Coral Reef Recovery for Fishery Resources and Habitat Rehabilitation: Experience of Japan

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Coral colonies co-existing with fish and shellfish near Phuket in Thailand (Photo: Akito Sato)

This report, which introduces the Japan's efforts in coral reef recovery, is based on the initial outcome of a project which aims to develop a practical technique for coral reef propagation conducted by the Fisheries Agency of Japan from 2006 to 2008 in "Okinotorishima" about 1100 km southeast from Okinawa. Already in its 2nd stage of the 5-year plan starting from 2009, the project aimed to develop a technology for the restoration of coral reefs where practical techniques are less developed than those for seaweed beds or tidelands. Under the project, activities were carried out for the technical development of spawning and rearing methods for the mass production of juvenile coral colonies using sexual reproduction technique, a potential useful technology for coral reef recovery measures in the future. Referring to the successful results of such Japanese initiative for the rehabilitation of fishery resources and their habitats, SEAFDEC intends to implement a program for the rehabilitation of fishery resources and their habitats/ fishing grounds starting in 2010 under the Japanese Trust Fund V Program. As planned, the SEAFDEC project will come up with sustainable technology for restoration of fishing grounds adoptable in the Southeast Asian region in order to rehabilitate the region's already degraded fishery resources and fishing grounds. One of the approaches could based on the coral propagation technique developed by Japan .

Coral reef is not only the richest example of biodiversity in the sea, but it's also one of the most economically important ecologies and an irreplaceable asset of mankind. However, coral reefs have been seriously degraded by many activities and factors that include climate change, development of coastal areas, sedimentation from rivers, and a variety of other human activities including fishing. Specifically, it is noticeable that high seawater temperature could result in massive coral bleaching and mortality due to stress to the coral colonies in the reefs. In order to conserve the coral colonies and the habitat environment for future generations while considering the present situation where coral reefs have been degraded, it would be a difficult task to rehabilitate the reefs to the level of self-restoration. Therefore, the development of restoration techniques to increase coral colonies is indeed necessary. Trials on coral fragmentation have been conducted in many countries as means of restoring the depleted coral colonies. However, the coral fragmentation method not only wounds the coral colonies but also affects the ecology of the coral reefs where large quantities of fragments are taken for restoration purposes.

Moreover, in reefs where coral colonies are degraded to a great extent or the density of the coral habitat is basically low, it is difficult to secure coral fragments in large amounts. In order to address such constraints, the propagation of corals using sexual reproduction method is now being developed in Japan. Since the reproduction method makes use of the gametes released by adult/parent corals (some release larvae depending on species), problems confronting the coral fragmentation method could be avoided.

The Technical Development Project for Coral Propagation

The research activities under the coral restoration project using sexual reproduction method are mainly divided into: larvae release method and transplantation of juvenile corals using seed production technologies. In the larvae release method, exceedingly large wastage of larvae occurs during the early period, so the survival of larvae was low. This need to be improved. For the transplantation of juvenile corals using seed production technology, the Akajima Marine Science Laboratory (AMSL) in Okinawa, Japan has succeeded in the seed production of *Acropora tenuis* at experimental scales.

The technical development project for coral propagation, which was started in 2006 by the Fisheries Agency of Japan, is mainly aimed at developing large-scale practical coral propagation technology by utilizing the outcomes from the basic studies of the AMSL. Specifically, the project also aims to establish a long-term rearing method of adult coral colonies in land-based tanks to obtain gametes without


Coral reef in Okinotorishima (left) and coral colonies in the reef (right)
(Photos: Fisheries Agency of Japan)

relying on the gametes from natural coral colonies in the sea, and develop the technology for spawning and rearing juvenile corals in seawater tanks in order to produce large quantities of coral seeds older than one year with high survival.

Based on the results of previous studies indicating that more than one-year old juvenile corals had exhibited improved survival after transplantation, the project also intends to confirm the technique of implantation by transporting parent corals from a remote area, and transporting and transplanting again the parent corals and the resulting juvenile corals back to their original source. For this project, the island of "Okinotorishima", located 1100 km southeast of Okinawa was chosen as the experimental area for the coral colonies propagation.

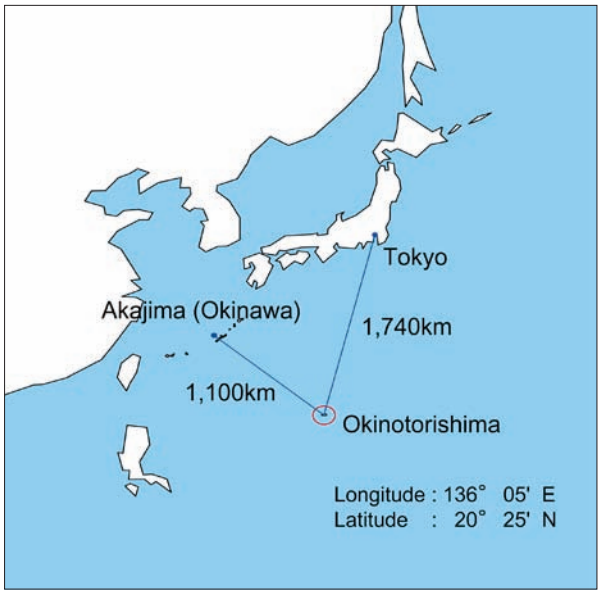
Transporting and rearing adult coral colonies

A. tenuis which commonly inhabits Okinotorishima was selected as the main species for the seed production activities. Colonies of *A. tenuis* were collected at 2-3 m depth in the reefs of Okinotorishima in August 2006 and May 2007. The size of the coral colonies ranged from 10.3 to 42.7 cm in length. The collected coral colonies were temporarily placed in the sea for 1 to 5 days, after which they were kept in tightly closed buckets to avoid air exposure while being transported by a research vessel. The corals were stocked in seawater tanks (1 ton water tank) onboard the vessel, and were brought from Okinotorishima to the land tanks of the Akajima Coral Hatchery (ACH) in Akajima Island, Okinawa after 64-hour travel time.

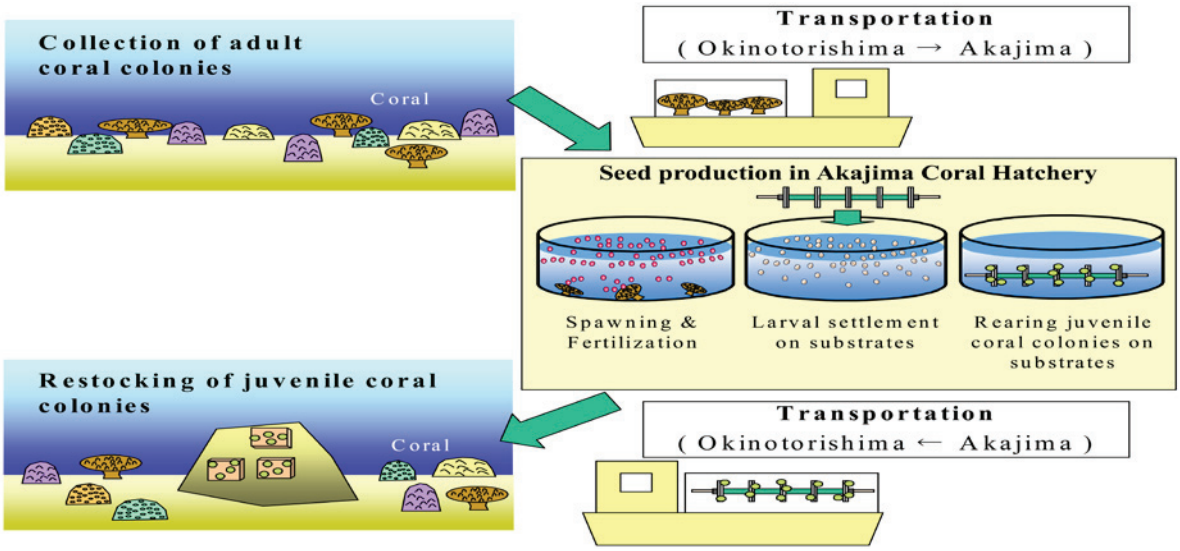
In order to keep the corals in good condition on the research vessel during transport to the ACH, water temperature in the tank was maintained at 22.5~28.4ºC by regulating the amount of light using a shading net (photon flux density: 100~280 µmol $m^{-2}s^{-1}$). One-third of seawater in the tank was replaced three times a day with seawater from the open sea.

The adult coral colonies brought to the ACH were reared in 2 ton fiber glass rectangular tanks set in open-air area and 1-ton round-shaped polycarbonate transparent water tanks at the indoor area of the ACH.

During the rearing period (August 2006~April 2008), the monthly average seawater temperature in the tanks ranged from 21.8 to 29.1ºC. In natural conditions, the coral colonies are exposed to oscillatory flow by waves and tidal current in the seawater. In this project, the adult coral colonies were reared in simulated seawater tanks where the water flow was generated by aeration. At the start of the rearing period, the coral colonies appeared to be weak, so the speed of the water flow in the tanks was increased to approximately 10 cm/second since September 2006 and continued during the rearing of the adult coral colonies.



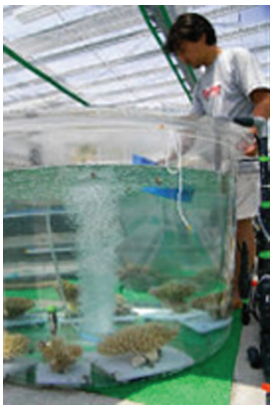
Okinotorishima Island, Okinawa, Japan



Schematic outline of coral propagation technologies of the project (Source: Fisheries Agency of Japan)

The amount of light is also an important environmental condition for coral growth. Until August 2006, because water temperature was high, 80% shading nets were used but since the coral colonies seemed weak, the shading ratio was gradually reduced so that light amount in the tanks was close to that of the coral habitat (about 1,000 µmol $m^{-2}s^{-1}$ at noon on a fine weather day). There was no shading during winter and spring (from November 2006 till May of the following year). From June to November 2007, 30% shading nets were used for the outdoor tanks and 15% shading nets for the indoor tanks.

As a result, from this rearing environment improvement, the two coral colonies collected in 2006 which were relatively weak, have recovered and grown healthily together with the other adult coral colonies collected in 2007. Almost all the adult corals were returned to their original habitat in May 2008 keeping in good condition. The remaining coral colonies were also returned to their original habitats in 2009.

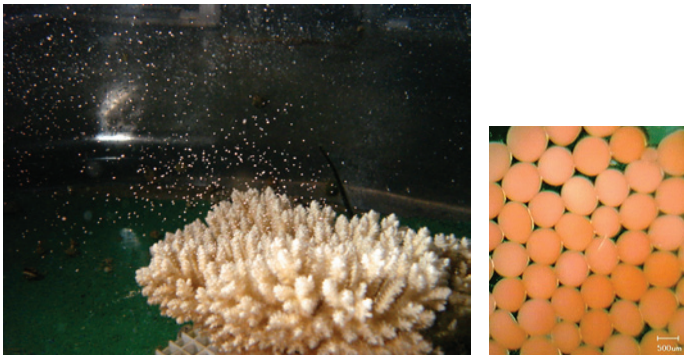


The Akajima Coral Hatchery in Okinawa, Japan (above) and rearing of adult coral colonies (right) (Photos: Fisheries Agency of Japan)

Spawning and juvenile rearing

Spawning of *A. tenuis* in the tanks was observed on the 27th of May as well as on the 8th and 9th of June in 2007. The rearing trials were started by using about 237,000 fertilized eggs spawn on the 8th and 9th of June. All sperms and eggs released on the same day were collected during spawning or within an hour after spawning, and fertilized in the same container. One hour after spawning, rearing of the fertilized egg started in separate containers. After five (5) days of spawning, the planula larvae gathered at the bottom of the tanks showed their behavior for settlement. Then the larvae were moved to other seawater tanks for settlement (500L rectangular tank). The number of larvae which survived was presumed to be about 205,000 or at 86.5% survivorship.

Before stocking the larvae in the water tanks for settlement, 640 pieces of unglazed ceramic plates with lattice structure were placed at the bottom of the tanks as settlement substrates. Such ceramic substrates had been sunk in the seawater for 4~16 months so that calcareous algae or bacteria film could attach. About 111,000 larvae out of 205,000 (54.1%) settled onto the substrates. The juvenile corals were moved to fiber glass tanks (1.4 tons) for rearing. The monthly average water temperature in the juvenile coral rearing tanks during June 2006~April 2008 was 20.9~29.2ºC. About 5 cm/sec of water flow was generated in the tanks using aeration similar to the adult coral rearing tanks. For shading, 30% shading nets (from June to November) and transparent vinyl tents (other months) were used. In order to remove the algae from the substrates in the tanks, which compete with the juvenile coral colonies, juvenile snails such as the trochus shells

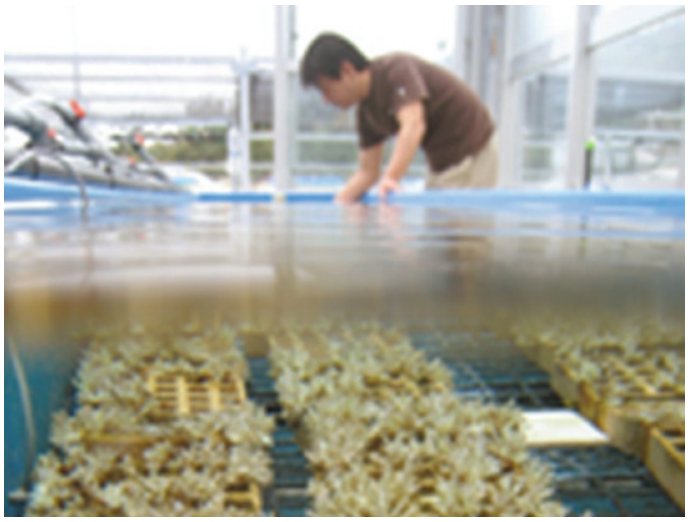


Coral spawning (left) and fertilized eggs (right)
(Photos: Fisheries Agency of Japan)

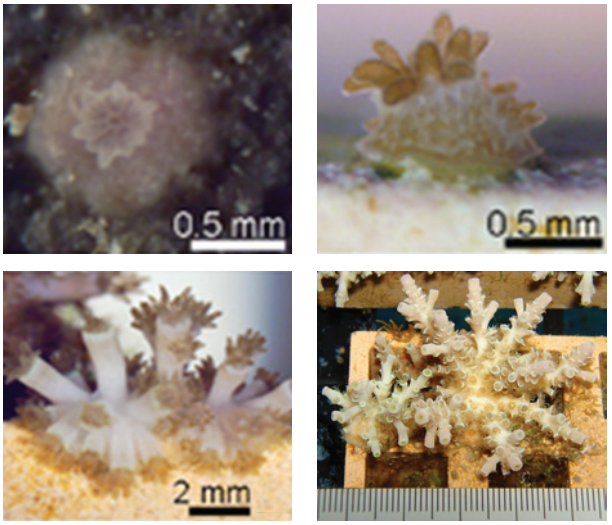
that feed on tiny algae were put in the tank soon after the settlement. After four (4) months from settlement, young rabbit fish and butterfly fish were also used to remove the competitive algae and sea anemones.

The survivorship of juvenile *A. tenuis* on the 200th day after spawning was 82% with an average length of the juvenile corals at 7.9 mm (SD: + 3.1 mm) as shown in **Fig. 1**. In April before transplanting the coral colonies to Okinotorishima (307th day after spawning), 65,622 juvenile coral colonies had survived with survivorship of 59.2%. Average length at that time was 13.1 mm. The survivorship and the mean longest diameter 424 days after spawning of the juveniles

Fig. 1. Growth and survivorship of juvenile *A. tenuis* in tank
(Solid line - mean longest diameter; Broken line - survivorship)



Rearing of juvenile coral colonies
(Photo: Fisheries Agency of Japan)



Growth of juvenile coral (*A. tenuis*) colonies after larval settlement (from upper left: at 10 days, one month, 6 months, and 10 months) (Photos: Fisheries Agency of Japan)

was 57.1% and 22.9 mm, respectively, which were left at the ACH without transplantation to the island.

Transporting juvenile coral colonies

The 564 pieces of substrates with settled juvenile *A. tenuis* (approximately 63,000 colonies) were transported from the ACH to their native island of "Okinotorishima" on the 22nd of April 2008 after a 60-hour voyage by a research vessel. The substrates were put in fiber glass seawater tanks with acrylic plate covers, and water flow was generated in the tanks using small pumps. Above the tanks, 30% shading nets were used to cover and adjust the amount of light and control the temperature which could rise due to sunlight.

The water temperature in the tanks was also controlled by replacing 1/3 of the seawater in the tanks with seawater obtained from the open sea 3 times a day during the transport period and gradually increased from the seawater temperature of 22.5°C around Akajima to the seawater

Transport set-up for juvenile coral colonies
(Photo: Fisheries Agency of Japan)

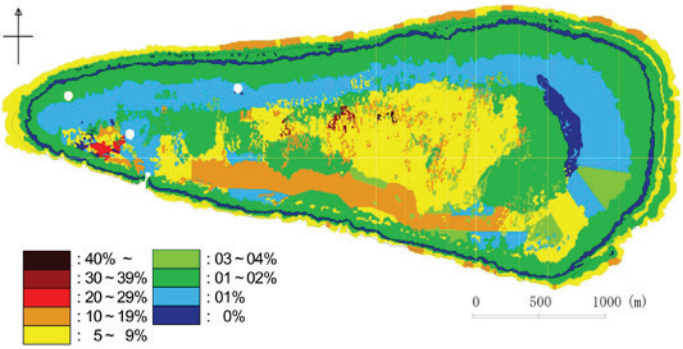
temperature around Okinotorishima at 29.0°C. In addition, waste matters that accumulated at the bottom of the tanks were also removed. The juveniles did not show signs of weakening during the transport period.

Transplanting juvenile coral colonies

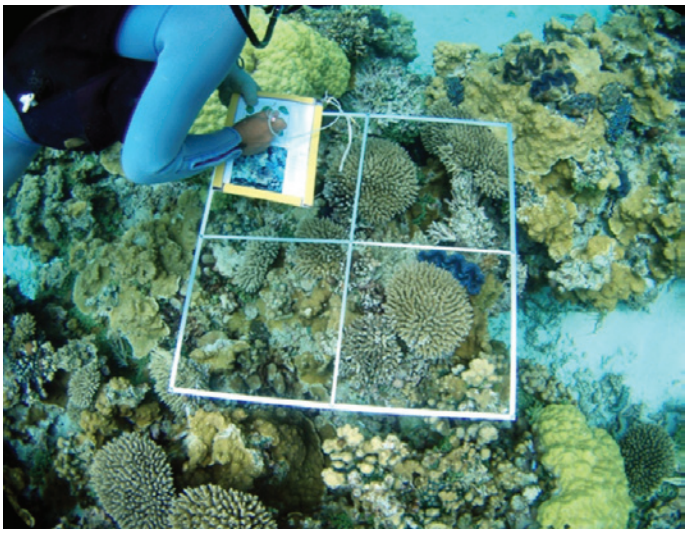
The juvenile coral colonies that spawned in June 2007 were transplanted to the coral reefs in Okinotorishima in May 2008. The transplantation sites for propagating juvenile coral colonies were selected based on information obtained from previous research mainly conducted during the past two years under this project, *e.g.* the coral habitat situation and marine environmental conditions. Several knolls around the southeast side from the center of the island were selected. At the transplantation sites, the coverage of coral colonies was low mainly due to few coral larvae but with potential to grow and propagate corals in view of their relatively favorable marine conditions. Based on the results of the previous research, it has also been estimated that within a range from sea bottom up to about 50 cm above the bottom, the distribution of coral colonies could be relatively less mainly due to the current and sediment movement.

Creek of coral spawn from the reefs
(Photo: Fisheries Agency of Japan)

Transplanting coral colonies in Okinotorishima
(Source: Fisheries Agency of Japan)



Coral coverage on the reef of Okinotorishima
(Source: Fisheries Agency of Japan and Ministry of Land, Infrastructure, Transport and Tourism of Japan)



Growth monitoring of coral colonies in Okinotorishima by the permanent quadrat method (Source: Fisheries Agency of Japan)

Therefore this project considered that the juvenile coral substrates could be better fixed on the surface of knolls higher than 50 cm from the sea bottom, and every substrate with juvenile coral colonies attached was transplanted based on such hypotheses and verification. Upon investigation on the 5th day after transplanting the 341 substrates, no degeneration of the coral colonies had occurred in the substrates that had sunk due to the flow of current and no damages occurred even with some fishes feeding on the organisms at the substrates. For the 2nd stage of this project which started from April 2009, several monitoring surveys have been continued to clarify the favorable and effective conditions and methods for juvenile coral colonies transplantation and their aftercare.

Discussion

Under this technological development project, mass production of juvenile coral colonies from the adult coral colonies of *A.tenuis* has been successfully conducted.

The project succeeded in determining the optimum conditions of the rearing environment of corals (such as light adjustment, water temperature control, replacement of water, maintaining water flow, control of competitive species). These environmental factors were checked in every stage (such as during transport, breeding adult coral colonies, spawning, larvae settlement, breeding juvenile coral colonies) and when problems were encountered, these were addressed and quickly placed under human control.

This project is different from previous seed production activities because fertilized eggs obtained from adult coral colonies reared for a long time on land using water tanks were utilized in the sexual reproduction technique. Based on such technology, seed production could be done in large quantities without relying on natural coral colonies in the sea. Moreover, there is no need to collect coral eggs spawned in the sea for every seed production activity where may be restricted by unfavorable weather conditions. This technique is therefore useful not only for conservation of natural coral colonies but it also paves the way for practical propagation of coral colonies by obtaining adult coral colonies tentatively from a remote area or from a place where there are less adult coral colonies.

The ACH is a simple and ordinary hatchery managed by two staff and with a relatively small amount of operational expenses. The survivorship of the 1-year-old juvenile coral colonies was very high as a result of this sexual reproduction method. Therefore, this technology could be applied as a feasible method that could contribute to the restoration and conservation of coral reefs, which globally are in a state of degradation.

Way Forward

In 2008, it was found that the larva settlement of *A. tenuis* would be improved to nearly 100% under favorable conditions principally by heightening the coverage of crustose coralline algae in the substrates. During the 2nd stage of the project starting in 2009, seed production has been extended to several species of coral colonies and also the effective transplantation techniques for propagating the juvenile coral colonies is being developed. Thus, the 2nd stage of the project would focus on the development of practical technology that could be applied to the restoration of coral habitats in many countries including those in the Southeast Asian region.

The Southeast Asian region comprises many islands with coral habitats. However, it has been reported that some coral colonies in the region's waters have been damaged, for instance destruction of coral reefs by the impact of the Asian Tsunami caused by an earthquake off the coast of Sumatra. Moreover, the effect of climate change at the global level is leading the coral reef communities in this region towards a worse scenario. Therefore, the restoration of degraded coral habitats in this region should be urgently considered in line with the respective countries' efforts in coastal habitat/fishing ground conservation and management. It would be a great pleasure for everyone involved in this project, if this report is utilized as reference or as guide for any effort towards the restoration of coral colonies in the Southeast Asian region.

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References

M. Omori, Coral Reefs 24, 563 (2005).
M. Omori, K. Iwao, M. Tamura, Coral Reefs 27, 165 (2008).

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