Abstract In order to find effective methods for coral restoration, we conducted experimental coral Transplantation on 20 limestone substrates set in the moat of Kuta in Bali Island, Indonesia, in September 2003. Coral fragments of about 5 cm length were prepared by cutting branches from colonies of Acropora sp., Pocillopora sp. and Montipora sp. growing in the moat. After one day of acclimation in the moat, these coral pieces were attached to both the horizontal and vertical surfaces of the substrates. We used 3 kind of materials on the substrate to attach the coral, a steel plate with 1 fixed point, fishing line with 2 fixed points and a wire spring with 2 fixed points. We monitored the transplanted coral intermittently for more than 2 years, by photographing with a digital camera, recording the retention and survival of corals, their attachment to the substrates and the width and height of the coral pieces. We found that: 1) the cumulative self-attachment to the substrate for Acropora sp. was the highest among the 3 species. The proportion of fragments that had self-attached was more than 85% on average after two months of transplantation for Acropora sp., whereas it was between 49% and 64% after three months for Pocillopora sp. and Montipora sp. 2) The retention of corals using the wire spring was the highest in Acropora sp. 3) The retention and survival were almost the same for those fragments between the horizontal and vertical surfaces of substrate. 4) Acropora sp. of 5 cm in length reached in average 39.4 cm in width and 28.8 cm in height in 24 months. 5) 30 to 50% of the whole colony of Acropora sp. bleached due to high water temperatures around March 2005, but they recovered after the water temperature lowered below 30°C.

Keywords Coral transplant, Bali Island, Kuta Beach, Growth, Retention, Attachment method,

Introduction

Studies and research on coral transplantation and propagation have been performed using both sexual and asexual reproduction (Okubo and Omori 2001, Omori 2011). The restoration of coral reefs using asexual reproduction can achieve satisfactory results in a comparatively short period of time (Yamashita et al. 1996), although care must be taken since there is the possibility to damage colonies of the coral donor and coral reefs during the collection of coral fragments for transplantation and site preparations. Some case studies of coral transplanting activities using asexual reproduction have been done in several tropical countries. However, there are few quantitative studies involving long term monitoring on the self-attachment and retention of coral fragments to the
substrate, growth, survival of different coral fragments, attachment methods and effects from external factors such as waves, currents, and temperature.

The greater part of the coral reef in the moat of Kuta, Bali Island, Indonesia had been damaged due to coral mining until the early 1970s and reclamation for an airport runway from mid to end of 1960s. As a result, the reef bottom level had become deeper. In order to test the possibility for large scale artificial restoration of a coral reef, experimental transplantation of coral fragments was conducted in September 2003 in the moat of Kuta Beach by supervision of Dr. M. Nishihira (see Nishihira 2006). Monitoring of the transplanted corals was carried out periodically for more than 2 years. The primary objectives of this study were to find the following: 1) a suitable method for attaching coral pieces, 2) the self-attachment rate to the substrate and growth of the coral pieces, 3) the probability for successful coral transplantation.

**Materials and methods**

We selected four study sites (Fig. 1) along the 2.5 km length in the moat of Kuta (long shore direction) and 0.5–1.3 km width (on-offshore direction). Twenty limestone rocks weighing approximately 500 kg were brought from neighboring land as substrates. Substrate for transplantation was selected taking into consideration the normal natural habitat for corals, and suitable environmental conditions. This weight and size were necessary, the predominance of heavy waves and current energy in the study area. Five substrates were installed in a row at 4 stations Fig. 1. The interval between substrates was 3 to 5 m to allow monitoring activities and boat mooring. Stns. 1 and 2 were shallower than Stns. 3 and 4 (Table 1). A portion of the substrates at Stn. 2 was exposed during Low Water Level (LWL) in spring tide. The tide condition was LWL = ±0.0 m, Mean Sea Water Level (MSL)=LWL+1.3 m and High Water Level (HWL)=LWL+2.6 m. We tried to check various external environments in order to grasp the suitable and unsuitable condition quantitatively.

Coral fragments from three coral genus *Acropora* sp., *Pocillopora* sp. and *Montipora* sp. that were growing on the moat of Kuta beach were collected. In order to minimize the damage to the donor colonies, 30% or less of each colony was removed in order to minimize the existence impact, and cut into 4.5 to 6.0 cm fragments in average using a chisel and scissors in order to easily attach fragments under water. After that, the fragments were acclimated on site for 24 hours.

In order to minimize the underwater required time for fragments attachment we selected easy attachment methods developed by Nishihira (2006) and other authors. If cement or epoxy is used as bonding material to substrate, the time required for attachment will be longer I comparison to the following methods: 1) Steel plate with 1 fixed point, 2) fishing line with 2 fixed points and 3) wire spring with 2 fixed points (Fig. 2). All three methods were used...
for *Acropora* sp. and the methods 1 and 2 were used for *Montipora* sp. and *Pocillopora* sp.

The transplantation protocol was as follows: Algae and sand on the surface of substrates were removed using a wire brush. Concrete nails with diameter of 3.5 mm and 50 mm in length were hammered into the holes on the substrate surfaces. Coral fragments were secured to the substrate using one of the 3 attachment methods.

Site monitoring was carried out from 23 September 2003 till 22 September 2005 at 10 days, 1 month, 2 months, 3 months, 6 months, 9 months, 12 months, 18 months, and 24 months after attaching the coral pieces. The items monitored were as follows: 1) taking photographs of coral pieces on the horizontal and vertical surface of the substrates, 2) measuring the size of the coral pieces (width and height), 3) monitoring the self-attachment (tissue growth on the substrate) of coral fragments, 4) monitoring the algal growth and marine organisms around the coral fragments and substrates, 5) monitoring for settling and movement of substrates.

Self-registering thermometers in situ proved were used at 6 points from October, 2004 (13 months after transplant) to February 2005 (27 months after transplant).

**Results and discussion**

**Self-attachment to the material and substrate**

The cumulative attachment of fragments that were retain and survived on substrates was more than 85% in average of all Stas. at 2 months after transplantation for *Acropora* sp., whereas it was between 50% and 60% at 3 months for *Pocillopora* sp. (Fig.3). The detachment of *Acropora* sp. from the substrate due to waves and currents was remarkably low since the self-attachment speed was very fast. However, the remaining 2 species experienced repeated detachment and self-attachment as they lack sufficient self-attachment strength. After 19 months all surviving coral fragments of the 3 species had self-attached (see Guest et al. 2011 for comparison).
Retention and survival (%) of the coral fragments by attachment methods

Fig. 4 shows the differences in average retention (%) among coral species and the attachment methods. After 24 months of transplantation the retention and survival of *Acropora* sp. was 78 to 85% among attachment methods. For *Pocillopora* sp., the retention and survival with the steel plate with 1 fixed point was lower than fishing line with 2 fixed points at 12 months after transplantation (13% vs. 53%). The retention and survival was about 10% for both species at 24 months after transplantation. Coral bleaching due to high water temperature that occurred after April 2005 caused remarkable decline of retention. The retention and survival of *Montipora* sp. with steel plate with 1 fixed point was again lower than the fishing line with 2 fixed points 2 months after transplantation (20% vs. 78%). After 24 months the retention and survival had declined sharply for both methods. It was thought that the low retention was caused by the slow self-attachment and repeated detachment of the specimens by wave action and current energy.

Retention and survival (%) of the coral fragments by external forces

Fig. 5 shows the retention of the fragments at 4 stations. The average retention of *Acropora* sp. was the highest (93%) at Station 2 and the lowest at Station 4 (73%) 24 months after transplantation. They were 83% and 80% at Station 1 and Station 3 respectively. The retention of *Pocillopora* sp. was highest at Station 2 for 6 months after transplantation, but it lowered to 5 to 15% after 18 months. We think that the reason was low self-attachment strength and detachment by the substrate by waves and currents. Similar tendency was found in *Montipora* sp., but the retention was highest (25%) at Station 4 at 24 months.
Retention and survival (%) of the coral fragments attached on horizontal and vertical surfaces of the substrate

For the 3 species, the average retention and survival (%) between horizontal and vertical surfaces after 12 months was almost the same. It was concluded that coral fragments can be attached not only to horizontal surface but also to vertical surface.

Growth of coral fragments after transplantation

Growth of each coral species

Growth of Acropora sp. was remarkably higher if compared with the other species in both width and height (Table 3). Acropora sp. of 5-cm fragments in length grew in average to 32.8 cm in width (in diameter) for 2 years when transplanted on horizontal surface. They became to 39.4 cm in width when transplanted on vertical surface. 5 cm-fragments of Pocillopora sp. grew to 13.4 cm (horizontal) and 14.8 cm (vertical), and 4.5-cm fragments of Montipora sp. to 7.0 cm (horizontal) and 11.0 cm (vertical).

Ten coral fragments of Acropora sp. that were transplanted on the horizontal and vertical surfaces of the substrate at Station 1 (Fig. 6) grew fast, and after 24 months coral coverage on the substrate was almost 100%. Various fish and crustaceans were living in and around the fully grown coral colonies.

Bleaching event caused by high seawater temperature

Seawater temperature was monitored from October, 2004 to February, 2005 (Fig. 7). The average seawater
temperature was over 30°C for 3 months from January to March, 2005 and attained to the highest 33°C in March, 2005. In all, 30 to 50% of the colonies of *Acropora* sp. were bleached during the high water temperature period. However, they had recovered by September, 2005 after the seawater temperature lowered to below 30°C.

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### References


