B I O D I V E R S I T A S
Volume 10, Number 4, October 2009
Pages: 181-186

ISSN: 1412-033X (printed edition)
ISSN: 2085-4722 (electronic)
DOI: 10.13057/biodiv/d100404

Growth Rate of *Acropora formosa* Fragments that Transplanted on Artificial Substrate Made from Coral Rubble

NUR FADLI♥
Marine Science Department, Faculty of Science, Syiah Kuala University, Banda Aceh 23111, Indonesia

Received: 25th March 2009. Accepted: 16th June 2009.

ABSTRACT

Coral reefs play an important physiological and ecological role in coastal ecosystems such as providing natural breakwaters that protect shorelines and human settlements from waves and storm. Corals killed by tsunami, waves and storms are often degraded into rubble. This rubble is dynamic, easily shifted by currents and storms, which effectively forms ''killing fields'' for coral juveniles, hindering coral recovery. In order to rehabilitate coral reefs, artificial substrates are used both for coral transplantation and recruitment. Unfortunately, most artificial substrates are expensive and use land-based material such as concrete/cement-bases. In order to develop a new low-cost artificial substrate that can replace concrete/cement-base as a media for coral transplantation, modified coral rubble was tested in a pilot study in Seribu Island, Jakarta. Two different nets (nylon and polyethylene) were used to form rubble into a compact shape, stable and strong substrate. The stability of the rubble and the complexity of the surface which is created by the net make this substrate suitable for coral transplantation. Additionally, from an economic perspective the nets are very cheap and locally available. In a number of experiments, modified coral rubble successfully replaced the concrete/cement-base as a media for coral transplantation. The coral transplants were growing over time. With this method, we can try to rehabilitate the degraded coral reef destroyed by tsunami or other factors with material that already is available at the site and with less money. However, this approach requires testing at additional sites and for longer periods, to determine the replicability of the results.

Key words: cement base, coral, rubble, transplantation.

INTRODUCTION

Coral reefs are regarded as one of the most diverse, complex (Buddemeier et al*.,* 2004; Veron, 1995) and productive ecosystems (Burke et al*.,* 2002; Tomascik et al*.,* 1997) on earth. At least, 794 species of scleractinian corals are known to build coral reefs (Spalding et al*.,* 2001). The majority of coral reefs are located in tropical and subtropical regions between 22. 5°N and 22. 5°S latitude, with the center of maximum coral diversity in the Southeast Asian region (Buddemeier et al*.,* 2004). The Indonesian archipelago with more than 17,500 islands and a coastline in excess of 80,000 km, is one of the largest countries with coral reefs in the region (Burke et al*.,* 2002; Nontji, 2004; Tomascik et al*.,* 1997). Approximately 18% of the world's coral reefs are located in Indonesia. More than 480 species of hard corals (which represents 60% of the described coral in the world) are located in Indonesia (Burke et al*.,* 2002). Unfortunately, in 2003, it was estimated that only 7% of Indonesia's reefs remained in an excellent state. Over 27% were in fair condition, and more than 36% were reported to be in poor condition (Nontji, 2004).

There are many factors involved in degradation of coral reef ecosystem in Indonesia. Some of them are natural, but several factors are anthropogenic. One of the common threats is blast fishing. In remote areas, were law enforcement is minimal, blast fishing is more commonly practiced (Erdmann, 1998; Kunzmann, 2002). Blast fishing has serious negative impacts on corals because the blast shatters the coral skeleton, which leads to mass fragmentation. Some of the fragments may initially survive for several months but eventually die (Fox et al*.,* 2003). A typical 1 kg beer bottle bomb can create a rubble field of 1-2 m in diameter (Burke et al*.,* 2002). Furthermore, blast fishing may leave fields of rubble that shift in the current, abrading or burying new coral recruits, and thereby slow down or prevent the reef from recovery even when an area is protected from further blasting (Fox et al*.,* 2005). In the Philippines, many rubble fields virtually show no hard coral cover upon 20-30 years post-blasting (Raymundo et al*.,* 2007). Due to this reason, artificial substrates are always used in coral transplantation in areas of unconsolidated

♥ **Alamat korespondensi:**
Jl. Syech Abdul Rauf, Darussalam, Banda Aceh 23111
Tel. +62-0651-7410248, Fax. +62-0651-7551381
e-mail: ivad29@yahoo.com

sediment and water movement. Unfortunately, most rehabilitation techniques are expensive and labor intensive (Clark and Edwards, 1995; Edwards and Clark, 1998). Researchers comparing various coral restoration methods found that costs could range from US$13,000 to more than US$100 million/ha (Spurgeon and Lindahl, 2000). Unsurprisingly, the methods are not suitable for developing countries like Indonesia (Fox et al*.,* 2005).

Artificial substrates should possess the ability to avoid the abrasion, dislodgement and transport due to water movement (Lindahl, 2003), and be placed high enough above the bottom substrate to minimize burial and abrasion (Fox et al*.,* 2005). As long as the artificial substrate can accommodate these problems, different material can be used. In order to develop a new low-cost method of artificial substrate as a media for coral transplantation and coral recruitment a net is used to modify coral rubble into suitable media for transplantation. The net will tie and make the rubble a compact shape, stable and strong substrate. The stability of the rubble and the complexity of the surface shape, which are created by the net may increase the natural coral recruitment (Edwards and Clark, 1998; Raymundo et al*.,* 2007). Furthermore, coral rubble provides an appropriate biofilm for larvae to settle (Harrington et al*.,* 2004; Mundy, 2000). Additionally, from an economic perspective the nets are very cheap and locally available.

MATERIALS AND METHODS

The main study was carried out from the first week of September 2007 until the second week of January 2008. The experiment was located on the reef-flat on the western side of Panggang Island (located in the mid region of Seribu Island); about 300 m from the island (Figure 1). The western part of Panggang Island is a sandy plateau, which is part of the reef-flat zone. The reef-flat, which is composed of limestone, is covered with coral rubble and sand. The coral in this site is considered in poor condition (coral cover ≤ 25%) 4 x 20 m^2 line intercept transect in each depth, (English et al*.,* 1997), with dead coral cover reaching almost 50% in both (6 and 10 m) depths. In addition, the rubble covers 25% of the site. The immense availability of rubble in this site provides enough material for the experiment. Additionally, most of the coral farmers place their coral farming in this area, indicating that this site is suitable for coral transplantation.

For the experiment, three different artificial substrates with approximately equal size (size ~30x50x10 cm^3) were used: the cement base (cement-base), rubble which was tied together with nylon net (nylon + rubble) and rubble which was tied together by polyethylene net (polyethylene + rubble) (Figure 2 and 3). The cement-based substrates were considered as the control since this substrate was commonly used as a medium for coral transplantation in Indonesian waters especially in the Seribu Island. In addition, the nets that were used in this experiment were locally available with a 2 cm diameter mesh size. The rubble which was used to form the rubble substrates was taken from the water on the western part of the Panggang Island. The rubble was filled into the net on the land and left for 2-3 days. The iron sticks (diameter = 10 mm) were used as a media to attach the coral fragment onto the substrate. These different artificial substrates constituted three different treatments. Afterward, on each artificial substrate, five of coral fragments were interspersed at approximately equal intervals. The coral were tied directly to the iron sticks using plastic cable ties. The artificial substrates were placed into two different depths (6 m and 10 m), representative of shallow and deep water. An exception was the cement-base substrates, where 8 substrates in 6 m and 10 substrates in 10 m were deployed due to technical problems. The substrates were deployed in the experimental site by using a fisherman boat. The total sample size was 180 fragments in 6 m and 190 fragments in 10 m. The SCUBA gear was used to put the constructions in position.

The species used during the experiment was identified as *Acropora formosa.* Fragments for the experiments were collected from a donor site about 100 m away from the experimental site. Donor colonies were located at about 2-3 m depth. For every surviving fragment, the change of the main branch in linear extension (the total length from the apical tip to the net) was measured with plastic Vernier calipers (0.01 mm error margin) for every sampling interval and the overall duration.

For the calculation of growth rates per day, the mean increment of all surviving fragments per treatment per time was used, divided by the number of days between two samplings. Fragments showing negative growth between surveys were not considered in calculation of average growth rates to make sure that only growth was considered. In order to determine if the growth rates of the fragments were different between substrate, the mean increment per day of transplants for each type of substrate was tested by Wilcoxon Rank Sum test. Each depth was examined separately. All data used in the statistical analysis were analyzed using JMP 7.0.1 software (trial version).

RESULTS AND DISCUSSION

Results

In a number of experiments, the transplants were increasing their length over time. Some fragments were also increasing the number of branches indicating that they can grow on the substrates. The stability of the rubble which is created by the net is

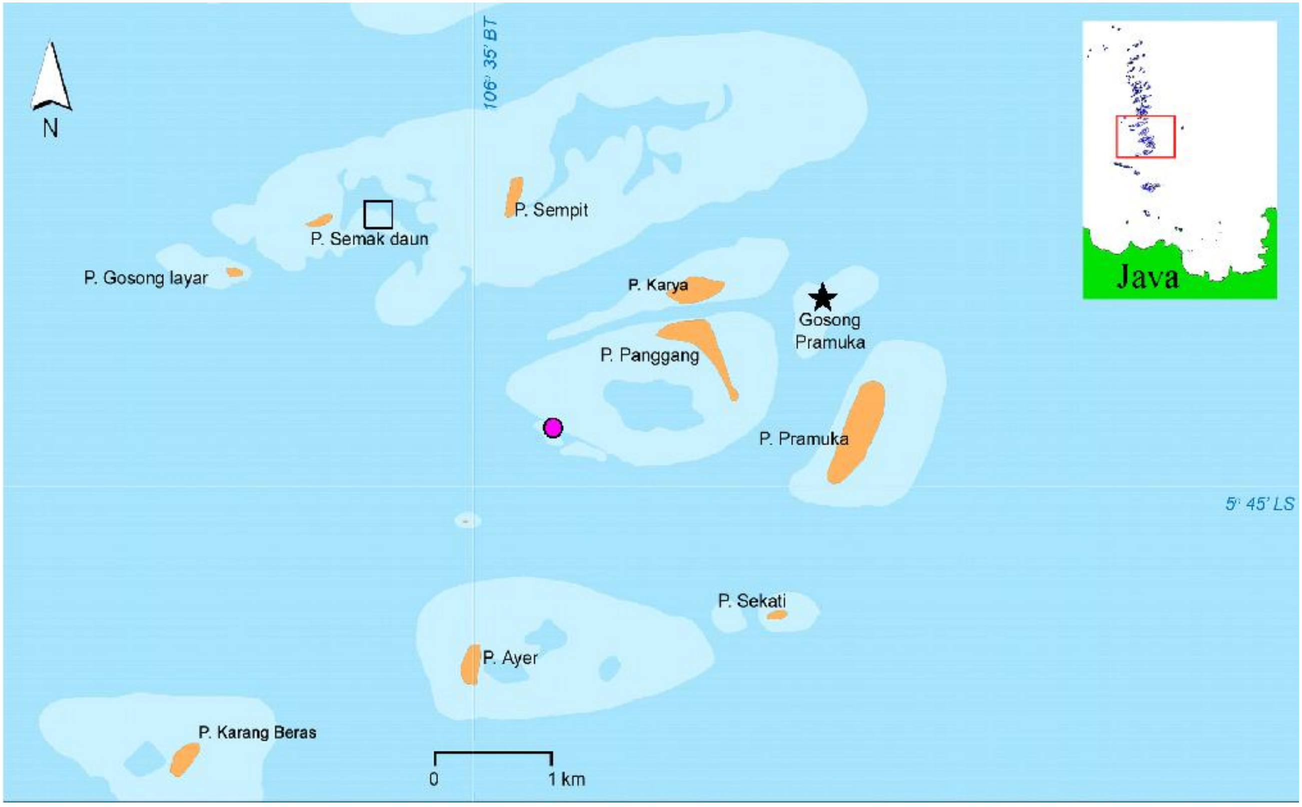

Figure 1. Location of the study site, (pink circle = experimental site, located in reef flat of Panggang Island; rectangular = location of rubble and sand mining; black star = location of rubble and sand reclamation).

Figure 2. Cement-base (left) and net + rubble substrate (right)

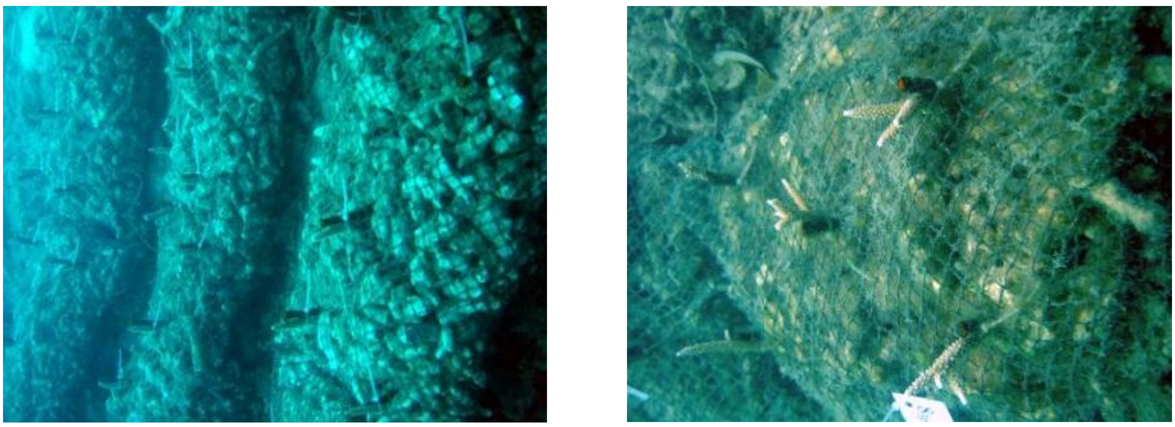

Figure 3. The rubble substrates after deployment.

suitable for coral transplantation. The average initial length of the coral transplants on the nylon + rubble substrate in 6 m was 55.6 ± 6.0 mm (n = 70). In January 2008 or at the end of the experiment, the average length was 84.1 ± 13.3 mm (n = 18), an increase of about 1.5 fold. The average length of the coral transplants on the polyethylene + rubble substrate was 60.9 ± 9.4 mm (n = 70) at the start of the experiment (September 2007), and 77.2 ± 14.7 mm (n = 26) in January 2008, an increase of about 1.2 fold. For the cement-base, the average initial length of the coral transplants was 55.6 ± 10.2 mm (n = 40), an increase of about 1.3 fold over the observation period (72.9 ± 3.4 mm, n = 23). There was no significant difference in term of growth rate between the transplants on the cement-base with the fragments on the nylon + rubble substrate and polyethylene + rubble substrate (P >0.1978, Table 1). The average increment of transplants on different type of substrates in 6 m is depicted in Figure 4.

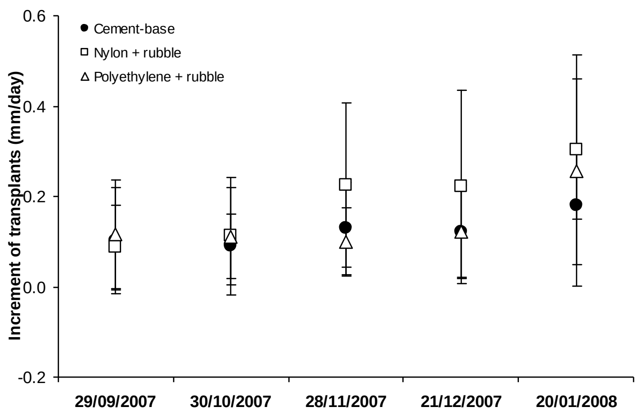

Figure 4. Mean increment of transplants in the different substrates and sampling intervals in 6 m standardized to length increase in mm per day. Error bars are standard deviations.

In 10 m, the average initial length of the coral transplants on the nylon + rubble substrate was 62.8 ± 11.4 mm (n = 70) in September 2007. In January 2008 or at the end of the experiment, the average length was 87.4 ± 23.0 mm (n = 5), an increase of about 1.5 fold. At the start of the experiment (September 2007), the average length of the coral transplants on the cement-base substrate was 66.7 ± 10.5 mm (n = 40), and 79.2 ± 9.1 mm (n = 20) in January 2008, an increase of about 1.2 fold. For the polyethylene + rubble, the average initial length of the coral transplants was 61.7 ± 7.7 mm (n = 70), an increase of about 1.3 fold over the observation period (77.7 ± 4.4 mm, n = 2). There was no significant difference in growth rate between the transplants on the cement-base with the fragments on the nylon + rubble substrate and polyethylene + rubble substrate (P >0.8276, Table 1). The average increment of transplants on different type of substrates in 10 m is depicted in Figure 5. Overall, there was a significant difference of transplant growth between 6 and 10 m. The growth rate was better in 6 m (Table 1).

Table 1. Comparison of growth rate by depths and substrates (*significant difference (p<0.05).

	Non-parametric comparisons Wilcoxon/Kruskal-Wallis test	
I. Comparing between depths	Statistic	P
6 m vs. 10 m	137070	0.0002*
	Wilcoxon/Kruskal-Wallis test	
II. Comparing substrates per depth	Statistic	P
Cement-base vs. nylon+rubble vs. Polyethylene+rubble (6 m)	3.24	0.1978
Cement-base vs. nylon+rubble vs. Polyethylene+rubble (10 m)	0.38	0.8276

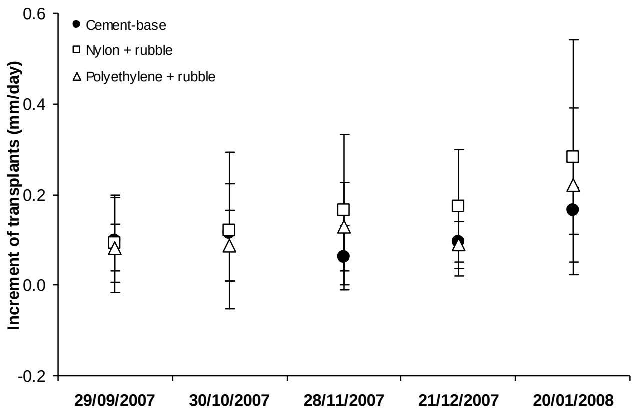

Figure 5. Mean increment of transplants in the different substrates and sampling intervals in 10 m standardized to length increase in mm per day. Error bars are standard deviations.

Discussion

The transplants were increasing their length over time. In addition, some fragments were also increasing the number of branches indicating that they can grow on the substrates. There were no differences in terms of growth detected among the substrate in 6 m or in 10 m. Overall, the transplants grew by 0.46 cm/month in 6 m and 0.33 cm/month in 10 m. Compared to other studies which used the same species in Seribu Island, this result was relatively low. It was reported that *A. formosa* increased their length by 0.88 cm/month (Sadarun, 1999), 1.1 cm/month (Alhusna, 2003), 1.14 cm/month (3 m) and 0.76/month (10 m) (Yarmanti, 2002). This result only corresponds with Johan (2001). He reported that the fragments increased by 0.374 cm/month.

The growth of the transplants was higher in shallow depth (6 m). This result corresponds with the result of other studies (Yap et al*.,* 1998; Freytag, 2001; Yarmanti, 2002; Ferse, 2003). *A. nobilis* fragments in shallow depths had higher growth rates than in deeper areas (Freytag, 2001). The depth had a significantly negative effect on *A. gomezi* (Ferse, 2003). Depth also had negative effects on *Porites cylindrical* and *P. rus* in the Philippines*,* the growth of the coral transplants were lower in deeper depth. The reduced light was the important factor for the difference (Yap et al*.*, 1998).

However, it is difficult to quantify the effect of the material used in this experiment on the growth of transplants. The quality of the water surrounding Seribu Island was assumed to be responsible for the differences. The water quality some years ago was better than the current water quality in this area. The transplants have higher survival and growth when the water quality is good (Clark and Edwards, 1995). Yap and Molina (2003) stated that environmental parameters like light, sedimentation, eutrophication, chemical pollution or coastal development activities may have negative impact to the growth and survival of coral especially if these parameters exceed the threshold. The transplants have higher survival when the water quality is good (Clark and Edwards, 1995). Most studies about transplants also reported that most of the reasons for transplant mortality were dominantly related to environmental impact, for example: sediment (Yap and Gomez, 1985); wave action (Clark and Edwards, 1995); algal competition and strong water movement (Yap et al*.,* 1998); sediments, algal bloom and grazing pressure by *Drupella* sp. (Schuhmacher et al*.,* 2000); water circulation, overgrowth by macroalgae due to increasing nutrient level and the absence of grazers (Yap and Molina, 2003); and combination of increasing temperature and algal overgrowth (Yap, 2004).

In this study, the combination of the turf/macro algae overgrowth and the sedimentation were assumed to be the cause of the mortality of the transplants. The algae started to grow on the substrates 3 weeks after deployment and overgrew the substrates in the next weeks. The algae that invaded and overgrew the transplants differed between the depths. *Dictyota* sp. invaded and covered the fragments in 10 m, while *Padina* sp. covered the fragments in 6 m. The algae in 10 m had relatively smaller size than that covered the fragments in 6 m. These small size algae overgrew and covered all the animal tissue or polyps of the coral easily and gave no opportunity for the coral to survive, while canopies of large/leathery algae like *Padina* sp. shade or whiplash corals (McCook *et al.,* 2001). This result corresponds with Yap and Molina (2003). They reported that their coral transplants (*P. cylindrica* and *P. rus*) died due to alga overgrowth. The higher number of algae in the experimental site was assumed to be a result of the combination of nutrient enhancement and removal of the herbivores. Nutrients can affect the algal growth. In addition, the abundance of the algae may or may not increase depending on herbivory rates (McCook et al*.,* 2001). Even at the experimental site which is a part of a Marine National Park, evidence of fishing activities by the islanders is easily observed. Some of them are working as marine ornamental fisher. The exact numbers of the fish that are caught by the fisherman is difficult to quantify; the fishermen catch any fish that has economic value including herbivorous fish. This activity is presumed to be responsible for the decreasing the numbers of herbivores.

Although sand and rubble mining are forbidden in this area, as a result of its inclusion in the Marine National Park; these activities were observed by the author in August 2007. Rubble and sand mining occurred in the eastern part of Semak Daun Island. This rubble was used for the reclamation of Gosong Pramuka, a sandy plateau between Panggang and Pramuka Island (Figure 1). It is estimated that more than 10.000 tons of rubble and sand (400 sacks x 60 boat per day x 20 kg per sack x 21 days) were mined within 3 weeks. This rubble and sand mining appeared to influence the high sedimentation levels in the water. The visibility of the water surrounding the Seribu Island, especially in the experimental site were also low (average ± 2-3 meters) indicating the sedimentation was high. Rachello-Dolmen and Cleary (2007) also indicated that the sedimentation problem is becoming one of the common problems across Seribu Island. During their study, they found that the corals and other benthic organisms such as sponges were often covered by sediment. Corals are not well adapted to pronounced sedimentation and produce mucus to remove the sediment that settles on their polyps (McCook et al*.,* 2001). Sediments overlying coral tissues can cause tissue death from smothering or bacterial infection, reduce the amount of available light and the capacity to capture food, and increase the energy demand for active sediment rejection (Rogers, 1983; Okubo et al*.,* 2005). Yusri and Estradivari (2007) also reported that coral diseases have already invaded corals in the Seribu Island. The sediment may also easily cause occlusion on the coral that have small corallites such as *Acropora* (Rachello-Dolmen and Cleary, 2007). In addition, the algae have indirect effects on coral due to sedimentation. Together with the mucus which produced by the coral for removing the sediment that settles on their polyps, the algae could become a sediment trap for sediment on the coral surface. This effect may significantly increase damage to underlying coral tissue (McCook et al*.,* 2001).

CONCLUSION

In terms of growth, there were no differences detected among the substrates, indicating that modified rubble can be used as an alternative media for coral transplantation. Furthermore, for future development, the shape of the layout still can be improved, the layout of the rubble in the water can be arranged into different shapes and creating more three dimensional substrate, for example pyramid-like “rubble piles” (Figure 6). However, this approach

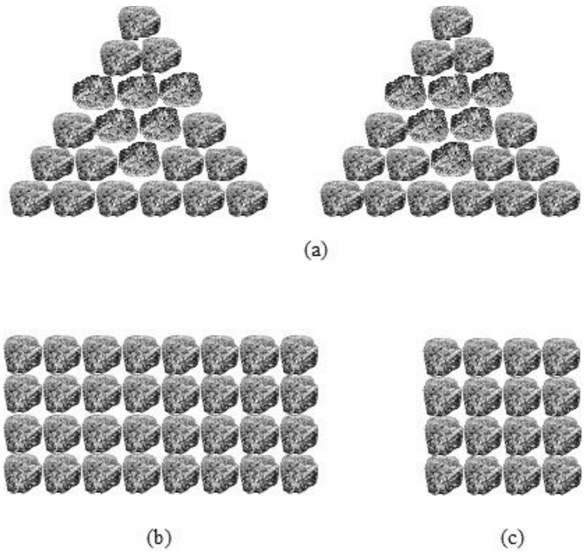

Figure 6. Example of the future layout of the rubble in the water introduced term "*rubble piles*"; pyramid like (a), rectangular (b) and square (c).

requires testing at additional sites, to determine the replicability of the results.

REFERENCES

Alhusna, I.S. 2003. *Studi Laju Pertumbuhan Induk Koloni dan Fragmen Transplant pada Transplantasi Karang Spesies* **Acropora formosa** *dan* **Hydnophora rigida** *di Perairan Pulau Pari, Kepulauan Seribu.* [Thesis]. Bogor: Bogor Agricultural University.

Buddemeier, R. W., J. A. Kleypas, and R. B. Aronson. 2004. *Coral Reefs and Global Climate Change. Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems.* Arlington, USA: Pew Center on Global Climate Change.

Burke, L., E. Selig, and M. Spalding. 2002. *Reefs at Risk in Southeast Asia.* Washington D.C., USA: World Resources Institute (WRI).

Clark, S., and A. J. Edwards. 1995. Coral transplantation as an aid to reef rehabilitation: evaluation of a case study in the Maldives Islands. *Coral Reefs* 14:201-213.

Edwards, A. J., and S. Clark. 1998. Coral transplantation: a useful management tool or misguided meddling? *Marine Pollution Bulletin* 37: 474-487.

English, S., C. Wilkinson, and V. Baker 1997. *Survey Manual for Tropical Marine Science.* Townsville: Australian Institute of Marine Science.

Erdmann, M. V. 1998. Destructive fishing practices in the Pulau Seribu archipelago. *In:* Soemodihardjo, S. (ed.) *Proceedings of the Coral Reef Evaluation Workshop, Pulau Seribu, Jakarta, Indonesia*, October 1998.

Ferse, S. 2003. *Growing Corals in An Ocean-based Nursery: The Use of Cages.* [Thesis]. Bremen: University of Bremen.

Fox, H. E., P. J. Mous, J. S. Pet, A. H. Muljadi, and R. L. Caldwell. 2005. Experimental assessment of coral reef rehabilitation following blast fishing. *Conservation Biology* 19: 98-107.

Fox, H. E., J. S. Pet, R. Dahuri, and R. L. Caldwell. 2003. Recovery in rubble fields: long-term impacts of blast fishing. *Marine Pollution Bulletin* 46:1024-1031.

Freytag, I. 2001. *Growth and Mortality of* **Acropora nobilis** *Anthozoa: Scleractinia Fragments in Shallow Waters of the Seribu Islands, Indonesia, Using Different Attachment Methods.* [Thesis]. Bremen: University of Bremen.

Harrington, L., K. Fabricius, G. De'ath, and A. P. Negri. 2004. Recognition and selection of settlement substrata determine post-settlement survival in corals. *Ecology* 85: 3428-3437.

Johan, O. 2001. *Tingkat Keberhasilan Transplantasi Karang Batu di Pulau Pari, Kepulauan Seribu Teluk Jakarta.* [Thesis]. Bogor: Bogor Agricultural University.

Kunzmann, A. 2002. On the way to management of West Sumatra's coastal ecosystems. *Naga, the ICLARM Quarterly (January-March)* 25: 4-10.

Lindahl, U. 2003. Coral reef rehabilitation through transplantation of staghorn corals: effects of artificial stabilization and mechanical damages. *Coral Reefs* 22: 217-223.

McCook, L. J., J. Jompa, and G. Diaz-Pulido. 2001. Competition between corals and algae on coral reefs: a review of available evidence and mechanisms. *Coral Reefs* 19: 400-417.

Mundy, C. N. 2000. An appraisal of methods used in coral recruitment studies. *Coral Reefs* 19:124-131.

Nontji, A. 2004. *COREMAP Tahap I: Upaya Anak Bangsa dalam Penyelamat dan Pemanfaatan Lestari Terumbu Karang.* Jakarta: Kantor Pengelola Program COREMAP, Pusat Penelitian Oseanografi, LIPI.

Okubo, N., H. Taniguchi, and T. Motokawa. 2005. Successful methods for transplanting fragments of **Acropora formosa** and **Acropora hyacinthus**. *Coral Reefs* 24:333-342.

Rachello-Dolmen, P. G., and D. F. R. Cleary. 2007. Relating coral species traits to environmental conditions in the Jakarta Bay/Pulau Seribu reef system, Indonesia. *Estuarine, Coastal and Shelf Science* 73:816-826.

Raymundo, L. J., A. P. Maypa, E. D. Gomez, and P. Cadiz. 2007. Can dynamite-blasted reefs recover? a novel, low-tech approach to stimulating natural recovery in fish and coral populations. *Marine Pollution Bulletin* 54: 1009-1019.

Rogers, C. S. 1983. Sublethal and lethal effects of sediments applied to common Caribbean reef corals in the field. *Marine Pollution Bulletin* 14: 378-382.

Sadarun. 1999. *Transplantasi Karang Batu Stony Coral di Kepulauan Seribu Teluk Jakarta.* [Thesis]. Bogor: Bogor Agricultural University.

Schuhmacher, H., P. van Treeck, M. Eisingert, and M. Paster. 2000. Transplantation of coral fragments from ship groundings on electrochemically formed reef structure. *Proceedings of the 9th International Coral Reef Symposium 2: 983-990.*

Spalding, M. D., C. Ravilious, and E. P. Green. 2001. *World Atlas of Coral Reefs*. Berkeley, USA: University of California Press.

Spurgeon, J. P. G., and U. Lindahl. 2000. Economics of Coral Reef Restoration. *In* Cesar, H. S. J. (ed.). *Collected Essays on the Economics of Coral Reefs*. Sweden: CORDIO, Kalmar University.

Tomascik, T., A. J. Mah, A. Nontji, and M. K. Moosa, editors. 1997. *The Ecology of the Indonesian Seas,* Part One and Two. Singapore: Periplus Editions HK Ltd.

Veron, J. E. N. 1995. *Corals of the World.* Townsville, Australia: Australian Institute of Marine Science.

Yap, H. T. 2004. Differential survival of coral transplants on various substrates under elevated water temperature. *Marine Pollution Bulletin* 49: 306-312.

Yap, H. T., R. M. Alvarez, H. M. Custodio III, and R. M. Dizon. 1998. Physiological and ecological aspects of coral transplantation. *Journal of Experimental Marine Biology and Ecology* 229: 69-84.

Yap, H. T., and E. D. Gomez. 1985. Growth of **Acropora pulchra**. III. Preliminary observations on the effects of transplantation and sediment on the growth and survival of transplants. *Marine Biology* 87: 203- 209.

Yap, H. T., and R. A. Molina. 2003. Comparison of coral growth and survival under enclosed, semi-natural conditions and in the field. *Marine Pollution Bulletin* 46: 858-864.

Yarmanti, K. D. 2002. *Studi Pertumbuhan dan Tingkat Keberhasilan Hidup Karang Batu Spesies* **Acropora nobilis** *dan* **Acropora formosa** *pada Dua Kedalaman yang Berbeda di Pulau Pari, Kepulauan Seribu.* [Thesis]. Bogor: Bogor Agricultural University.

Yusri, S., and Estradivari. 2007. Distribution of infection by White Syndrome and coral bleaching diseases to coral communities in Petondan Timur Island, Kepulauan Seribu. *Berita Biologi* 8 (4): 223-229.