Success of coral reef rehabilitation from 2016 bleaching phenomenon using dead coral substrates

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Abstract. This study was aimed to analyze the successful use of dead coral substrate as media in rehabilitation of coral reefs damaged by the 2016 bleaching phenomenon in the waters of Liukangloe Island, Bulukumba District. The study was conducted in five areas in the north and east sides of the island using three species of dead coral substrates (massive, branching, and tabulate) on three species of corals (*Acropora nobilis, A. formosa,* and *Porites cylindrica*) at 3-5 m depth. As a control, it also carried out marking and measurement of the three species of corals in their natural habitats. The variables measured were growth and survival rate of the tested corals which were monitored every 28 days for 112 days of observation. Measurement of changes in the length of coral branches was done by using calipers. Growth and survival rates were analyzed for differences between dead coral substrate media by analysis of variance for each coral species and observation time. The results showed that there was no difference in the growth of branch lengths of the three species of the tested corals at each time of observation in three dead coral substrate media, however, the survival values were significantly different, especially on the 84th and 112th days. The use of massive and branching dead coral substrate gave the best results on the survival value of the three species of coral tested.
Key Words: coral reef rehabilitation, transplantation, bleaching, dead coral substrate, Liukangloe Island.

Introduction. During the El Niño occurrence, the hotter water flowed from the Western Pacific to the colder eastern Pacific area causing a significant increase in the surface temperature of the ocean. In general, the influence was very large in reef areas, such as in the Galapagos Islands (97% dead coral), along the coast of Panama (75-85% dead coral) and Costa Rica (58% dead coral) (Glynn et al 1985). In 2010, global bleaching stretched from the western Indian Ocean to the Caribbean and in particular was devastating in Southeast Asia (Guest et al 2012; Alemu & Clement 2014). When the peak of the events of El Niño in November-December 2015, the bleaching spread throughout the Pacific and Indian Ocean in the 2016. In June 2017, the longest, the most extensive and the most severe global bleaching recorded in history with more than half of the reef areas, including Hawai'i and the Great Barrier Reef. Decrease in coverage of live coral as a result of the events of coral bleaching was also observed in Northwestern of Hawaiian Islands. Average live coral cover of reef in permanent monitoring site dropped by 68%, resulting in a fast reduction of habitat complexity (Couch et al 2017).

World Meteorological Organization (WMO) released that 2015-2016 was claimed as the hottest year in history as a result of the El Nino symptom. The average surface temperature of the earth between 2015-2016 has reached what is termed by the WMO as a "symbolic and significant milestone" around 1^oC Celsius from the pre-industrial era in 1880-1899, and around 0.73^oC above the average value in 1961-1990. The increase occurred around 16 to 20% due to El Niño, a natural weather pattern that indicates the warmth of sea surface temperatures in the Pacific Ocean. This year's El Niño was considered as the most severe in history (Viva News 2016). As global temperatures increase, water temperatures in Makassar Strait and Flores Sea increased from an average of 27 to 30^oC, or experienced an anomaly of 3^oC (Hajramunrni 2016).

Liukangloe Island is located in Bontobahari Subdistrict, Bulukumba Regency, precisely in the Flores Sea. Based on an investigation conducted by Marine Science Diving Club of Hasanuddin University in March 2016 (Hajramunrni 2016), coral bleaching was occurred and causing the whitening of coral cover > 50% and cause damage to live coral of > 40%. Results of the monitoring to study the effects of bleaching in 2017, found that at 3-5 m depth, the impact of bleaching was high and occurs at all observation points with dead coral cover which was overgrown with algae ranges from 35-60%. *Acropora* and *Montipora* are two coral genera with an intense bleaching attack. *Acropora palifera* is grouped as coral which is vulnerable to bleaching both at depths of 3-5 m and at 8-10 m with bleached colony intensities ranging from 12 to 93% (Rani et al 2017).

In the waters of Liukangloe Island, damage to coral reefs from the events of bleaching was > 50% (Nirwan et al 2017). As one of the locations of marine tourism destinations, this has become a problem for tourists, guides and observers of marine tourism in Bira Cape. Coral reefs in the island is relying on the beauty of the underwater objects as a tourist attraction, even some diving points (eastern side of the island) are frequently visited by tourists to enjoy a panoramic view of the corals and fishes associated with coral reefs. Coral death due to bleaching events itself becomes a problem because of decreased attractiveness (reduced beauty), coral reefs are dominated by white color by dead corals (Nirwan et al 2017). This may indirectly reduce the number of tourist visits. The decline in the number of tourists also directly affected the income of the people of Bira Cape and its surrounding areas, including groups of marine tourism observers. Similar problem is also faced by traditional fishermen who depend on their catches for fishes associated with coastal ecosystems, especially coral reef fishes.

Based on the above facts, it is necessary to conduct a comprehensive study on technical actions in accelerating recovery process of coral reef ecosystem that has been damaged due to the phenomenon of bleaching. Therefore, this research is directed to analyze the success of rehabilitation of coral reefs damaged by the 2016 bleaching event by utilizing various dead coral substrates available in nature based on the growth and survival of transplanted corals.

Material Method

Research location. This research was carried out in the coral reef area of Liukangloe Island waters. Coral reefs in these waters have been reported to experience the phenomenon of bleaching in wide scope in March 2016. Liukangloe Island is located in the Bira Cape area and is a tourist destination for coastal and diving tourism in the southern part of South Sulawesi (Figure 1). This research was conducted for 112 days from May to September 2019.

Determination of observation points. Research on technique of coral reef recovery from impacts of coral bleaching event was done at 15 observation points for each dead coral substrate form (natural substrate) which is used as attachment media in recovery efforts through rehabilitation. Area was selected based on the extent of the bleaching event at a depth of 3-5 m. Based on previous studies, several locations in the depth of 3-5 m suffered many deaths due to bleaching events, especially areas in the north and east of the island (Nirwan et al 2107; Rani et al 2017). The three stations were respectively put on the north and east sides of the island. The main consideration was because these three stations are diving areas for foreign tourists but have experienced significant bleaching. At station 3, there were three substations, while stations 2 and 3 only had one substation each. At each substation, three observation points were determined for each substrate.

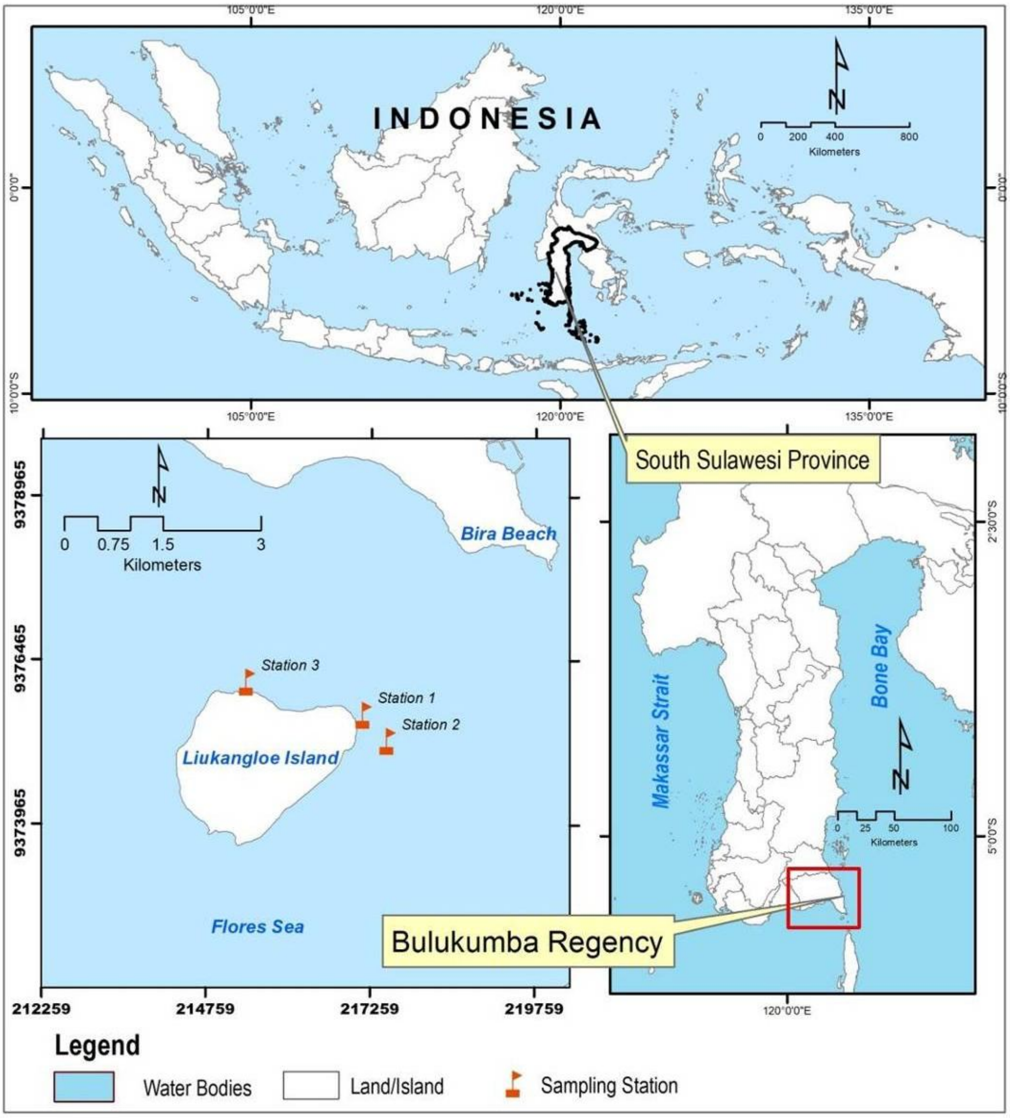

Figure 1. The location of the study on Liukangloe Island, which is situated on the southern coast of Bulukumba Regency.

Research design. The study used three forms of utilization of the natural substrate that available in the surroundings, i.e. dead coral with large colony sizes. The three forms of natural substrate, namely 1) massive corals, 2) branching corals, and 3) tabulated corals. Each form of substrate (treatment) was repeated five times (5 substations). At each substation, all of these three substrates were available as transplant media (15 planting points). The distance among the separated media was about 25-50 m and it was assumed that there was no interaction among the sampling units.

In each selected substrate media, three species of branched corals (growing faster) were transplanted whose colonies were found around the transplant sites (relatively similar depth between the donor and the rehabilitation areas). Those three species of corals were: 1) *Acropora nobilis*, 2) *Acropora formosa*, and 3) *Porites cylindrica*. Colony of the coral donor was selected which was healthy (brighter color) and colony diameter > 25 cm. The colonies were taken in part and made into small fragments that measuring 5-8 cm as coral transplant. Each coral species was determined as many as 10 fragments (a total of 30 fragments in each substrate media) to be transplanted with a spacing of about 20 cm. The placement of the 30 fragment planting points was done randomly. As a control, three coral species were also selected in each region, each with 10 colonies. The 10 colonies were marked on their main branches to monitor their growth and survival.

Techniques for acceleration of coral reef recovery due to coral bleaching. The technique of coral reef recovery was done by transplantation techniques which were carried out with three different methods, namely by 1) utilizing natural substrate (dead coral as a medium for attaching corals) in massive form, 2) utilizing natural substrate with branched form, and 3) utilizing natural substrate with a table form (tabulate).

Natural substrate of dead coral in massive form. This technique was applied by firstly finding a natural substrate of dead coral that suitable as a media for attaching transplanted corals. The search for natural substrate was carried out in the vicinity of coral reefs that have died due to bleaching.

Dead coral in a massive form with large colony sizes then was spiked by stainless nails with length of 10 cm which had previously been coated with coarse sand using adhesives. These nails were embedded as deep as five cm into the massive coral by using a hammer as a medium for attaching transplanted corals.

Coral fragments that have been collected were then attached to a concrete nail that has been embedded using a plastic rope (cable tie). The model of this technique is presented in Figure 2.

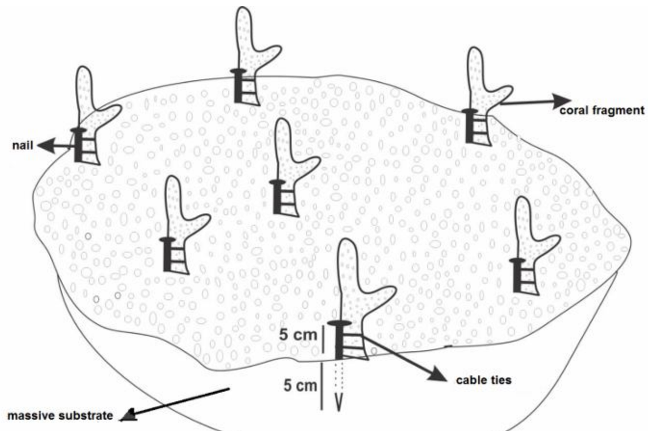

Figure 2. Rehabilitation techniques using natural substrates in the form of dead massive corals.

Natural substrate in the form of branching dead corals. Coral species used and attached to the natural substrate of branching coral was just kind of branching coral only. The natural substrate was selected from dead branching corals with large branching structures. Furthermore, live coral fragments were bound to the natural substrate on the main branch by using cable ties (Figure 3).

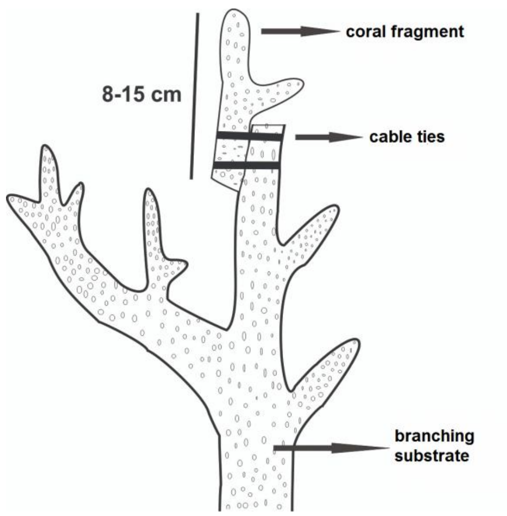

Figure 3. Rehabilitation techniques using natural substrates in the form of dead branching corals.

Natural substrate in the form of table-shaped dead coral (tabulate). Selected table-shaped coral colonies are quite large in diameter (±50 cm) with strong colony structures and thick branches. Furthermore, live coral fragments were tied to the natural substrate on large branches using cable ties (Figure 4). The branching structure of the table-shaped corals was classified as dense and short, therefore, some branches were removed to provide sufficient space to place the transplanted coral by tying it with a plastic strap on the branch of the tabulated corals.

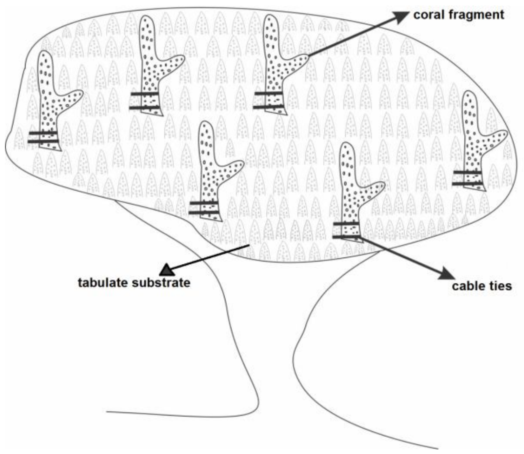

Figure 4. Rehabilitation technique using natural substrates in the form of dead tabulate corals.

Measurement of growth and survival. Before conducting observations of growth and survival of all the fragments of the transplanted corals, firstly performed was the cleaning of mosses around the transplants for approximately 12-14 days. Survival and growth of the transplanted corals were monitored and growth of coral transplants in each area were conducted every 28 days for 112 days of observation. The monitoring techniques used were as follows: at the initial measurement, the transplanted corals were firstly measured their branch length as an initial length (preliminary data). Measurements were made using a caliper ruler (smallest scale: 0.01 mm). Then monitoring was done every 28 days for 112 days of observation. In addition to measuring changes in branch length, the number of dead coral fragments was also counted.

Data obtained from the results of subsequent measurements, were tabulated to determine the magnitude of the growth and survival of coral.

Coral growth within a certain time (28 days) was calculated using the following formula (Effendie 1997):

$$\beta = L_t - L_0$$

where: β = growth (mm);
Lt = mean height after the t-observation;
Lo = mean height at the beginning of the study.

The survival rate of corals was calculated using the formula (Effendie 1997):

$$S = \frac{N_t}{N_0} \times 100$$

where: S = survival rate (%);
Nt = number of coral fragments at the end of the study;
No = number of coral fragments at the start of the study.

Data analysis. Values of growth and survival rates among the three natural substrates used for transplantation were grouped according to the observation time (every 28 days) and analyzed for their differences by analysis of variance. The best natural substrate to be used in coral reef recovery from bleaching events was analyzed based on the significance of the mean values of the two parameters. The calculation process was carried out using SPSS 12 software and graphics were made using Excel software. The results of the analysis were presented in graphical forms.

Results and Discussion. It was observed that within 112 days of growth and survival monitoring of transplanted corals, all transplants responded positively in terms of branch length increase each month. However, some fragments (a small portion) were lost, and this was considered as death and was taken into account in analyzing the survival rate of each coral species.

Coral growth. We have observed for 112 days a number of 450 transplanted coral fragments from three branched coral species. These observations showed variations in the length increase of coral branches according to species and media of transplant substrate. Changes in the length of the three species of transplanted corals over 112 days are presented in Figure 5.

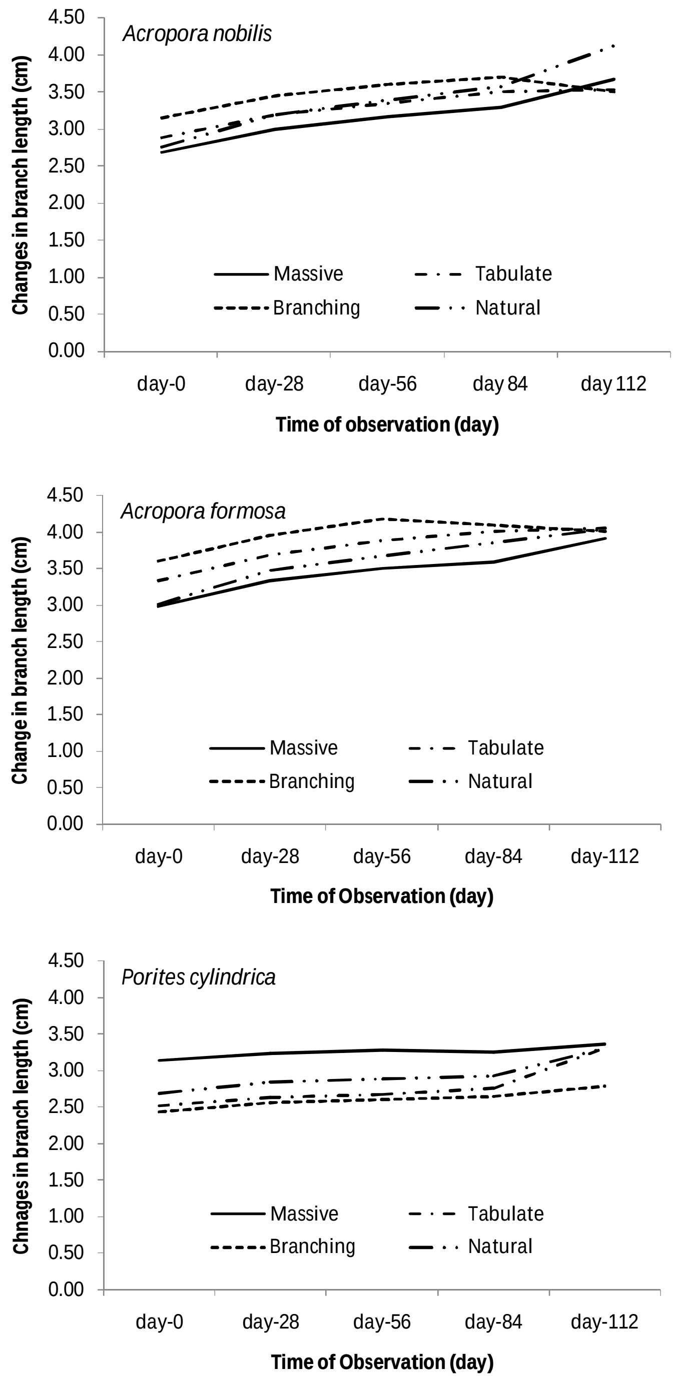

Figure 5. Changes in branch length on all three species of branching coral transplanted at several media of dead coral substrate.

Changes in the length of all species of transplanted corals indicate a growth response from transplanted corals. Length changes tend to decrease in branching coral substrate at day 84 on the species *A. nobilis* and at day 56 for *A. formosa*. The results of data tracer showed that some transplanted coral individuals are lost (apart from the substrate) and generally have longer branches. This situation causes a decrease in the average value of branch length. On the 56th day (July) and 84th day (August), extreme weather occurred with large waves during the peak of the eastern moonson in the waters of Bulukumba.

Absolute growth per 28 days in the tested coral species that transplanted at four natural substrates showed a pattern that varied according to the time of observation. The pattern that was formed, i.e. increased on the 56th day and decreased on the 84th day and subsequently experienced an increase on the 112th day (Figure 6). The average absolute growth per 28 days for species *A. nobilis* ranges from 0.15 to 0.19 cm in natural corals. Then followed by massive dead-coral substrate with a range of 0.13-0.18 cm, and the lowest was on dead-branching coral substrate with a growth range of 0.10-0.17 cm. Coral species *A. formosa*, has the highest growth in natural corals with a range of 0.16-0.21 cm, followed by a massive dead coral substrate with a range of 0.14-0.20 cm. The lowest was on dead-tabulated coral substrate with a range of 0.13-0.2 cm. Whereas in species *P. cylindrica*, the growth range is also highest in natural corals with an average growth of 0.03-0.07 cm. Followed by massive dead coral substrate, tabulate and branching with the same range, i.e. 0.03-0.05 cm.

In general, high absolute growth is visible on natural coral (control), however, the statistical test results showed no significant differences ($p > 0.05$) in all three species of coral transplants. This phenomenon proves that the use of natural dead coral substrates, either massive, tabulate or branching, was equally effective in transplantation activities in terms of growth parameters.

The average absolute growth per 28 days (perceived as one month) for species *A. nobilis* at all treatment substrates ranged from 0.10 to 0.19 cm month^{-1}. Results obtained in this study were relatively different from the studies done in other locations, such as study carried out by Aaron-Amper et al (2015), who got an average absolute growth of 0.81 cm month^{-1}; by Muhlis (2019) 0.44 cm month^{-1}; by Saptarini et al (2017) ranging from 0.58 to 1.14 cm month^{-1}. For coral species *A. formosa*, the average absolute growth ranged from 0.13 to 0.21 cm month^{-1}. The result is relatively different from a research conducted by Xin et al (2013), which obtained an average absolute growth ranging from 0.39 to 0.65 cm month^{-1}; Xin et al (2016) ranging from 0.55 to 1.20 cm month^{-1}. Whereas for the species *P. cylindrica*, the average absolute growth is 0.03-0.07 cm month^{-1}. The results obtained are relatively similar to those obtained by Rojas et al (2008), who obtained an average absolute growth of 0.08 cm month^{-1}.

There were differences in the average growth of coral species *A. nobilis, A. formosa,* and *P. cylindrica* with other studies, due to differences in location (environment) and difference in measurement methods. Luthfi et al (2015) conducted their research at Sempu Nature Reserve, Malang with the method of measuring photography using Image-J software; Saptarini et al (2017) in the discharge of cooling water generating electricity by the method of direct measurement using calipers; Aaron-Amper et al (2015) did it in Alona Beach, Tawala, Panglao, Bohol, Philippines with the direct measurement method using calipers; and Xin et al (2013) and Xin et al (2016) did it in naturally coral reefs and in the nursery reef for restoration in Renggis Island and Tioman Island, Malaysia with a method of measuring the direct use of flexible roll metertape.

No significant difference was found ($p > 0.05$) of absolute growth from *A. nobilis, A. formosa,* and *P. cylindrica* which was transplanted on massive dead-coral substrate, dead-tabulate coral substrate, dead-branching coral substrate, and coral substrate at all time of observation. This phenomenon confirms that the attachment of coral fragment media (dead coral substrate used) does not affect growth and was merely a place to attach/substrate. Basal part of coral fragment was attached to substrate, while the growing point of the test coral used (branch coral) is at the end of the branch which was not in contact with the attachment substrate. The growth point of stony corals in general was located at the end of branches on the branching corals, tabulate corals, and sub massive coral; in foliose corals the point of growth lies on the edge of the corallum strand, while on the massive coral is on the surface of the corallum, and not on the basal part. Anderson et al (2017) that performed measurements of coral growth using alizarin red, explained that part of the red light of the framework was result of the dye alizarin red that was inserted into the frame, while the part of the white was the new framework increases, which was located at the tip of a branch on the coral species *Acropora muricata, Isopora palifera,* and *Pocillopora damicornis*, whereas Luthfi et al (2015) explained that branch growth on *Acropora* sp. takes place on axial corallites, not radial corallites.

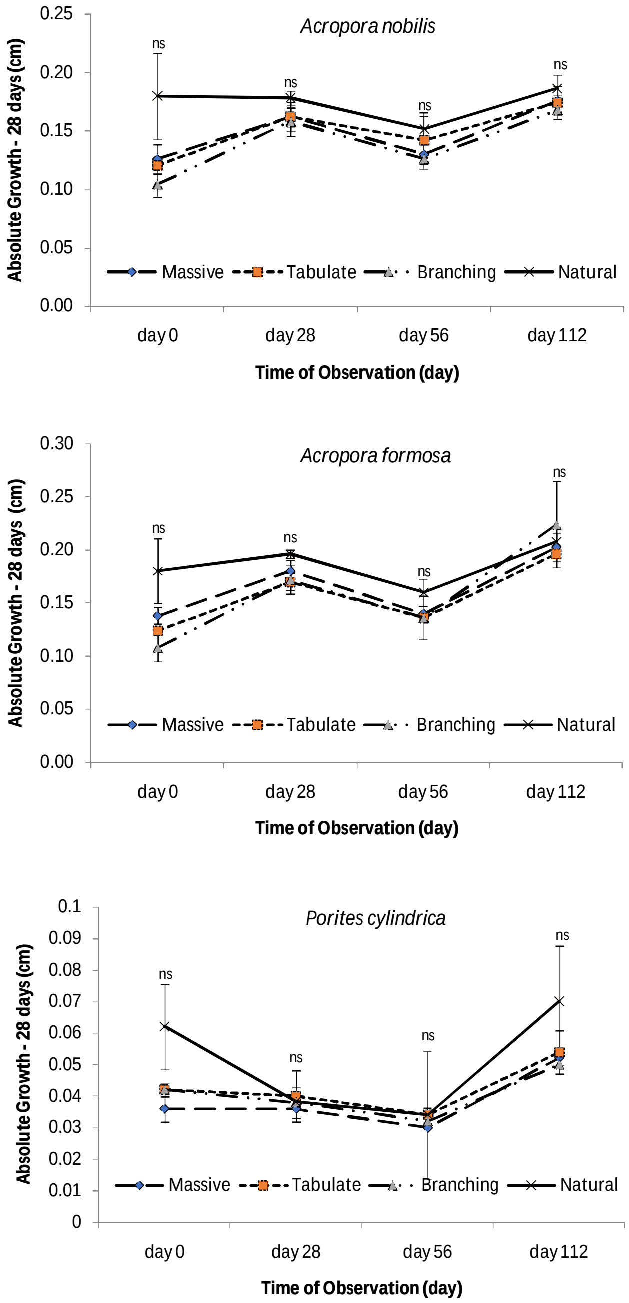

Figure 6. Absolute monthly growth (28 days) of branch length of the three species of branching corals that were transplanted in various media of different dead coral substrates.

***Survival rate**.* The survival rate of all three species of the transplanted corals firstly decreased at day 28 in all substrates of dead corals, except for stable natural coral to the end of the study (100% survival). In general, the survival rate for all dead coral substrate used was ≥ 85% (Figure 7). This value is relatively high. Deaths on some transplanted coral fragments were not due to environmental conditions but due to the release of bonds in the media, especially on the 56th and 84th days of the eastern season. In this study, the use of dead coral substrate which showed the large number of coral fragments detached from the substrate was tabulate coral substrate. This incident is quite reasonable, because the branching corals tabulate is relatively short, only about 4-5 cm thus the water movement may cause a friction of the bond towards the ends of branches that create fragment detachment.

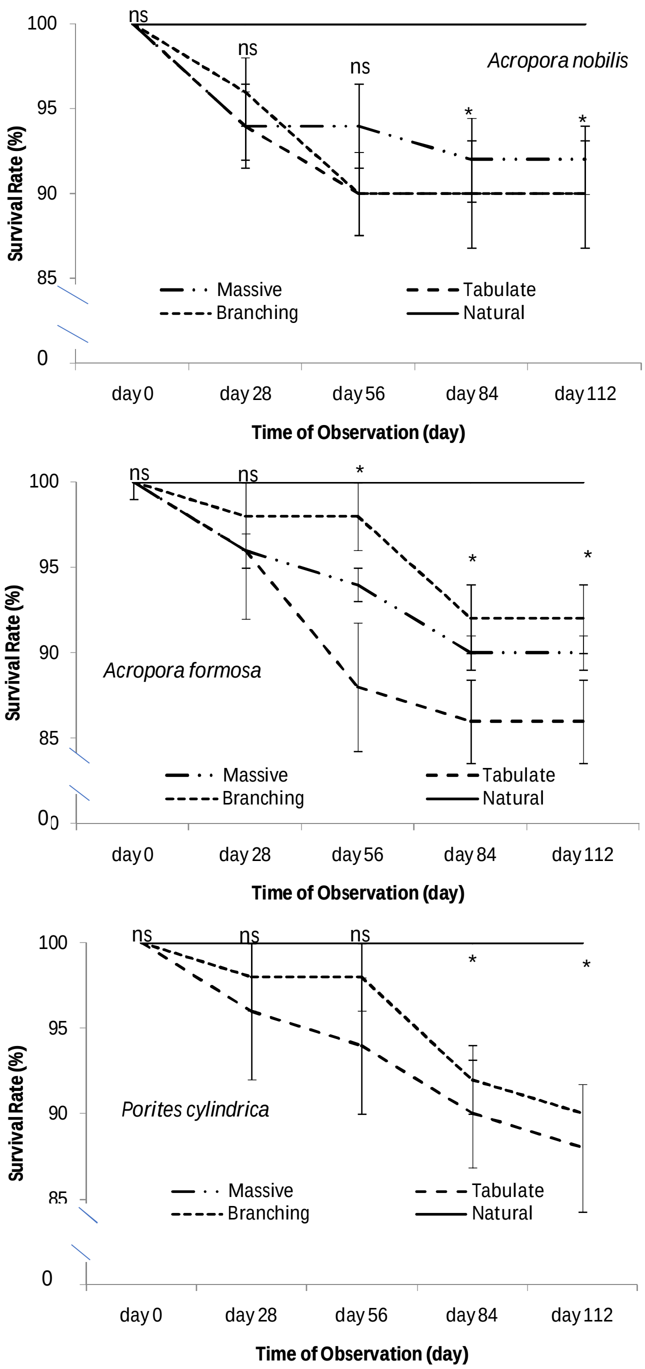

Figure 7. The monthly survival rate (28 days) of all three species of branching corals that transplanted in various media of dead coral substrate.

The results of the analysis of variance showed that no significant variations were found in the survival value of the three species of corals from the beginning of the study to the 56th day, except for *A. formosa* species. Significant variations were observed on the 84th day until the 112th day, while on the *A. formosa* species began to appear on the 56th day. Further test results, for the species of *A. nobilis*, the value of the highest survival rate at dead coral-massive (94%) and natural coral (100%) and not significantly different ($p > 0.05$) between the second treatments, but it was significantly different ($p < 005$) with dead- branching and dead-tabulate corals substrates with a value of 90% each (Figure 7). Continuing on day 112, the survival rate values were appeared to be significantly different among substrat used. The highest survival rate was found in natural corals and was significantly different from the three dead coral substrates used. Meanwhile, the three dead coral substrates themselves, showed no real difference.

In coral species *A. formosa*, a marked variation in survival was observed starting on the 56th day. The highest survival rate was found on natural corals (100%) and dead-branching coral substrate (98%) and significantly different from dead-tabulate coral substrate (88%). Significant variations continued on the 84th and 112th days, natural corals showed the highest survival values and were significantly different from the three dead coral substrates, while the three dead coral substrates did not show any significant differences (Figure 7). For *P. cylindrica* species, noticeable variations were found on days 84 and 112. On day 84, there were no significant differences between natural corals, dead-branching corals, and massive dead corals, but significantly different from dead corals-tabulate. Similarly, there were no significant differences observed among the dead coral-branching, dead-massive coral and dead coral-tabulate. On the 112th day, natural corals were still the best and were significantly different from the three forms of dead coral substrates tested. While among the three dead coral substrates, it is equally good in maintaining the survival of transplanted corals.

The survival rates of the tested coral species were not significantly different at the beginning of the study, but were seen to be different on the 84th and 112th day on the three types of test corals ($p < 0.05$). The survival rate at the beginning of the observation was no different, probably due to the relatively same physiological condition of the coral and also the oceanographic condition (especially the waves and currents) when the observation period was relatively good. Different wave conditions in observation time at the 84th day and 112th day (July and August are the peak of the eastern moonson in the waters of Bulukumba Regency), most likely due to large waves around the transplant site, thus affecting the stability of coral transplants tied to the media dead coral substrate. Dead-branching coral substrate (having longer branches as a binding point for fragments) and dead-massive coral substrate (concrete nails embedded as attachment media) were more sturdy and stronger in maintaining for transplant corals position. Whereas the tabulate dead substrate, had a short branching structure, so that coral fragments are more easily released when there was a large wave action. Some research results on transplanted corals, showed that coral mortality in the early stages of the study were generally caused by poor oceanographic conditions, so that the coral transplants were detached and lost, as research conducted by Luthfi et al (2015) on coral *Acropora* sp.; Aaron-Amper et al (2015) on *A. nobilis*, Yap & Molina (2003) on *P. cylindrica* and *Porites rus* corals.

Based on the survival values that were tested on three species of corals, the test confirmed that the use of dead-massive coral substrates and dead-branching corals gave high survival values and did not make a significant difference with natural corals. The average survival raet of three species of coral transplants in the study was relatively high in the range of 88-100% for all treatment susbtrate adhesion and observation times. Value range of the mean survival rate obtained in this study was relatively similar with research conducted by Aaron-Amper et al (2015), Putchim et al (2008), and Thornton et al (2000) with the mean survival rate of coral *A. nobilis* transplanted respectively 88.7% (during three months), 94.8-95.8% (during four months), and 87% (during three months); Yap & Molina (2003) premises level of a continuity lived an average of 70-100% on the coral *P. cylindrica* were observed for 10 months; Xin et al (2013) and Xin et al (2016) with a degree of continuity of life on average respectively 98.08-100% and 94.64% on the reef *A. formosa* observed during the six months of observation.

Conclusions. The growth of the examined corals on various dead coral substrates (massive, branching, and tabulate) as transplantation media is equally effective in supporting the growth of three species of tested corals (*Acropora nobilis*, *A. formosa*, and *Porites cylindrica*), however, in terms of their survival value, the use of dead-massive corals and dead-branching corals are recommended as media for rehabilitation activities by using dead coral substrate as an attachment medium in coral transplantation activities.

Acknowledgements. The authors would like to thank profusely to DP2M Research and Technology and Higher Education who funded this research. Acknowledgment is also addressed to Aidil Syam, S. Kel., Fachril Muhajir, S. Kel., Takbir Dg. Sijaya, S. Kel., Farid Indrastata, and Indra Dwiantara for their assistance in collecting field data.

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Received: 31 October 2019. Accepted: 06 January 2020. Published online: 20 February 2020.
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How to cite this article:
Rani C., Haris A., Faizal A., 2020 Success of coral reef rehabilitation from 2016 bleaching phenomenon using dead coral substrates. AES Bioflux 12(1):41-52.