attach to surfaces with a biological layer, especially communities of CCA which inhabit the surface of substrate. This is supported by observations by Harrington et al (2004) that certain species of microalgae belonging to the CCA group act as an important stimulus for the attachment of the acroporid corals *A. tenuis* and *A. millepora*.

Despite the many factors which can affect the settlement of coral planulae, our data indicate that, at least on a seasonal basis, seaweed farming with close spacing (10 and 20 cm planting distances) can affect coral recruitment. Although causal mechanisms were not investigated, a plausible causal factor is inhibition of or reduction in coral recruitment due to macroalgal or other shading (Jompa & McCook 2003; Diaz-Pulido et al 2010; Hehre & Meeuwig 2015). However, with a spacing of 30 cm between seaweed clumps, coral recruitment was not significantly different from that observed with no seaweed farming (control plots) at both depths (2 m and 5 m) studied. Despite the lack of statistical significance, the results indicate that scleractinian coral recruitment is positively correlated with seaweed planting distance at close spacings, with recruitment approaching the no seaweed level (maximum) at some planting distance between 20 and 30 cm. While our data do not have sufficient resolution to determine a precise minimum planting distance, it can be inferred that the commonly used 25 cm planting distance should have less impact than the 20 cm planting distance, and that planting distances of around 30 cm should have little or no impact on coral recruitment.

**Conclusions**. The results of our study indicate that the effect of seaweed farming in coral recruitment can vary between seasons. We found no significant negative impact of seaweed farming (*Kappaphycus alvarezii*) on coral recruitment at any planting spacing during the first planting period (October-December); however, during the second planting period (January-March) there was a negative effect at the two closer seaweed planting distances (10 and 20 cm) but not at 30 cm spacing. Coral recruitment density did not differ significantly with depth during the first planting period but was higher at the 5 m depth than at 2 m during the second period. These results indicate that seaweed farming over coral reefs can be implemented with minimal impact on coral recruitment; however, the seaweed planting distance should be more than 20 cm.

**Acknowledgements**. The authors gratefully acknowledge research funding from the COREMAP II Program and the Seaweed Development and Empowerment Centre of Excellence, Hasanuddin University. The authors wish to express their appreciation and gratitude to the government of Jeneponto District for permitting the field research, and to the Head of Brackish Water Aquaculture Development Centre for supporting the research.

## References

Abrar M., 2011 Kelulusan hidup rekruitmen karang (*Scleractinia*) di perairan gugus Pulau Pari, Kepulauan Seribu, Jakarta. Institute Pertanian Bogor, 98 pp. [in Indonesian]

Babcock R. C., 1988 Age-structure, survivorship and fecundity in populations of massive coral. Proceedings 6th International Coral Reef Symposium Townsville 2:625-633.

Babcock R., Davies P., 1991 Effects of sedimentation on settlement of *Acropora millepora*. Coral Reefs 9:205-208.

Babcock R. C., Baird A. H., Piromvaragorn S., Thomson D. P., Willis B. L., 2003 Identification of scleractinian coral recruits from Indo-Pacific reefs. Zoological Studies 42(1):211-226.

Baird A. H., Morse A. N. C., 2004 Induction of metamorphosis in larvae of the brooding corals *Acropora palifera* and *Stylophora pistillata.* Marine and Freshwater Research 55(5):469-472.
Barbot Y. N., Al-Ghaili H., Benz R., 2016 A review of the valorization of macroalgal wastes for biomethane production. Marine Drugs 14(6):120.
Baulcomb C., 2013 Aquaculture and ecosystem services: reframing the environmental and social debate. In: Ecosystem services in agricultural and urban landscapes. Wratten S., Sandhu H., Cullen R., Costanza R. (eds), A John Wiley & Sons, Oxford, pp. 58-82.
Bramanti L., Edmunds P. J., 2016 Density-associated recruitment mediates coral population dynamics on a coral reef. Coral Reefs 35(2):543-553.
Cabral R. B., Geronimo R. C., 2018 How important are coral reefs to food security in the Philippines? Diving deeper than national aggregates and averages. Marine Policy 91:136-141.
Cinner J. E., McClanahan T. R., Graham N. A. J., Daw T. M., Marina J., Stead S. M., Wamukota A., Brown K., Bodin O., 2012 Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Global Environmental Change 22(1):12-20.
Cinner J. E., Maire E., Huchery C., MacNeil M. A., Graham N. A. J., Mora C., Chabanet P., Gough C., Tupper M., Ferse S. C. A., Sumaila U. R., Pardede S., Mouillot D., 2018 Gravity of human impacts mediates coral reef conservation gains. Proceedings of the National Academy of Sciences 115(27):6116-6125.
Cottier-Cook E. J., Nagabhatla N., Badis Y., et al, 2016 Safeguarding the future of the global seaweed aquaculture industry. United Nations University (INWEH) and Scottish Association for Marine Science Policy Brief 12 pp.
Diaz-Pulido G., McCook L. J., 2002 The fate of bleached corals: patterns and dynamics of algal recruitment. Marine Ecology Progress Series 232:115-128.
Diaz-Pulido G., Harii S., McCook L. J., Hoegh-Guldberg O., 2010 The impact of benthic algae on the settlement of a reef-building coral. Coral Reefs 29(1):203–208.
Erwin P. M., Song B., Szmant A. M., 2008 Settlement behavior of *Acropora palmata* planulae: effects of biofilm age and crustose coralline algal cover. Proceedings of the 11th International Coral Reef Symposium, Florida, pp. 1219–1224.
Fadli N., Kunzmann A., von Jutarzenka K., Rudi E., Muchlisin Z. A., 2013 A preliminary study of corals recruitment using coral rubbles substrate in Seribu Island waters, Indonesia. AACL Bioflux 6(3):246-252.
FAO, 2018 The global status of seaweed production, trade and utilization. Globefish Research Programme Volume 124. Rome: Food and Agriculture Organization of the United Nations, 120 pp.
Ferse S. C. A., Nugues M. M., Romatzki S. B. C., Kunzmann A., 2013 Examining the use of mass transplantation of brooding and spawning corals to support natural coral recruitment in Sulawesi/Indonesia. Restoration Ecology 21(6):745-754.
Gleason M. G., 1996 Coral recruitment in Moorea, French Polynesia: the importance of patch type and temporal variation. Journal of Experimental Marine Biology and Ecology 207(1-2):79-101.
Glynn P. W., Gassman N. J., Eakin C. M., Cortes J., Smith D. B., Guzman H. M., 1991 Reef coral reproduction in the Eastern Pacific: Costa Rica, Panama and Galapagos Islands (Ecuador). Marine Ecology 109:355-368.
Graham N. A. J., Nash K. L., Kool J. T., 2011 Coral reef recovery dynamics in a changing world. Coral Reefs 30(2):283-294.
Giyanto M., Abrar T., Hadi A., Budiyanto A., Hafizt M., Salatalohy A., Iswari M. Y., 2017 Status terumbu karang Indonesia. Jakarta: Puslit Oseanografi-LIPI, ix+30 pp. [in Indonesian]
Hadi T. A., Giyanto, Prayudha B., Hafizt M., Budiyanto A., Suharsono, 2018 Status terumbu karang Indonesia 2018. Jakarta: Pusat Penelitian Oseanografi – Lembaga Ilmu Pengetahuan Indonesia, 26 pp. [in Indonesian]
Harrington L., Fabricius K., De'ath G., Negri A., 2004 Recognition and selection of settlement substrata determine post-settlement survival in corals. Ecology 85(12):3428-3437.

Hehre E. J., Meeuwig J. J., 2015 Differential response of fish assemblages to coral reef-based seaweed farming. PLoS ONE 10(3):e0118838.
Hodgson G., 1990 Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*. Coral Reefs 9:41-43.
Jompa J., McCook L. J., 2003 Coral-algal competition: macroalgae with different properties have different effects on corals. Marine Ecology Progress Series 258:87-95.
Kelly E. L. A., Cannon A. L., Smith J. E., 2020 Environmental impacts and implications of tropical carrageenophyte seaweed farming. Conservation Biology 34(2):326-337.
Krause-Jensen D., Duarte C. M., Hendricks I. E., Meire L., Blicher M. E., Marta N., Sejr M. K., 2015 Macroalgae contribute to nested mosaics of pH variability in a subarctic fjord. Biogeosciences 12:4895-4911.
Lukoschek V., Cross P., Torda G., Zimmerman R., Willis B. L., 2013 The importance of coral larval recruitment for the recovery of reefs impacted by cyclone Yasi in the central Great Barrier Reef. PLoS ONE 8(6):e65363.
Mariño M., Breckwoldt A., Teichberg M., Kase A., Reuter H., 2019 Livelihood aspects of seaweed farming in Rote Island, Indonesia. Marine Policy 107(103600):1-9.
Moberg F., Folke C., 1999 Ecological goods and services of coral reef ecosystems. Ecological Economics 29(2):215-233.
Mulyani S., Tuwo A., Syamsuddin R., Jompa J., 2018 Effect of seaweed *Kappaphycus alvarezii* aquaculture on growth and survival of coral *Acropora muricata*. AACL Bioflux 11(6):1792-1798.
Munasik, 2002 Reproduksi seksual karang di Indonesia: suatu kajian. Pengelolaan Sumberdaya Pesisir dan Lautan Indonesia, 10 pp. [in Indonesian]
Neish I. C. 2008 Good agronomy practices for *Kappaphycus* and *Eucheuma*: including an overview of basic biology. SEAPlant.net Monograph no. HB2F 1008 V3 GAP. SEAPlant.net, 72 pp.
Nikijuluw V. P. H., 2017 Coastal resources conservation in Indonesia: issues, policies, and future directions. Sumatra Journal of Disaster, Geography and Geography Education 1(1):15-23.
Nontji A., 2004 COREMAP Tahap I: upaya anak bangsa dalam penyelamatan dan pemanfaatan lestari terumbu karang. Kantor Pengelola Program COREMAP. Pusat Penelitian Oseanografi. LIPI, Jakarta, 130 pp. [in Indonesian]
Nybakken J. W., Eidman H. M., 1988 Biologi laut: suatu pendekatan ekologis. PT. Gramedia Pustaka Utama, Jakarta, pp. 325-363.
Okamoto M., Roeroe K. A., Yap M., Lalamentic L. T. X., Fujiwara S., Oyamada K., 2012 Experimental transplantation of corals using sexual reproduction in Manado, Indonesia. Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 5 pp.
Ompi M., Svane I., 2018 Comparing spawning, larval development, and recruitments of four mussel species (Bivalvia: Mytilidae) from South Australia. AACL Bioflux 11(3):576-588.
Pascal N., Allenbach M., Brathwaite A., Burke L., Le Port G., Clua E., 2016 Economic valuation of coral reef ecosystem service of coastal protection: a pragmatic approach. Ecosystem Services 21:72-80.
Permata D., Indrayanti E., Haryanti D., Fika L., Arfiyan H., Achmad A., 2012 Biannual multispecific spawning in Karimunjawa Archipelago, Indonesia. Coral Reefs 31(3):907.
Pendleton L., Comte A., Langdon C., et al, 2016 Coral reefs and people in a high-CO2 world: where can science make a difference to people? PloS One 11(11):e0164699.
Purnomo W. P., Afiati N., 2018 Post west monsoon planulae recruitment in damaged coastal corals of Panjang Island, Jepara, Central Java, Indonesia. AACL Bioflux 11(1):132-142.
Rahman A., Haris A., Jamaluddin, 2014 Pola rekrutmen karang Scleractinia pada kondisi lingkungan berbeda. Jurnal Sains & Teknologi 14(3):209-219. [in Indonesian]
Richmond R. H., Hunter C. L., 1990 Reproduction and recruitment of corals: comparisons among the Caribbean, the Tropical Pacific, and the Red Sea. Marine Ecology Progress Series 60:185-203.
Ritson-Williams R., Arnold S. N., Fogarty N. D., Steneck R. S., Vermeij M. J. A., Paul V. J., 2009 New perspectives on ecological mechanisms affecting coral recruitment on reefs. Smithsonian Contributions to the Marine Sciences 38:437-457.

Romero C., Athayde S., Collomb J. G., DiGiano M., Schmink M., Schramski S., Seales L., 2013 Conservation and development in Latin America and Southern Africa: setting the stage. Ecology and Society 17(2):17.
Rudi E., Soedharma D., Sanusi H. S., Pariwono J. I., 2005 Affinitas penempelan larva karang (Scleractinia) pada substrat keras. Jurnal Ilmu-Ilmu Perairan dan Perikanan Indonesia 12(2):129-137. [in Indonesian]
Salinas-de-Leon P., Dryden C., Smith D. J., Bell J. J., 2013 Temporal and spatial variability in coral recruitment on two Indonesian coral reefs: consistently lower recruitment to a degraded reef. Marine Biology 160(1):97-105.
Samidjan I., 2005 Suksesi struktur komunitas pada terumbu buatan di perairan Pulau Menjangan Besar dan Gon Waru, Kepulauan Karimunjawa, Jawa Tengah. Doctoral Dissertation, Institut Pertanian Bogor, 10 pp. [in Indonesian]
Sawall Y., Jompa J., Litaay M., Maddusila A., Richter C., 2013 Coral recruitment and potential recovery of eutrophied and blast fishing impacted reefs in Spermonde Archipelago, Indonesia. Marine Pollution Bulletin 74(1):374-382.
Sievanen L., Crawford B., Pollnac R., Lowe C., 2005 Weeding through assumptions of livelihood approaches in ICM: seaweed farming in the Philippines and Indonesia. Ocean and Coastal Management 48(3-6):297-313.
Stevant P., Rebours C., Chapman A., 2017 Seaweed aquaculture in Norway: recent industrial developments and future perspectives. Aquaculture International 25:1373-1390.
Tuhumena J. R., Tapilatu R. F., Boli P., 2019 The effect of type and duration of substrate collector placement to the coral genus recruitment in Saleo Beach Area, Dampier Strait, Raja Ampat, Indonesia. AACL Bioflux 12(5):1643-1652.
van Woesik R., 2009 Calm before the spawn: global coral spawning patterns are explained by regional wind fields. Proceedings of the Royal Society B: Biological Sciences 277:715-722.
Veron J. E. N., Stafford-Smith M. G., 2000 Corals of the world. Volume 1 – 3. Australian Institute of Marine Science and CRR. Qld Pty Ltd. Australia, 1382 pp.
Waite R., Kushner B., Jungwiwattanaporn M., Gray E., Burke L., 2015 Use of coastal economic valuation in decision making in the Caribbean: enabling conditions and lessons learned. Ecosystem Services 11:45-55.
Westmacott S., Teleki K., Wells S., West J., 2000 Management of bleached and severely damaged coral reefs. IUCN Publications Services Unit, Cambridge, UK, 37 pp.
Wijayanti D. P., Indrayanti E., Wirasatriya A., Haryanto A., Haryanti D., Sembiring A., Fajrianzah T. A., Bhagooli R., 2019 Reproductive seasonality of coral assemblages in the Karimunjawa Archipelago, Indonesia. Frontiers in Marine Science 6:195.
Woodhead A. J., Hicks C. C., Norström A. V., Williams G. J., Graham N. A. J., 2019 Coral reef ecosystem services in the Anthropocene. Functional Ecology 33:1023-1034.

Received: 12 March 2020. Accepted: 12 June 2020. Published online: 30 June 2020.
Authors:
Sri Mulyani, Department of Fisheries, Faculty of Agriculture, Bosowa University, Makassar, 90231, South Sulawesi, Indonesia, e-mail: smjournal45@gmail.com
Ambo Tuwo, Faculty of Marine Science and Fisheries, Universitas Hasanuddin, Jl Perintis Kemerdekaan km 10, Makassar 90245, Indonesia, e-mail: ambotuwo62@gmail.com
Rajuddin Syamsuddin, Faculty of Marine Science and Fisheries, Universitas Hasanuddin, Jl Perintis Kemerdekaan km 10, Makassar 90245, Indonesia, e-mail: rajuddinsyamsuddin@yahoo.com
Jamaluddin Jompa, Faculty of Marine Science and Fisheries, Universitas Hasanuddin, Jl Perintis Kemerdekaan km 10, Makassar 90245, Indonesia, e-mail: j.jompa@unhas.ac.id
Indra Cahyono, Marine Technology College of Balik Diwa, Makassar, 90245, South Sulawesi Indonesia, e-mail: indracahyono@stitek-balikdiwa.ac.id

How to cite this article:
Mulyani S., Tuwo A., Syamsuddin R., Jompa J., Cahyono I., 2020 Effect of *Kappaphycus alvarezii* mariculture on the recruitment of scleractinian corals. AACL Bioflux 13(3):1746-1757.