Chapter 5

Coral reef restoration

Coral reef ecosystems in the world are on the declining trend mostly due to anthropogenic disturbances. When it was disturbed beyond its regenerating ability, it cannot be regenerated and will further proceed on the declining track. For coexistence with coral reefs in the future, needless to add that the top priority should be to prohibit as much disturbances and conserve the existing ecosystems, inducing its natural recovery. However, when natural recovery is considered hardly progressive or too slow without artificial assistance, rehabilitation measures to induce the recovery is sometimes necessary. Moreover, it is us humans that is to be responsible for the degradation itself, thus such efforts should partly be conducted if adverse effects are not caused and with careful implementation. In this chapter, restoration techniques and attempts of coral reef restorations in Japan are introduced.

5-1 Restoration techniques

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1 Introduction

Coral reef ecosystems have been in decline, worldwide, for the past 100 years. This decline has been caused by pollution and overexploitation, and is predicted to worsen over the next 20–30 years if appropriate measures are not taken immediately. Added effects of the mass bleaching and coral diseases have occurred in recent years (Pandolifi *et al*. 2003). In developing countries, destructive fishing methods, such as fishing with dynamite and poison, have added to the damage. Coral reefs in Japan are also declining because of repeated disturbances, such as outbreaks of crown-of-thorns starfish (*Acanthaster planci*) beginning in the 1970s, inflows of terrestrial soil, and recent mass bleaching events.

In response to these events, a number of countries, including Japan, the U.S., and Australia, set up the International Coral Reef Initiative (ICRI) in 1995, and developed a framework to discuss the conservation of coral reefs worldwide. The ICRI considered various conservation activities. Of these, coral restoration and regeneration have attracted attention, and their importance has been recognized as a management tool (ICRI 2003).

The recruitment of coral larvae on degraded reefs differs greatly with location, due to the effects of geographic and hydrographic conditions. Therefore, the artificial restoration of reefs should help to regenerate coral communities where natural recovery is limited; artificial restoration will hasten their recovery, expand the source of larvae, create habitat for other organisms, and recover the underwater scenery.

This section first introduces the disturbances that have affected coral reefs in the past, and the effort that has been exerted for their recovery, by referring to the case of Sekisei Lagoon in the Yaeyama Archipelago, Okinawa. It then overviews the research on restoration and current restoration/regeneration techniques, and finally discusses future perspectives.

2 Previous efforts at coral reef restoration in Sekisei Lagoon

Sekisei Lagoon in the Yaeyama Archipelago is the largest coral reef in Japan; the entire area was designated as Iriomote National Park in 1972. After establishing the national park, the government established an administrative office for the park in the city of Ishigaki. In addition, the Marine Parks Center of Japan set up the Yaeyama Marine Park Research Station at Kuroshima Island in Sekisei Lagoon in 1975, and has been conducting research there. Consequently, the changes in Sekisei Lagoon since it became a national park have been monitored relatively closely. Initially, Sekisei Lagoon was a pristine coral reef at 'physiognomy climax', unaffected by outbreaks of *A. planci* or anthropogenic disturbances. This is evident from a coral distribution map of the lagoon based on aerial photographs (in 1977, Geographical Survey of Japan) created by the Environment Agency in 1980 (Nature Conservation Bureau, Environment Agency 1981). This map suggests that the reefs were at the stage of maximum development and dominated by branching *Acropora*.

In 1980, immediately after the survey, an explosive outbreak of *A. planci* occurred in the lagoon and most of the corals were predated, except in the northern part of Kohama Island (Fukuda and Miyawaki 1982). At that time, the local residents, as well as Okinawa Prefecture and the National Government, began a large-scale removal of *A. planci*; it failed, however, to keep pace with the scale of the outbreak. Little recovery of the coral community occurred in the 1980s and a state of stagnation has continued.

To determine the state of decline in the reefs that has been caused by *A. planci* predation, the Environment Agency surveyed the coral reefs in Sekisei Lagoon in 1991, using the latest aerial photographs. It was apparent

that the coral communities were in poor condition; more than half of the lagoon had coral coverage below 5% (Nature Conservation Bureau, Environment Agency 1994b).

Therefore, the Environment Agency initiated research into the recovery of coral reefs. In 1992-1994, coral restoration techniques using coral fragment transplantation were attempted (Nature Conservation Bureau, Environment Agency 1993, 1994a, 1995). At that time, a framework for the recovery of Sekisei Lagoon was developed, and the Yaeyama Coral Reef Conservation Committee was established in April 1990, with participants representing Iriomote National Park, the Okinawa Prefecture Nature Conservation Section, the city of Ishigaki, the town of Taketomi, local diving unions, and Yaeyama Marine Park Research Station. This conference resulted in a coral fragment transplantation pilot project, in the sea, approximately 1 km south of Taketomi Island. In this project, 5,000 fragments of branching *Acropora* (mainly *A. formosa*) were transplanted within an area of 1,000 m^2. This was continued for several years; Misaki (1998a) has reviewed the results.

The corals in Sekisei Lagoon started to recover gradually in the early 1990s, and had nearly recovered to their previous state by the late 1990s when high water temperatures in 1998 caused mass coral bleaching, killing corals over a wide area.

In addition, terrestrial soil runoff has also affected the coral communities in Okinawa, when construction related to land improvement enterprises started after Okinawa's handover to Japan in 1972. The Ministry of the Environment (the former Environment Agency) conducted research into coral tolerance of fine suspended matter in Sekisei Lagoon in fiscal 2000-2002 (Fujiwara 2003). In addition, the Yaeyama Coral Reef Conservation Conference expanded its scope and monitored coral and related sedimentation, with public participation, in an attempt to get the community involved in these activities.

3 Restoration techniques

Most hermatypic corals (hereafter, corals) reproduce sexually, and colonies grow by budding polyps. When parts of a colony are broken off, such as by waves, the fragments can settle on the neighboring substrate and grow asexually to form a new colony. Using this characteristic, attempts have been made to transplant coral fragments, in order to restore coral reefs, since the 1980s overseas, and since the 1990s in Japan. This fragmentation technique can be further divided into two basic methods: the fragments are simply fixed directly to the substrate, or they are allowed to settle on a plate, which is then transplanted once the fragment has grown to a certain size. Other methods of restoring coral reefs have been attempted in Japan. For example, a method that involves suspending numerous ropes with attached coral fragments in the sea and letting them grow has been patented in Japan. In addition, an attempt to promote the calcification of transplanted fragments using electrolysis has been tested in the sea off the village of Chinen, in Okinawa (Kudo and Yabiku 1988). Okubo and Omori (2001) have reviewed coral fragment transplantation techniques.

Recently developed restoration techniques include seedling production and larvae-settlement-inducing techniques using sexual reproduction. The development of restoration techniques using sexual reproduction has been one of the main topics of research at the Akajima Marine Science Laboratory since the beginning of the 1990s. Various basic biological studies have been conducted in cooperation with universities and private enterprises. These include inducing corals to spawn in tanks, breeding larvae and juveniles, promoting larvae settlement, and transplanting the larval and juvenile corals to the field.

This section reviews these restoration techniques, including methods using asexual reproduction, sexual reproduction, and colony and community transplantation, as well as transplant management.

1. Asexual reproduction techniques

a) Transplantation of coral fragments

Okubo (2003) has brought together and described various coral fragment transplantation techniques, including the results of the author's studies in this respect. The following is a summary of these techniques:

i) *Collecting fragments*: Fragments for transplantation are collected from adult (donor) colonies. The effects of fragmentation on the donor colony should be minimized in the course of this operation. Although there are insufficient physiological studies of these effects, experience shows that if about 80% of the adult colony is left, the donor is likely to survive and

will not have problems spawning eggs the following year. It is thought that the bigger the fragment, the higher its probability of survival, although Becker and Muller (1999) have reported that a 2.5-cm-long fragment is sustainable as a transplant.

ii) *Transportation methods*: It is preferable to transport fragments by submerging them within a container, by having them carried by divers to a nearby destination (Dodge *et al*. 1999), or by suspending them from a boat (Dodge *et al*. 1999; Munoz-Chagin 1997). It is often convenient to carry fragments by boat, immersed within a bucket, but this requires attention to temperature changes (Bowden-Kerby 1997). The tolerance to exposure varies with the species: while *Acropora gemmifera* and *Favia stelligera* can survive exposure for up to about two hours, *Stylophora pistillata* and *Rumphella* sp. should not be exposed (Kaly 1995).

iii) *Fixation on a natural platform*: There are many ways to attach fragments (Fig. 1), but underwater cement is what is commonly used. While the chemical influences of underwater cement on corals are not well understood, some researchers have attempted to reduce this influence by mixing equal amounts of calcium carbonate with the cement. The method of Okubo *et al*. (2002), in which branching fragments are fixed to pre-fixed nails with cable ties, revealed the benefits of underwater cement. The outcome is generally better when a branching fragment is fixed to the substrate vertically, as opposed to horizontally; this may be due to the reduced accumulation of silt.

iv) *Fixation on an artificial substrate*: When transplanting fragments to artificial structures, it is useful to know what kinds of substrate corals attach to easily. Comparative experiments using ferrite-added-concrete, unglazed pottery tile, concrete block, iron, and coral carbonate showed that coral fragments attached best to concrete and ferrite-added concrete (Okubo 2003). An artificial substrate made by mixing concrete with lime ash (an industrial by-product) also had a high fixation rate (Ikeda and Iwao 2001). These findings suggest that coral fragments attach well to substrates that contain concrete.

v) *Environmental factors*: The growth characteristics of corals depend on the species and the environment. Therefore, it is necessary to survey the physical characteristics of both the donor colony habitat and the destination of transplants (e.g., waves, current, turbidity, depth, irradiance, sedimentation level, and salinity) before transplantation. When the two sites have similar environments, the outcome is usually successful, but when they differ, the survival rate is likely to be unsatisfactory (Auberson 1982; Nature Conservation Bureau, Environment Agency 1993, 1994a, 1995). A study of the relationship between the survival rate of transplants and temperature and photoperiod found that the rate was inversely correlated with temperature and directly correlated with photoperiod (Yap and Gomez 1984; Yap *et al*. 1992). The mortality rate was higher during periods of high temperature (Yap and Gomez 1984); therefore, the season in which transplantation is conducted should be considered. It is also necessary to avoid sites where coral predators, such as *A. planci* and coral eating gastropods (e.g., *Drupella cornus*), prevail.

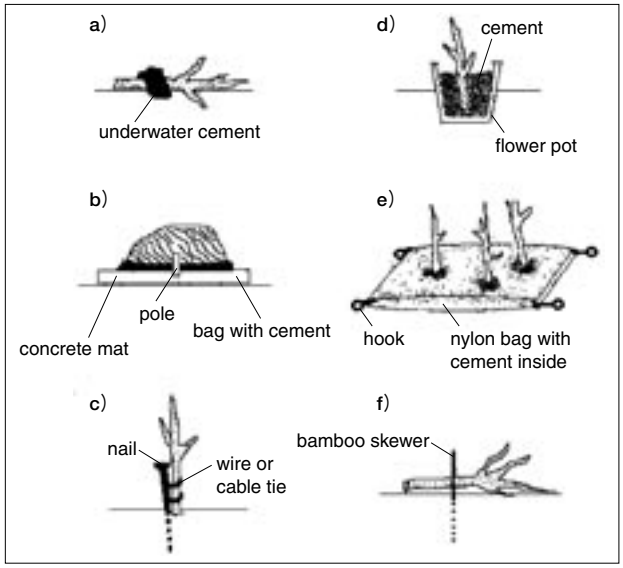

Fig. 1. The transplantation of fragmented colonies (Okubo and Omori 2001).

The problems associated with fragment transplantation include those associated with obtaining fragments by breaking donor colonies, difficulty in standardizing transplantation methods, lack of information about the long-term survival rate after transplantation, and the considerable labor and costs required for large-scale transplantation.

b) Juvenile coral transplantation

Okamoto and Nojima (2003a) compiled data on how to collect and transplant juvenile corals in the field, and these are summarized here. First, juvenile corals can be collected with the substrate in a core, using an air drill. At the transplantation site, holes for fixation are drilled using the same caliber drill. A small amount of underwater cement is put in the hole, and the core with

Photo. 1. Juvenile coral transplantation. A core with the juvenile coral will be cemented in the same caliber drill (Okamoto and Nojima 2003a).

Photo. 2. A spawn slick (coral gametes and larvae) offshore.

the juvenile coral is inserted. If the transplantation site is affected by silt accumulation, it is desirable to drill shallow holes and insert the cores with the juvenile corals so that they are raised slightly above the sea bottom (Photo. 1). Using this method, the substrate is unified with a smooth core. Therefore, many cores can be carried in the sea or by ship, and there is less danger of hurting the juvenile corals, even if many are stored standing in a container. In addition, this method is simple, and can be used for large-scale transplantation.

2. Techniques using sexual reproduction

a) Seedling production

Hatta *et al*. (2003) devised a method of producing *Acropora* seedlings, which is summarized here. Gametes are either collected from slicks (Photo. 2) or by placing a funnel-like device on top of a colony (Kitada 2002); fertilization is allowed to take place in a tank. For *Acropora tenuis*, about one million eggs can be collected from three colonies, about 30 cm in diameter (Shimomura *et al*. 2002). It is also possible to induce spawning artificially on a small scale in some species of *Acropora* and *Montipora* using hydrogen peroxide (Hayashibara *et al*. 2003).

The larvae can be raised in a small container or a large tank (1-5 tons) containing more than 100,000 individuals (Shimomura *et al*. 2002). The gametes obtained from a bundle are fertilized easily, with 500,000 individuals per ton of seawater, while those obtained from slicks are susceptible to deteriorating water quality owing to the mixing of impurities and the death of unfertilized eggs, requiring breeding at lower densities. Aota *et al*. (2003) succeeded in producing more than two million larvae in eight floating culture ponds measuring 2 m × 2 m with 1 m depth.

A chip of *Hydrolithon reinboldii* can induce the settlement of *Acropora* larvae (Morse *et al*. 1996). In addition, higher rates of larvae settlement can be induced using the neuropeptide Hym-248 (Iwao *et al*. 2002; Hatta and Iwao 2003). Moreover, bacteria that induce the settlement of *Acropora* larvae have been isolated from coralline algae (Negri *et al*. 2001); Hatta (unpublished data) has conducted a follow-up study of this.

Larval settlement has been tested on a wide variety of substrates, including concrete, unglazed pottery tile, shell, pottery stone tile, earthenware, and slate. Generally, settlement is greater on materials that have been submerged in the sea until a layer of organisms has formed.

Trials to induce larvae settlement in the field have also been undertaken. Tetra Co., Ltd., and the Akajima Marine Science Laboratory prepared a 6.0×5.5×5.5-m enclosure and introduced larvae, allowing them to settle on concrete blocks on the bottom (Aota *et al*. 2003). Dr. A. Heyward who had assisted the studies in Japan at initial period, bred larvae inside a floating tank, moved the tank to the desired destination, ran tube from the bottom of the tank to a tent set up on the sea bottom, and introduced larvae into the tent from the tank using hydraulic pressure, so that the larvae could settle on the substrate under the tent (Heyward *et al*. 2002) .

When polyps settle on a reef or a substrate in a running seawater tank, with parent colonies, zooxanthellae symbiosis is seen within one week or so. Although an initial polyp has been raised to produce a large colony in some cases (Misaki 1998b, 2002; Petersen and Tollrian 2001), there have been no reports of successful large-scale breeding of corals. Future research in this field

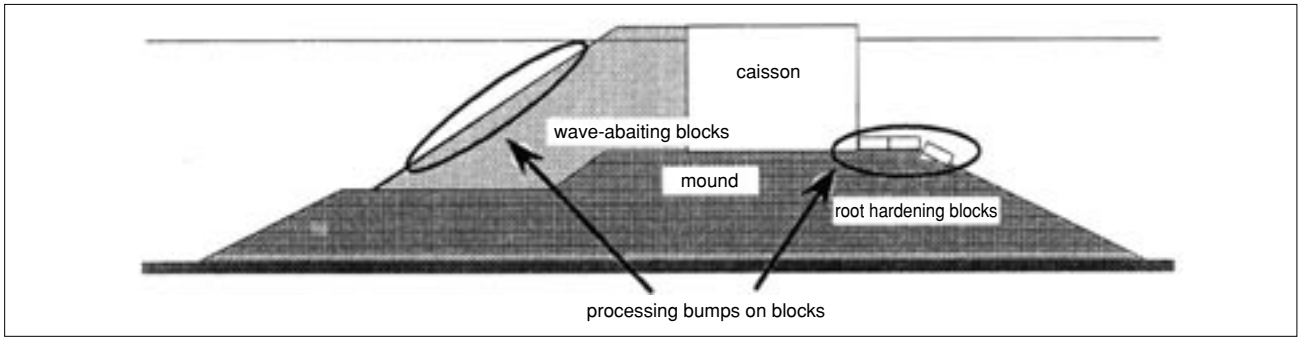

Fig. 2. Target area for substrate processing on a breakwater to induce coral larval settlement (Port and Marine Environment Research Institute, and Waterfront Vitalization and Environment Research Center 1999).

should examine how to improve the growth and survival of juvenile corals after settlement. Measures may also be necessary to protect corals against algae overgrowth and coral-eating fishes.

b) Inducing larval settlement by substrate processing

This is a method of inducing coral larvae settlement on 1- to 3-cm bumps on the surface of breakwaters and other artificial structures. These bumps are thought to cause a vortex at the structure's surface, increasing the probability that larvae attach and settle. Moreover, they are thought to decrease the risk of sea urchin grazing after settlement. In this respect, concrete is a suitable manufacturing material. Figure 2 shows a breakwater with wave-abating blocks in front of the bank, and root-hardening blocks behind the bank (Fig. 2). Methods for processing the surfaces of these concrete blocks include i) leaving irregularities on the surface of the blocks by omitting the smoothing process, ii) forming bumps by a) placing wooden blocks at the top of the mold after the concrete is poured, b) placing pieces of wood or rubber on the inner surface of the mold, or c) attaching secondary material, such as plates, to the blocks using adhesives or bolts, and iii) spraying concrete on the surface of a block (Port and Marine Environment Research Institute, and Waterfront Vitalization and Environment Research Center 1999).

Studies monitoring coral recruitment on the surface of processed blocks have shown remarkable recruitment on bumps produced using rough squares of wood. Horizontal and 45-degree surfaces tended to have greater recruitment than vertical surfaces at a depth of 20 m, while these differences did not occur at a depth of 10 m.

c) Collecting seedlings using a larvae settlement tool

Okamoto and Nojima (2003b) developed a settlement device for collecting larvae in the sea. This small, light

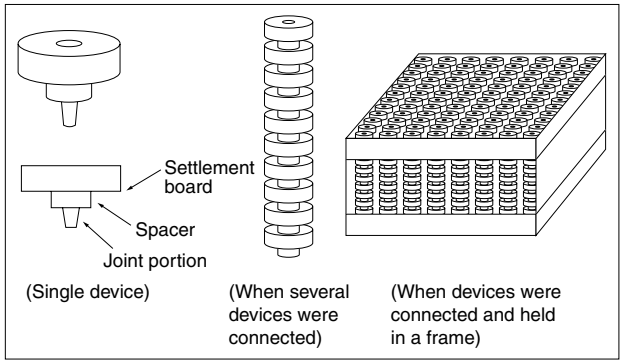

Fig. 3. Diagram of the larvae settlement device (Okamoto and Nojima 2003b).

device is shaped like a wooden top and consists of a 'settlement board', a 'spacer', and a 'joint portion'; it is designed to facilitate the settlement of larvae so that they can be transplanted readily (Fig. 3). It is made of potter's clay and can be mass-produced inexpensively. The 'settlement board' has a hole on top for connecting several of the devices, and grooves to increase the settlement area. The 'spacer' maintains a space between connected settlement boards, and the 'joint portion' functions as a guide when connecting and transplanting. Since these devices can be connected to each other and held in a frame, mass-transportation and mass-installation in the sea are possible. Predators can be kept away from the larvae by adjusting the frame interval. This device can be transplanted on a reef substrate by drilling small holes in the substrate, putting adhesives in the holes, and inserting the joint portion of the device. The spacer functions as a 'stopper' that prevents damage to juvenile corals growing sideways from the undersurface of the settlement board after they have been transplanted.

The settlement of larvae is thought to be completed by roughly ten days after spawning. After one month, when the larvae are settled firmly on the settlement devices, they can be transported to an appropriate calm area for

growth. The frames can be transported either by divers or by using an air lifter. This method is being tested, but a large-scale project has not yet been conducted. For enough juvenile corals to settle on the devices in the sea, information is needed regarding the distribution of fertilized eggs generated by mass spawning and where the larvae settle.

3. Transplantation of colonies and the relocation of coral communities

Coral transplantation is generally conducted using fragments. In cases where coastal development threatens whole coral communities, as many colonies or communities as possible should be transplanted to adjacent sites. In such cases, a comprehensive environmental survey is necessary; however, there is insufficient information on this technique. There have been some trials in other countries combining clipped coral communities and artificial coral reefs, but such cases are limited, and only replacement of a community that was unavoidably removed or reclaimed during harbor construction has been carried out in Japan (Fukunishi *et al.* 1998).

a) Colony transplantation

Hosoya (2003) reported the transplantation of *Porites lutea* colonies during the construction of the Kouriohashi Bridge on Okinawa. Massive *Porites* are unsuitable for transplantation, as large corals exceed 1 m in diameter. Therefore, colonies 20-30 cm in diameter, which were comparatively easy to handle, were used. Transplantation involved separating the colony using a chisel, transporting the colony underwater in a container to the site, and gluing the colony to the substrate using underwater cement. Concrete blocks and natural carbonate rock were tested as substrates. With carbonate rock, a method that involved driving an anchor bolt into the colony base was also tested as a means of fixing the colony, and was proven effective. A follow-up survey conducted four years after transplantation showed that survival and growth were better on natural carbonate rock. Since massive *Porites* are usually distributed in moats, it seems appropriate to transplant them to moats. However, moats generally have sandy bottoms, which are unstable. Corals can be transplanted to a sandy bottom by installing iron piles in the bottom and attaching the corals to the piles.

b) Relocating coral communities

Fukunishi *et al.* (1998) and the Port and Marine Environment Research Institute, and Waterfront Vitalization and Environment Research Center (1999) introduced a technique that involved transplanting parts of a coral community, together with the underlying substrate; this technique is for use during harbor reclamation or breakwater construction. In addition, a new experimental approach for advanced harbor construction, one that takes coral communities into consideration, has been used in Hirara, on Miyako Island, Okinawa Prefecture, since 1998. The results have been reported in Ishii *et al.* (2000, 2001) and in a pamphlet published by the Hirara Port Construction Office, Okinawa General Bureau (2002). The following is a summary of these reports.

To relocate a coral community, it is necessary, first of all, to conduct pilot studies and select the destination carefully. After a period of trial and error, the transportation of a large coral community first became possible in fiscal 2000. This involved digging up the carbonate rock using a water jet system, and transporting the coral by airlift, without removing it from the water. Using this method, coral communities were relocated around the breakwater mound inside the harbor. The coral communities relocated in January 1999 were mostly small ones, some of which were carried away by waves during typhoons. In contrast, all the larger, stable corals were in good condition and only a few died as a result of the stress of relocation and environmental change. By 21 months after the relocation, the coral coverage had increased at some points, according to a survey conducted in October 2000. There is presently an application for a patent on this technique (Fig. 4).

The relocation of a coral community has advantages, as compared to fragment or colony transplantation, since the flora and fauna adhering to the substrate are also relocated and conserved; this technique can also handle massive corals, such as *Porites*, which are difficult to fragment.

4. Managing transplants

After transplantation, algae often overgrow the transplanted colony and sometimes kill the colony. When water temperatures are low and algae grow vigorously, it may be necessary to remove the algae. Moreover, where coral-eating organisms, such as *A. planci* and *D. cornus* are present, they should be exterminated before transplantation, because fragmented coral releases mucus, which may attract these predators. Furthermore,

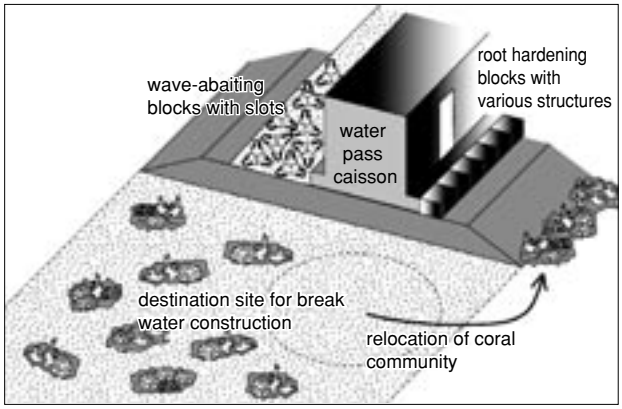

Fig. 4. General description of the relocation procedure used for coral communities in an 'environmentally friendly breakwater' (Ishii *et al.* 2001).

the hooks of surfcasting fishermen and boat anchors can destroy corals. Therefore, it is necessary to educate fishermen about the consequences of their actions and to place mooring buoys in areas where boats often anchor.

Transplants should be monitored to evaluate the method used. Preferably, follow-up should last for at least five years, since transplanted juvenile corals are thought to take about four years to adapt to their environment. The parameters to be monitored include coral survival and death rates, the health of the coral, and environmental factors such as water temperature, water flow, and sedimentation.

A long-term rise in water temperature is fatal to coral, and causes bleaching. Therefore, long-term monitoring of water temperature provides useful preliminary information. Recently, cheap, compact, self-recording thermometers have been introduced, and some can measure hourly data continually for about six months (Nature Conservation Bureau, Ministry of the Environment 2001). In general, more coral species can be transplanted to locations with greater water flow (Nature Conservation Bureau, Environment Agency 1995). A handy method for measuring water flow characteristics is that of methodology using plaster balls (Komatsu and Kawai 1992; Furushima *et al.* 2001). Sedimentation is especially susceptible to human influences, especially in moats. Sedimentation can be estimated visually, using the SPSS method (Omija and Mitsumoto 2001), or with sediment traps (Nature Conservation Bureau, Ministry of the Environment 2001). The first method is the easiest; the latter is more difficult. All of these methods provide useful data, so the method to be applied can be selected according to the scale of monitoring. In addition, irradiance and nutrient salts are also important environmental parameters, but their long-term measurement is expensive.

In coral transplantation, the rate of growth is more important than reproduction. However, if transplanted corals spawn, the supply of larvae is increased, which will further contribute to the recovery of coral reefs. The spawning of transplants also indicates that the colony is stable, so monitoring the formation of gametes and spawning may be necessary.

4 Deployment and future issues

1. Progress and comparison of restoration techniques

The first case of coral transplantation in Japan was probably in 1970, when the Kushimoto Marine Park Center in Wakayama Prefecture constructed an underwater observatory and transplanted coral colonies to restore the surrounding underwater landscape. This area contains corals that are typically distributed in Honshu (mainland Japan), and a large tabular *Acropora hyacinthus* community. In transplantation experiments with this species, the corals grew to a size showing typical colony features within 1–2 years (Tatsuki 1977).

As already stated, the development of restoration techniques has recently shifted to seedling production and larvae-settlement-inducing techniques, using sexual reproduction. Such advances should eliminate the necessity of manipulating an existing community. Advances in coral restoration techniques are not only effective in restoring coral reefs and creating artificial reefs but will also reduce the damage caused by the collection of existing colonies once ornamental corals can be cultured in aquaria. If full-scale 'coral farming' becomes possible, Japanese aquaculture technologies, which lead the world, should support progress in projects that transfer such restoration techniques to tropical countries, and contribute to the conservation of the marine environment worldwide. Table 1 summarizes the progress, thus far, of research and development in coral reef restoration techniques; future advances are expected.

2. Future research

In the future, the main coral reef restoration techniques

Table 1. Comparison of coral restoration techniques.

	Fragment transplantation	Juvenile coral transplantation	Seedling production	Larvae releasing	Induction of larvae settlement
Outline of the method	Colony fragmentation and fixation on substrate	Collection of juvenile colonies and transplantation	Collection of larvae from tank or field, nurture larvae, induce settlement on plate, and transplant plate to the field	Collection and nurturing larvae is same as left. Transport larvae and releasing (establish sheet on destination)	Induce larvae settlement on settlement tool or surface processed structure
Time required	ca. three years (fix in spring)	ca. three years (can fix year-round)	Five years after transplantation (collect larvae in summer)	ca. five years after settlement (settle in summer)	ca. five years after settlement (settle in summer)
Equipments and materials	Wire, nail, cable tie, and adhesive	Adhesive	Nurturing devices, settlement plate, and adhesive	Nurturing devices and surface processed structure	Surface processed structure
Required effort*	100 fragments fixation/ worker/day	same as left	ca. one week, every-day care for larvae nurturing, and 100 plates fixation/worker/day	ca. one week, every-day care for larvae nurturing	Transplantation and collection of settlement tools, and structure processing
Scale of restoration	Number of settlement plate will be restricted by number of divers	same as left	Amount of seedling and fixation will be restricted by nurturing facility and number of divers, respectively	Relatively broad scale, although amout of larvae will be restricted by scale of nurturing facility	Number of settlement tool and processed structure will be restricted by number of divers and project's scale

* Required efforts after fixing on to the field substrate is common, thus will be abbreviated.

are expected to make use of larvae. For that purpose, forecasting the destination of slicks in the open sea is indispensable. However, oceanographic information is presently insufficient for such forecasts, and research in this field is anticipated.

The selection of a proper site is very important when transplanting colonies and releasing larvae. Restoration cannot be considered successful unless the corals introduced to a new environment grow, reproduce, and expand their range. In this respect, it is necessary to clarify the detailed relationships at each stage in coral life histories with *in situ* factors, such as interspecies competition, the effects of predation by coral-eating organisms, and the kinds of substrate that larvae are most likely to settle on. As stated previously, there has been insufficient research undertaken on micro- or medium-scale physical factors (e.g., the water flow regime) in coral reef regions; this will be an important future research topic.

Lastly, the possibility of altered genetics within a taxonomic unit, owing to hybridization or a decrease in gene diversity resulting from a restoration program, should be mentioned. If corals are transplanted within the area where eggs are distributed under natural conditions, these factors should not be problematic. However, the transportation of corals to remote regions, outside their natural range, might alter the regional gene composition. Moreover, because corals have high genetic diversity and easily hybridize (Hatta *et al.* 1999; Willis *et al.* 1997), it is necessary to use eggs and fragments obtained from many colonies that are widely distributed. If the number of donor colonies is limited or the genetic diversity is lost, corals that are extremely susceptible to environmental change and disease will result. The Hawaiian *Porites compressa* has greater genetic diversity where environmental disturbance is frequent and lower diversity where disturbance is infrequent (Hunter 1993). It is necessary to determine the level of gene diversity of existing coral communities, using molecular techniques, before cross-fertilization or transplantation of fragmented colonies takes place.

5 Conclusions

The Ministry of the Environment established the International Coral Reef Research and Monitoring Center at Ishigaki Island in 1998 as a base for monitoring coral reef communities. It is the focus of the activities of the ICRI, and conducts conservation activities in Sekisei Lagoon. The ministry also enacted the Law for the Promotion of Nature Restoration in 2002, and selected Sekisei Lagoon as the site of a nature restoration project, in cooperation with various local agencies; work is currently being undertaken on coral reef restoration. The techniques introduced in this chapter should prove useful for restoring coral reefs, and the results will be applied to other coral reefs in Japan and overseas. But, needless to say, the development of such techniques should not merely assume that the destruction of the coral reefs from the growth of human activities is inevitable.