

Test of transplantation method and survival and growth of transplanted corals

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In order to find effective methods for coral transplantation, we conducted experimental coral transplantation on 20 limestone substrates set in the moat of Kuta in Bali Island, Indonesia. Coral pieces of about 5 cm length were prepared by cutting branches from the colonies of *Pocillopora damicornis*, branching *Acropora* sp. and *Montipora aequituberculata* all growing in the moat. After one day acclimation in the moat, these coral pieces were fixed to both horizontal and vertical surfaces of the substrates. We used 3 kinds of fixing material such as a steel plate with 1 point fixing, a fishing line with 2 points fixing and a wire spring with 2 points fixing. We monitored transplanted corals intermittently for more than 2 years, by photographing with a digital camera, and recorded existence of corals, their re-attachment to substrates, width and height of coral pieces. We found that 1) re-attachment rate to the substrate for *Acropora* sp. was more than 80 %, 2) re-attachment rate of corals fixed by a wire spring was highest (85 %), 3) no differences between re-attachment rates between horizontal and vertical surface, 4) annual growth rate of *Acropora* sp. was 16.4 cm in width and 13.5 cm in height, and 5) *Acropora* sp. recovered from bleaching of 30 to 50 % of whole colony caused by high water temperature after temperature returned to normal.

Keywords: Coral transplantation, Bali, Re-cementing rate, Growth rate, Remaining rate

1. BACKGROUND

The studies and researches for coral transplantation and propagation have carried out by sexual reproduction and asexual reproduction. Generally, the sexual reproduction takes for a long time to get an effect by transplantation. On the other hand, the asexual reproduction will be got satisfactory results comparatively short period. But there is some possibility of damaging coral colonies during the preparation of coral pieces for transplantation.

There are some cases of coral transplantation activities by asexual reproduction in some tropical countries so far. However, there is hardly any case to study quantitatively and a long term such as remaining rate, re-cementing speed to substrate, growth rate, etc, with different condition among coral species, fixing method and natural condition such wave, current, sea bed, etc.

The greater part of coral in the moat of Kuta, Bali island had damaged due to coral mining, reclamation of a runway, etc. in 1970'. It was confirmed that corals have lived at some parts in the moat of Kuta.

In order to confirm the possibility of large scale coral reef restoration artificially, the experimental coral transplantation was carried out in the moat of Kuta Beach and the periodic monitoring also was carried out for 2 years. The objective of this study was to find 1) the suitable fixing method for coral pieces, 2) the re-cementing to substrate, growth rate of coral pieces and 3) the possibility of coral transplantation considering the above mentioned.

2. OUTLINE OF STUDY

The study site is shown in Fig.1. Four study sites were selected in the moat of Kuta with 2.5km length (longshore direction) and 0.5 – 1.3 km width (on-offshore direction). Limestone rocks with approximately 500 kg were selected in consideration of wave and current condition. 5 substrates with a row were installed in 4 places as shown in Fig.1. The interval between substrates was 3 to 5 m in consideration of monitoring activities and mooring boat during the monitoring period. The depth of seabed and surface elevation of substrate each place is shown in Table 1. St. 1 and St.2 is shallower than St. 3 and St.4 and A part of substrates in St.2 exposed during LWL in the spring tide. The tide condition is LWL=±0.0m, MSL=±1.3m and HWL±2.6m.

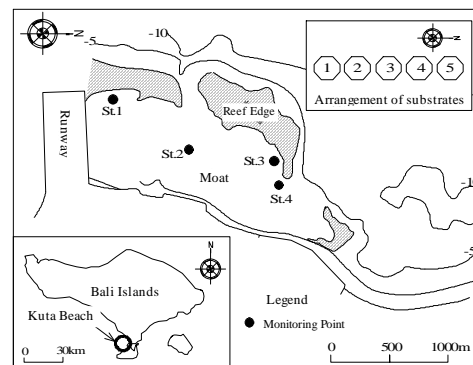


Fig.1! Study site (St.1, St.4) and arrangement of substrates for experimental coral transplantation(1, 5)

Table 1 Depth and height of substrates

	Average depth(m)	Average height of substrate (m)	Average depth on the surface of substrate (m)
St.1	-0.77	0.47	-0.30
St.2	-0.49	0.44	-0.05
St.3	-1.71	0.41	-1.30
St.4	-1.61	0.39	-1.21

Three species such as *Acropora* sp., *Pocillopora* sp., and

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Montipora sp. were selected for coral transplantation. These corals were collected from the moat of Kuta beach. In order to minimize the damage of the existing coral colonies, at least 70 % of whole colony was remained and these colonies were cut into pieces with 4.5 to 6.0 cm by chisel and scissors carefully. The permit for collecting coral pieces was got from Indonesian government in advance.

The cut coral pieces acclimated in the sea on sites for 24 hours. Table 2 shows summary of coral species, fixing material, number and size of coral pieces for experimental coral transplantation.

Table 2 Arrangement of coral pieces and fixing material

No.	Fixing surface	Species	Fixing material	Number of pieces	Size of pieces
1	Horizontal	<i>Acropora</i> sp.	Fishing gut	5	6 cm
			Steel plate	5	6 cm
	Vertical		Fishing gut	5	6 cm
			Steel plate	5	6 cm
2	Horizontal	<i>Pocillopora</i> sp.	Fishing gut	5	5 cm
	Vertical			5	5 cm
3	Horizontal	<i>Montipora</i> sp.	Steel plate	5	5 cm
	Vertical			5	5 cm
4	Horizontal	<i>Acropora</i> sp.	Wire spring	5	6 cm
	Vertical			5	6 cm
5	Horizontal	<i>Montipora</i> sp.	Fishing gut	5	4.5 cm
			Steel plate	5	4.5 cm
	Vertical		Fishing gut	5	4.5 cm
			Steel plate	5	4.5 cm

On the assumption that the coral transplantation in the moat of Kuta will be carried out by constructions of coral reef restoration and public involvement, an easy method is desirable as much as possible.

In order to reduce time for underwater works, three kind of fixing methods such as 1) steel plate with 1 point fixing, 2) fishing gut with 2 points fixing and 3) wire spring with 2 points fixing were selected. The above three kinds of fixing method were selected for *Acropora* sp. and the above 1) and 2) method were selected for *Montipora* and *Pocillopora* sp.

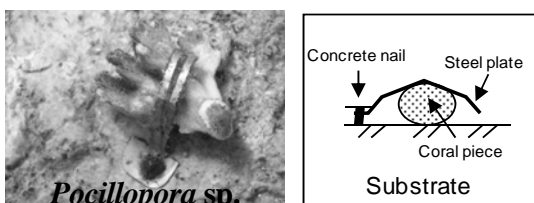


Fig.2 Steel plate with 1 point fixing

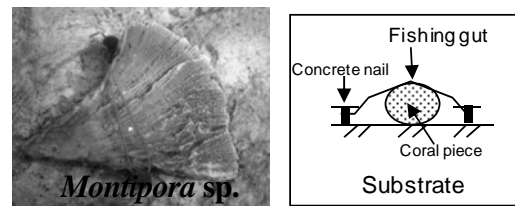


Fig.3 Fishing gut with 2 points fixing

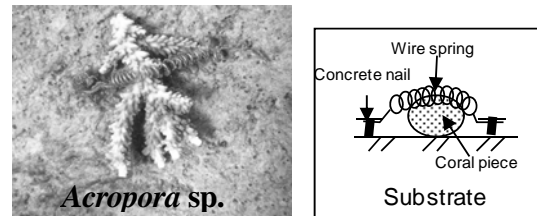


Fig.4 Wire spring with 2 points fixing

Five substrates which were drilled five or ten pairs holes at interval of 5 cm to both horizontal and vertical surfaces were installed on each site. The process of fixing works consists of 1) algae and sediment was removed by wire brush, 2) concrete nails were driven by a hammer and 3) coral pieces were fixed by each fixing material.

The study had carried out for 24 months since September 2003 and the periodic monitoring was carried out as of 10 days, 1 month, 2 months, 3 months, 6 months, 9 months, 12 months, 18 months and 24 months after fixing coral pieces. The items of monitoring consists of 1) taking photographs of coral pieces on the horizontal and vertical surface of substrates, 2) measurement of size of coral pieces (width and height), 3) re-cementing of coral pieces to fixing material and substrate, 4) clinging algae and marine organism to substrates and coral pieces and 5) visual monitoring for settlement and movement of substrates.

In order to check the effect to coral due to the change of seawater temperature, the hourly observation had carried out by self-registering thermometer at 6 points in the moat of Kuta beach since October, 2004.

3. RE-CEMENTING AND REMAINING RATE AFTER TRANSPLANTATION

(1) Re-cementing to fixing material and substrate

Fig.5 and 3 shows the re-cementing rates to fixing material and substrate by coral species at all places and fixing points. The re-cementing rate to fixing material was more than 90 % as of 1 month for *Acropora* sp. and *Montipora* sp. and 2 months for *Pocillopora* sp.

According to Fig.6, re-cementing rate for *Acropora* sp. to substrate reached to 87.1 % as of 2 months after transplantation. However, the re-cementing rate for *Pocillopora* sp. and

Montipora sp. was limited between 50 and 60 % as of 3 months and time for re-cementing of all coral pieces to substrate was for 18 months.

The detachment rate of *Acropora* sp. against exerting force such as waves and currents was remarkable low since the re-cementing speed is very first and it spread out on the surface of substrate after re-cementing to fixing material. *Pocillopora* sp. and *Montipora* sp. had started to re-cement to substrate 2 months after transplantation. However, these corals repeated detaching and re-cementing due to the lack of re-cementing strength.

As a result, the fixing material which can be certain fixed for at least 2 months was recommended to select for *Acropora* sp. The fixing material which can be certain fixed for 6 to 12 months was recommended to select for *Montipora* and *Pocillopora* sp.

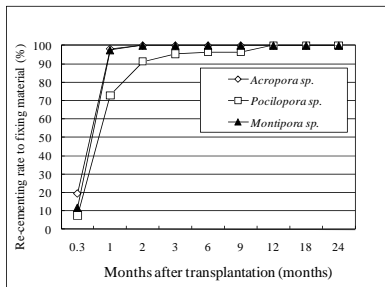


Fig.5 Re-cementing rate to fixing material

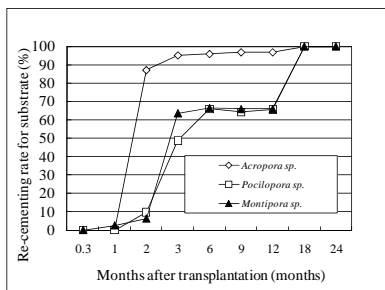


Fig.6 Re-cementing rate to substrate

(2) Remaining rate for coral piece by fixing material

Fig.7 to 9 shows the remaining rate with different condition between coral species and fixing material. The remaining rate for *Acropora* sp. reached to 78 to 85 % as of 24 months after transplantation. Regarding to the remaining rate for *Pocillopora* sp., the rate between steel plate with 1point fixing and fishing gut with 2 points fixing was remarkable different such as 13 % and 53 % respectively as of 12 months. The rate both of them became about 10 % as of 24 months. It is thought that the decline of remaining rate is caused by bleaching and death of coral due to high water temperature as described later. Regarding to the remaining rate for *Montipora* sp., the rate between steel plate with 1point fixing and fishing gut with 2

points fixing was remarkable different such as 20 % and 78 % respectively as of 2 months. These rates had declined to 20 % for fishing gut with 2 points fixing and 0 % for steel plate with 1 point fixing as of 24 months. It is thought that the low rate is caused by slow re-cementing speed to substrate and detachment due to wave and current energy.

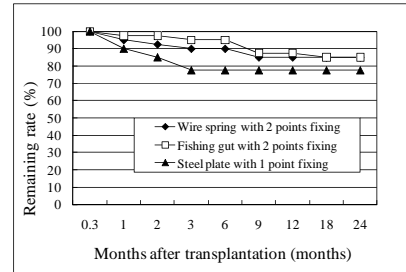


Fig.7 Change of remaining rate for *Acropora* sp.

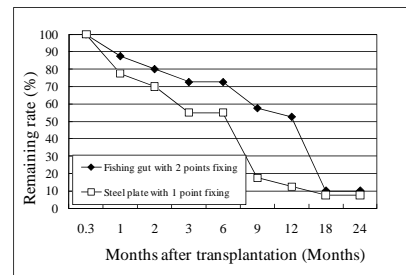


Fig.8 Change of remaining rate for *Pocillopora* sp.

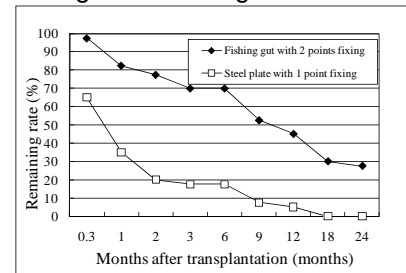


Fig.9 Change of remaining rate for *Montipora* sp.

(3) Remaining rate of coral pieces by different of exerting force

Fig.10 to 12 shows the remaining rate each coral species. The average wave height and current velocity each site is shown in Table 3.

Table 3 Average wave height and current velocity each site (During HWL)

	K1	K2	K3	K4
Average wave height (m)	0.90	0.60	0.80	0.95
Average current velocity (m/s)	0.10	0.15	0.20	0.25

Regarding to *Acropora* sp., the remaining rate at St. 2 was the highest value as 93 % and St.4 was the lowest value as 73 %. The remaining rate at St. 1 and St.3 was 83 % and 80 % respectively. The remaining rate showed tendency to fall as waves and currents increased.

Regarding to *Pocillopora* sp., the remaining rate showed a

different tendency among stations such as 75 % for St. 2 and 55 % for St.1 and St.4 as of 6 months after transplantation. However, the rate had declined after 9 months and these values showed low value such as 5 to 15 % as of 18 months. It is thought that the reason was due to low re-cementing strength to substrate and detachment by wave and current.

Regarding to *Montipora* sp., the remaining rate at St.2 showed the highest value of other stations until 6 months, but this rate had declined to 0% as of 24 months. The rate at St. 4 showed the highest value of other stations as 25 % as of 24 months. It was confirmed that the algae was grown thickly on the substrate at St.2 since these surface of substrates exposed during LWL in the spring tide due to high seabed elevation. Therefore, the algae covered up coral pieces of *Montipora* sp. because foliaceous coral grows horizontally.

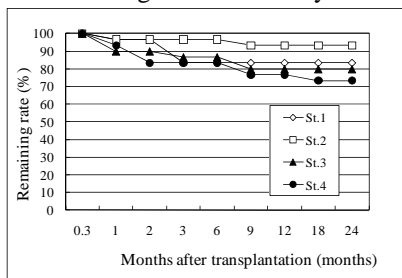


Fig.10 Remaining rate for *Acropora* sp. at each site

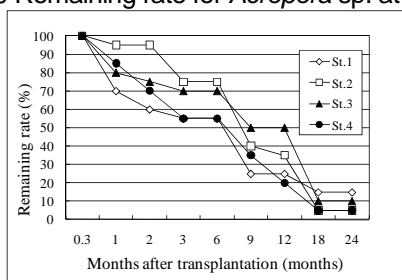


Fig.11 Remaining rate for *Pocillopora* sp. at each site

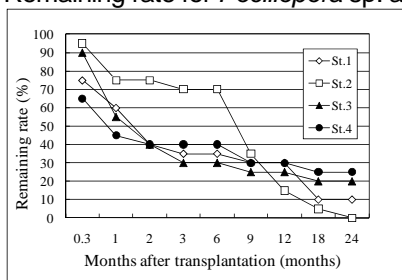


Fig.12 Remaining rate for *Montipora* sp. at each site

(4) Remaining rate on horizontal and vertical surface of substrate

Generally, coral pieces have fixed on a horizontal surface of natural and artificial substrate up to this day. In this study, coral pieces were fixed on a horizontal and a vertical surface of substrates in order to find difference of remaining rate between them. The results are shown in Fig.13.

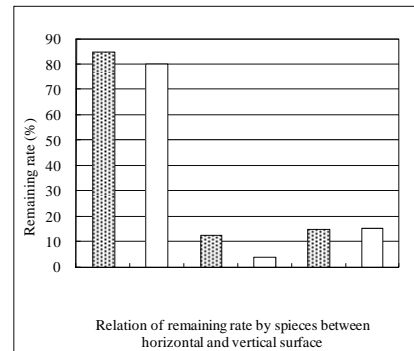


Fig.13 Difference of remaining rate between horizontal and vertical surface

It was confirmed that the remaining rate between them was almost same though the rate on the horizontal surface is a little higher than the vertical surface. As a result, coral pieces can be fixed on not only horizontal surface but also vertical surface.

4. GROWING PROCESS OF CORAL PIECES AFTER TRANSPLANTATION

(1) Annual growth rate each coral species

Table 4 shows the annual growth rate each coral species. The change of width and height was used as an index of growth rate. The change of width of coral pieces was at 16.4 cm/year (horizontal) and 19.7 cm/year (vertical) for *Acropora* sp., at 6.7 cm/year (horizontal) and 7.4 cm/year (vertical) for *Pocillopora* sp., and at 3.5 cm/year (horizontal) and 5.5 cm/year (vertical) for *Montipora* sp.

The change of height of coral pieces was at 13.5 cm/year (horizontal) and 14.4 cm/year (vertical) for *Acropora* sp., at 7.7 cm/year (horizontal) and 4.3 cm/year (vertical) for *Pocillopora* sp., and at 3.1 cm/year (horizontal) and 3.4 cm/year (vertical) for *Montipora* sp. The growth rate of *Acropora* sp. was remarkable high as compared with other species both width and height.

Table 4 Annual growth rate each coral species

Species (fixing point)	Annual growth rate (cm/year)	
	Width	Height
<i>Acropora</i> sp. (Horizontal)	16.4	13.5
<i>Acropora</i> sp. (Vertical)	19.7	14.4
<i>Pocillopora</i> sp. (Horizontal)	6.7	7.7
<i>Pocillopora</i> sp. (Vertical)	7.4	4.3
<i>Montipora</i> sp. (Horizontal)	3.5	3.1
<i>Montipora</i> sp. (Vertical)	5.5	3.4

Fig.14 shows the growing process of *Acropora* sp. which were transplanted on substrate in St.1. Each 10 coral pieces on horizontal and vertical surface of a substrate were transplanted. The coverage rate showed to remarkable high as of 12 months and reached to almost 100 % as of 24 month. The various kinds of fish and shellfish have lived in coral colonies which grew up

sufficiently. A newly environmental condition of habitat was established by growing coral colonies.

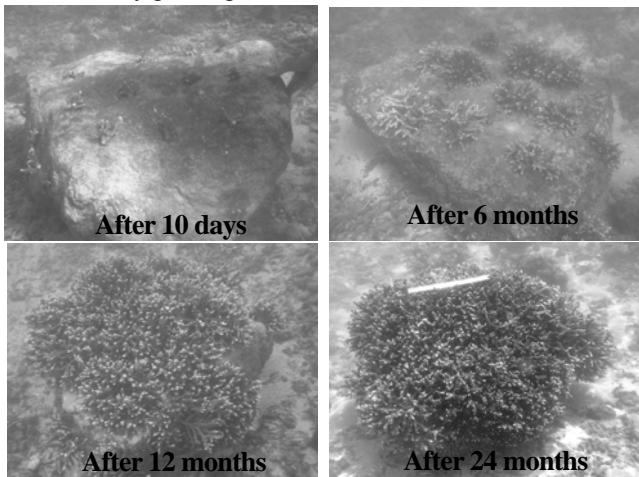


Fig.14 Growing process of *Acropora* sp.

(2) Relation between bleaching coral and sea water temperature

Fig.15 shows the change of minimum, maximum and average water temperature from October, 2004 (after 13 months) to February, 2005 (after 27 months). The average water temperature was over 30 °C for 3 months from January to March, 2005. The maximum temperature reached to 33 °C on March, 2005. It was confirmed that some parts of colonies of *Acropora* sp. and *Pocillopora* sp. was bleaching during this period.

Fig.16 shows the change of condition for *Acropora* sp. between in high temperature period on March 2005 and in normal temperature period. In March 2005, 30 to 50 % part of coral colonies was bleaching during the high temperature period, but all part of colonies recovered in September, 2005 after recovering the normal temperature.

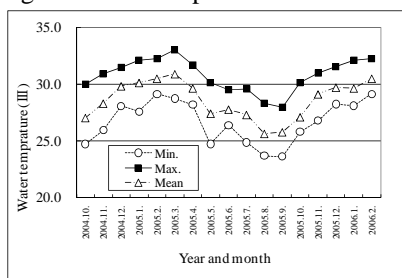


Fig.15 Change of water temperature very month

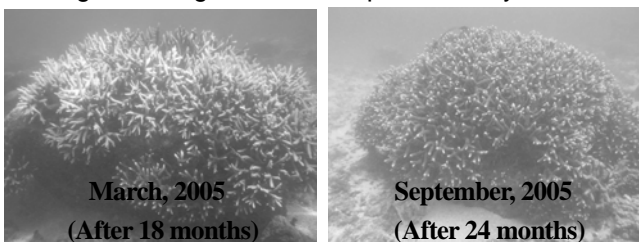


Fig.16 Recovering from bleaching corals

5. CONCLUSION

The conclusion of this study was summarized as follows;

- ① It is necessary to select the suitable fixing material which can be fixed coral pieces certainly as follows:
 - For at least 2 months for *Acropora* sp.
 - For 6 to 12 months for *Pocillopora* sp. and *Montipora* sp.
- ② The remaining rate by using wire spring and fishing gut with 2 points fixing was remarkable high as compared with steel plate with 1 point fixing.
- ③ The remaining rate of coral pieces was low at place of strong exerting force such as wave and current especially near reef gap.
- ④ The remaining rate showed low value in the place where expose surface of substrate during LWL and was covered by algae on surface of substrate.
- ⑤ The remaining rate attached to horizontal and vertical surface of substrate was almost same value. As a result, the vertical surface of substrate also can be fixed.
- ① The annual growth rate of *Acropora* sp. was the fastest of all species such as 16.4 cm/year with width and 13.5 cm/year with height.
- ① 30 to 50 % part of coral colonies was bleaching during the high temperature period. The bleaching coral recovered during normal temperature.

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