

Experimental coral transplantation in the moat of Kuta beach, Bali Island, Indonesia

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! In a search for suitable coral species and fixing methods in coral transplantation and to elucidate environmental factors affecting survival and growth of corals, we conducted experimental transplantations in the moat (shallow lagoon) of Kuta beach, Bali. On 20 limestone substrates set in the lagoon, we transplanted each 40 fragmented pieces of 10 species of corals. Coral pieces were fixed using either a spring or a cable tie. Corals used for experiments consisted of *Acropora* (4 spp.), *Montipora* (3 spp.), *Hydnophora* (1 sp.), *Galaxea* (1 sp.) and *Pocillopora* (1 sp.). These corals were obtained from a coral farm in Bali. Corals were transplanted on substrates, and underwater working time was also measured. Monitoring for more than 2 years was continued intermittently for coral survival, growth, effect of environmental factors on the survival, etc.

Key words : Coral transplantation, Bali, growth rate, Survival rate, Mortality factor

1. BACKGROUND

The coral transplantation studies have been carried out in tropical countries. However, the experimental coral transplantation and a long term monitoring have hardly ever carried out for the large-scale coral reef conservation.

In the lagoon of Kuta, Bali Island, Indonesia, the quantitative study called “1st experimental coral transplantation in the lagoon of Kuta” was carried out in order to find re-attachment rate, remaining rate and growth rate for each coral species and fixing materials¹⁾. The principal results were summarized as follows:

- the growth of *Acropora* sp. is faster than other species,
- the suitable fixing material was wire spring with 2points fixing, and
- the bleaching and recovering depended on change of water temperature.

However, considering large-scale coral transplantation in the lagoon of Kuta, we should find not only the above result but also efficient underwater fixing methods and large number of donor corals.

The objective of this study is to find suitable coral transplantation method. Donor corals from which coral fragments are collected were obtained from a coral farm in Bali. In order to improve underwater workability and cost efficiency, it was necessary to find other fixing method in addition to wire spring and 2 points fixing method.

2. OUTLINE OF STUDY

(1) Study Site

The study site is shown in Fig.1. The site was selected at the center of Kuta lagoon (2.5 km length and 0.5 - 1.3 km width). The selected study site has comparatively strong wave and tidal current and bottom is covered by shingles. Limestone rocks with approximately 600 kg and 50-80 cm height were selected as substrate. 10 substrates were installed in 2 rows (L1 and L2) as shown in Fig.1. The interval between substrates was 3 to 5 m considering monitoring activities and mooring boat. Substrates were not exposed even during low tide since the depth of study site was 1.0 to 1.5 m below LWL. The average wave height and current velocity was 0.8 m and 0.2 m/s respectively.

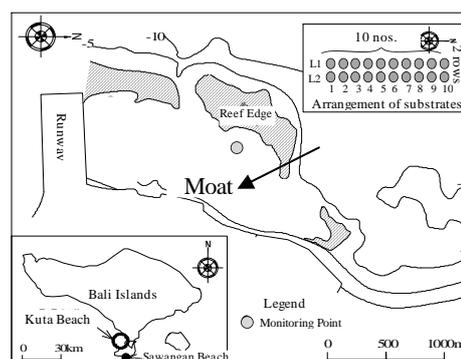


Fig. 1. Location of study site and arrangement of substrates

(2) Preparatory works

Twenty holes of 3.2 mm diameter for installation of nails were drilled on both horizontal and vertical surfaces of the substrate on land. Holes were drilled by a handy drilling machine to oblique direction and about 3.0 cm depth. In order to avoid entering sand into holes during the transportation and

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installation of substrates and make it easy to find holes underwater, holes were sealed bonding agent with paint.

Donor corals were obtained from a coral farm at Sawangan beach which is located on the southern tip of Bali island. Ten species were selected as shown in Table 1: *Acropora* (4 spp.), *Montipora* (3 spp.), *Hydnophora* (1 sp.) *Galaxia* (1 sp.) and *Pocillopora* (1 sp.). These corals packed by cushion with ice in a styloform box were transported by a truck. The transportation distance and time from coral farm to Kuta beach was about 20 km and 30 minutes.

After arriving at Kuta beach, styloform boxes were transferred to boat immediately. The boat with boxes moved to coral table (L=2.0 m, W=1.0m, H=0.5m) in the lagoon and the corals were put on coral table. The surface of coral table is about 0.8 m below LWL.



Fig. 2. After transplantation



Fig.3. Coral table

Table 1. Transplanted coral

No	Spices	Substrate No.	Coral pieces	
			Number	Size (cm)
1	<i>Pocillopora verrucosa</i>	L1-1⇄ L2-1	40	4.0
2	<i>Montipora digitata</i>	L1-8⇄ L2-10	40	4.0
3	<i>Montipora cactus</i>	L1-4⇄ L2-5	40	6.0
4	<i>Montipora aequituberculata</i>	L1-7⇄ L2-6	40	4.5
5	<i>Acropora valida</i>	L1-2⇄ L2-9	40	3.5
6	<i>Acropora tenuis</i>	L1-3⇄ L2-4	40	6.0
7	<i>Acropora parilis</i>	L1-5⇄ L2-3	40	6.0
8	<i>Acropora millepora</i>	L1-9⇄ L2-8	40	4.0
9	<i>Galaxea fascicularis</i>	L1-10⇄ L2-2	40	3.5
10	<i>Hydnophora rigida</i>	L1-6⇄ L2-7	40	5.0

After acclimation for 24 hours on the coral table, corals were cut into pieces with 3.5 to 6.0 cm long by chisel and scissors. Prepared pieces were kept untouched further for at least 24 hours for acclimation. Prepared number and size of coral pieces were summarized in Table 1.

(3) Transplantation work

The process of transplantation is as follows;

- Concrete nails with diameter of 3.5 mm and 5.0 cm length were driven by a hammer to holes on the surface of substrate. The projection height of nail was about 2.0 cm,

- Algae and sand on the surface of substrate were removed by a wire brush,
- Two kinds of fixing material such as wire spring with 2 points fixing (Fig.4, WS) and tie bund with 2 points fixing (Fig.5, TB) were applied. These methods were employed by considering fixing strength and workability, and
- 1) A side of fixing material was fixed to a nail, 2) coral piece was put between nails and 3) the other side of fixing material was fixed to the other nail.

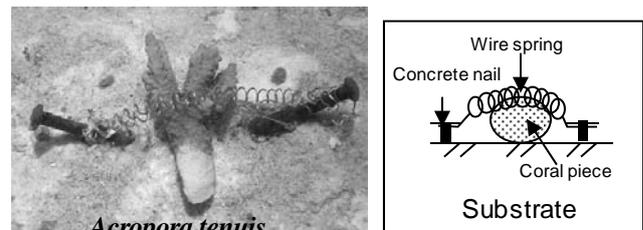


Fig. 4. Wire spring with 2 points fixing

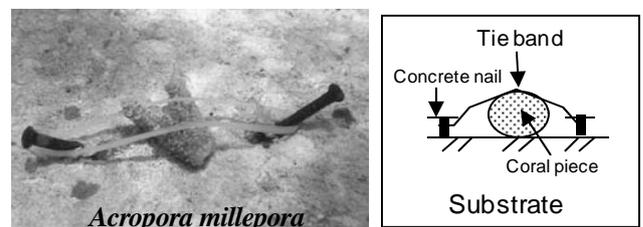


Fig. 5. Tie band with 2 points fixing

(4) Monitoring

The monitoring was carried out at 10 days, 1 month, 2 months, 3 months, 6 months, 9 months, 12 months, 18 months and 24 months after fixing coral pieces from 24 September, 2004 till 23 September, 2006. The items of monitoring consists of 1) taking photographs of all coral pieces 2) measurement of size of coral pieces (width and height), 3) recording re-cementing to substrate and survival rate, 4) recording recover of donor coral colonies on coral tables after cutting, etc. The hourly water temperature was recorded at 6 points in the lagoon.

3. DATA COLLECTION AND ANALYSIS

(1) Number of coral pieces

The number of coral pieces got from a donor colony was decided based on the number of available colonies and the number of necessary coral pieces of each species (Table 2). Thus, the number of prepared coral pieces was 60 to 90 for each species. As a result, the number of coral pieces from a colony was variable depending on species such as 30 pieces from *Acropora parilis* and 4 pieces from *Montipora aequituberculata*. Especially, a lot of pieces can be got from blanching corals.

Table 2. Number of coral pieces getting from coral colony

Spices	Number of coral colony	Number of coral pieces	
		Coral pieces	Coral pieces from a colony
<i>Pocillopora verrucosa</i>	3	60	20.0
<i>Montipora digitata</i>	4	60	15.0
<i>Montipora cactus</i>	7	90	12.9
<i>Montipora aequituberculata</i>	14	60	4.3
<i>Acropora tenuis</i>	4	90	22.5
<i>Acropora parilis</i>	3	90	30.0
<i>Acropora millepora</i>	10	60	6.0
<i>Acropora valida</i>	5	60	12.0
<i>Galaxea fascicularis</i>	10	60	6.0
<i>Hydnophora rigida</i>	7	90	12.9

The price of a coral colonies was between Rp. 41,250 and Rp.75,000 (1US\$=Rp.9,000). The price of a colony of *Acropora* spp. was cheaper than those of other genera and families (Rp. 41,250 and 45,000). Therefore, the unit price of a coral piece for *Acropora parilis* and *Acropora tenuis* was Rp.1,375 (Rp.41,250 /30.0 pieces) and Rp. 1,833 (Rp.41,250 /22.5 pieces) respectively. The highest unit price was *Montipora aequituberculata*, Rp. 12,558 (Rp. 54,000/4.3 pieces) .

(2) Fixing method and working time

The underwater fixing time by wire spring with 2 points fixing (WS) and tie band with 2 points fixing (TB) was recorded during the transplantation works at Mean Seal Level (MSL) and Low Water Level (LWL). These results are summarized in Table 3. The fixing works which were carried out by 6 skilled divers consists of 1) cleaning the surface of substrates, 2) fixing coral pieces, 3) cutting and collection of the surplus part of fixing material.

The average of fixing time of one coral piece for WS and TB was 39 seconds and 29 seconds respectively during LWL, and 53 seconds and 47 seconds respectively during MSL. As a result, the time for fixing of TB was shorter than WS, since WS takes a time to put the wire around a nail.

The fixing time was much different between tidal phase LWL and MSL due to obstruction by waves and currents as tide level increased.

Table 3. Underwater fixing time of a coral piece

Tide condition	Fixing materials	Fixing time (Piece/seconds)		
		Average	Min.	Max.
Low water level (LWL)	WS	39	20	65
	TB	29	12	57
Mean sea level (MSL)	WS	53	42	72
	TB	47	30	66

Remarks:!

WS: Wire spring with 2 points fixing

TB: Tie band with 2 points fixing

4. REMAINING AND GROWTH RATE OF CORAL PIECES

The change of remaining rate for each fixing material is shown in Fig. 6. Each 200 coral pieces were fixed by WS and TB. The remaining rate in WS and TB fixing was very high both 89 % at 12 months after fixing, 85 % and 83 % respectively at 24 months. Two methods showed almost equal rates.

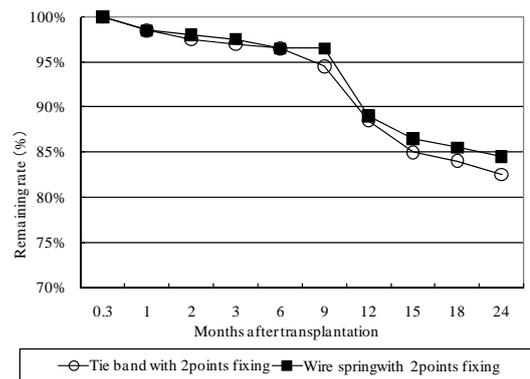


Fig. 6. Remaining rate by fixing material

The results of survival, mortality and detachment rate for all coral pieces are shown in Fig. 3. The survival rate at 3 months showed remarkable high value of 99 %. However, it declined to 56 % by 9 months after transplantation. Thereafter, it settled and become 52 % by 24 months.

The mean sea water temperature reached higher than 30 III for 4 months from December 2004 (after 3 months) to March 2005 (after 6 months). The maximum water temperature reached 33 III in March, 2005.

Therefore, susceptible species died during high water temperature period.

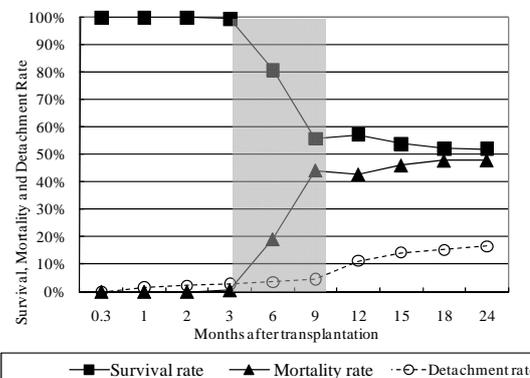


Fig. 7. Survival, mortality and detachment rates of transplanted coral

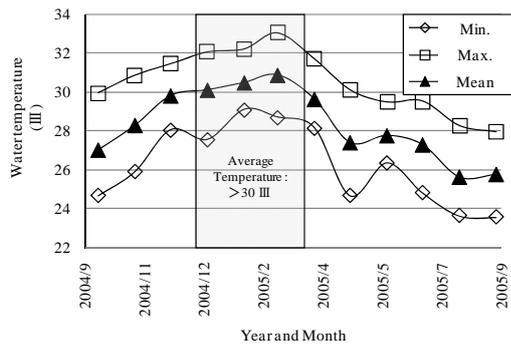


Fig. 8. Change of water temperature for 1 year after transplantation

Survival rate, detachment rate and growth rate of each species is summarized in Table 4. The survival rate of six species showed high rates 68 % to 100 %, the other four showed very low rate from 0 % to 3 %. *Acropora tenuis* and *Acropora parilis* showed 100% survival rate. On the other hand, all *Pocillopora verrucosa* died (0 %). The survival rate showed remarkable difference among species.

The detachment rate showed 35 % in *Pocillopora verrucosa*, >20 % of *Montipora cactus* and *Montipora digitata*, and <15 % in other species. Four *Acropora* spp. of blanching type showed remarkable low value (5 to 13 %). It was thought that the rate is connected with type of fixing material and speed of re-cementing to substrate.

Table 4. Survival and growth rates of transplanted corals

Species	Survival (S), Mortality (M) and Detachment (D) rates			Growth rate (cm/year)	
	S (%)	M (%)	D (%)	Height	Width
<i>Acropora tenuis</i>	100	0	5	8.3	14.0
<i>Acropora parilis</i>	100	0	5	7.1	10.6
<i>Hydnophora rigida</i>	82	18	15	3.4	4.0
<i>Montipora digitata</i>	78	22	20	5.2	8.3
<i>Montipora cactus</i>	72	28	10	6.6	15.0
<i>Acropora millepora</i>	68	32	23	6.1	9.0
<i>Galaxea fascicularis</i>	3	97	8	(Death)	(Death)
<i>Montipora aequituberculata</i>	3	97	8	(Death)	(Death)
<i>Acropora valida</i>	3	97	13	(Death)	(Death)
<i>Pocillopora verrucosa</i>	0	100	35	(Death)	(Death)

Growth rate was expressed by maximum height and width. It reached the highest value of 8.3 cm/year in *Acropora tenuis* and 7.1 cm/year in *Acropora parilis*. The highest value in width was 15.0 cm/year of *Acropora millepora* and 14.0 cm/year in *Acropora tenuis*. *Acropora tenuis* showed the greatest growth in both height and width. In 24 months after transplantation, all surface of substrate was covered by corals.

No data were collected for 4 species including *Galaxea fascicularis*, since these corals died soon after transplantation.

The growth rate of *Acropora millepora* is shown in Fig. 9.

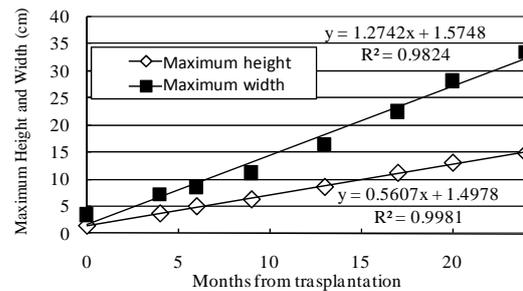


Fig. 9. Growth rate of *Acropora millepora*

Figs.10 and 11 show the growing process of *Acropora millepora* at L2-9.

Coral pieces had re-cemented to substrate and grew to vertical and horizontal directions in 3 months after transplantation. They reached 16 cm in maximum width and 9 cm in maximum height in 12 months. After that, the coral became 33 cm in maximum height and 15 cm in maximum width at 24 months, and a lot of fishes are found living in and around colonies.

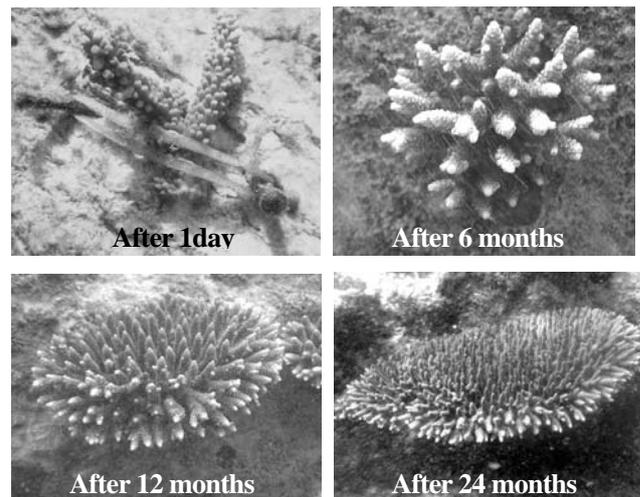


Fig. 10. Growing process of *Acropora millepora*

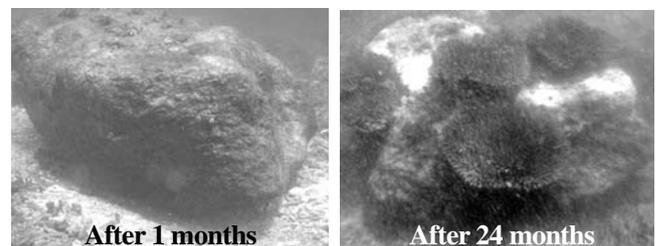


Fig. 11. Growing process of *Acropora millepora* (L2-9)

Fig. 12 shows conditions of *Acropora parilis* which were transplanted on L2-3. The most of the surface of substrate was covered by corals at 24 months as in the case of *Acropora millepora*.

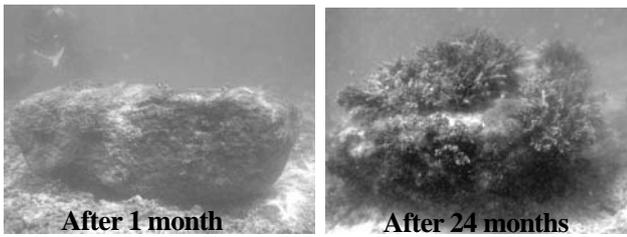


Fig. 12. Growing process of *Acropora parilis* (L2-3)

5. RECOVERING AND GROWING OF CORAL COLONIES AFTER CUTTING

To test a possibility of re-use of donor corals, from which coral pieces had already cut, and set on the coral table, the recovering process after cutting was monitored regularly. Fig.13 shows the recovering process of *Acropora tenuis*. According to photo as of 10 days after cutting, coral colony had not changed. The cutting parts had recovered little by little till 1 month. The whole cut parts had already recovered and grown up to initial size in 3 months. The coral grew steadily and the colony become several times larger than initial size in 12 months.

Even those most of fragments had been cut off, it was confirmed that donor colonies recover on the coral table in a short period. Coral colonies can be used as donors at 6 to 12 months after cutting.

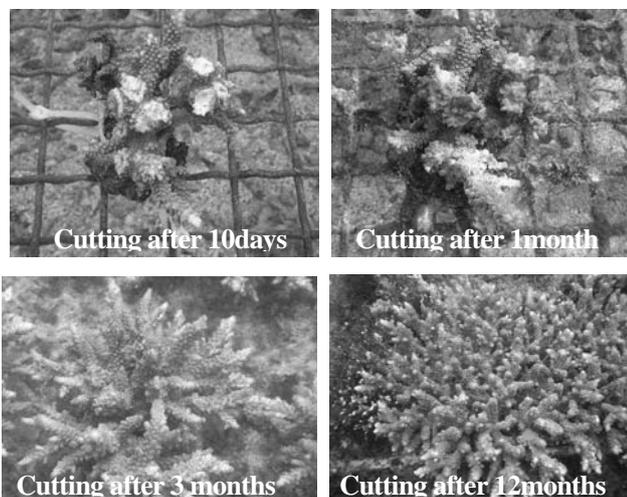


Fig. 13. Recovering and growing process of *Acropora tenuis* after cutting

6. CONCLUSION

The conclusion of this study was summarized as follows:

- 1) The number of coral pieces obtainable from a donor colony is quite variable ranging from 4 to 30 pieces depending on coral species.
- 2) The remaining rate of coral pieces fixed by WS (wire spring with 2 points fixing) and TB (tie bund with 2

points fixing) showed high value of 85 % and 83 % respectively at 24 months after transplantation.

- 3) TB was recommended as fixing method compared with WS for underwater workability, cost-effectiveness and high remaining rate.
- 4) The survival rate of transplanted coral pieces showed a high value of 99% at 3 months after transplantation. However, it declined to 56 % during high sea water temperature period (Average water temperature > 30 III) at 4 months. Susceptible coral species (*Galaxea fascicularis*, *Montipora aequituberculata*, *Acropora valida*, *Pocillopora verrucosa*) died during high water temperature period.
- 5) *Acropora tenuis* showed the highest growth rates 14.0 cm/year in width and 8.3 cm/year in height.
- 6) It was found that donor colonies from which coral pieces were cut off recovered and grew well on the coral table. It means that they can be used again as donors.

According to data obtained in monitoring of survival and detachment rates, the suitable coral species and fixing method was decided. We could obtain the necessary base data such as unit price of coral pieces and underwater workability in order to prepare the implementation plan for a large scale of coral transplantation work in future.

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