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REVIEW ARTICLE

Coral reefs are dying, we can only prevent it if we act now

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Abstract

This paper begins with a brief overview of the status of coral reefs of Japan and around the world, followed by a review concerning present research on coral reef rehabilitation at Akajima Marine Science Laboratory in Okinawa, Japan. With respect to the latter, effort has been aimed at developing techniques for the mass culture of *Acropora* spp. from eggs. Colonies of *Acropora tenuis* that were reared from eggs and transplanted to the seabed at Akajima began spawning by approximately 20-25 cm in diameter at 4 or 5 years of age. Many fish and crustaceans have inhabited the newly transplanted coral colonies. This demonstrated the possibilities of culturing using sexual propagation as a technique to assist local coral reef rehabilitation and hence, conservation of marine biodiversity. It is humbling and somewhat depressing to compare the small scale of success relative to the wide range of degradation. However, the present method of coral reef rehabilitation has shown enough promise for us to continue with this effort.

Keywords: Coral reef, rehabilitation, zooxanthella, Okinawa, spawning, cultivation

Introduction

Status of the coral reefs of Japan

Coral reefs are diverse, productive biological communities that thrive in shallow, tropical and sub-tropical marine environments. Reef-building corals provide the initial trophic link through their symbiosis with unicellular dinoflagellates (zooxanthellae) and produce the majority of the habitat structure for other organisms, including commercially important species (Figure 1). Many invertebrate, fish and algal species are integral members of a healthy reef community. About 100,000 described species, representing some 94% of the planet's phyla have been recorded on coral reefs (Edwards and Gomez 2007). Besides supporting fisheries, coral reefs draw tourism and afford recreational opportunities. They provide the sandy beach and the structures that buffer waves that would otherwise cause extensive coastal erosion. A coastal population of more than 100 million in over 100 countries lives with the blessings of coral reefs. Despite coral reefs constituting only 0.17 % of the planet's ocean area, the economic value of goods and services provided by coral reefs is said to be roughly 37.5 billion US dollars per year (Cesar *et al*. 2003).

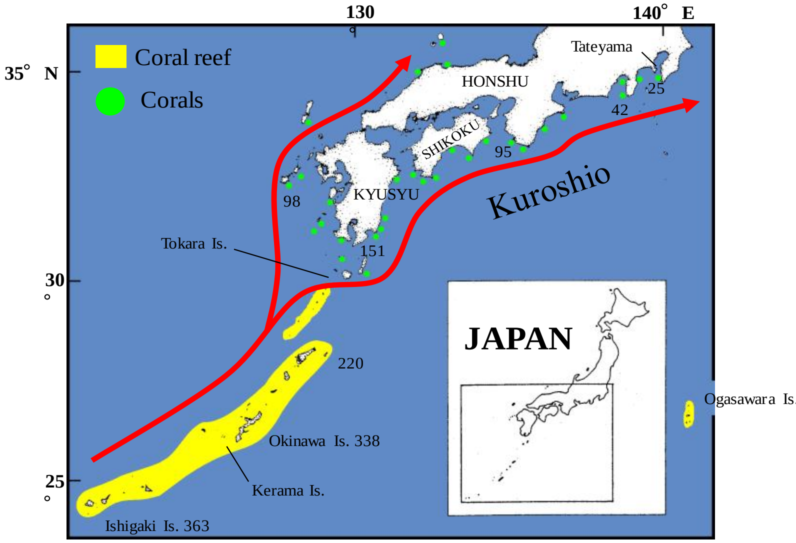

Figure 1. Regional distribution of coral reefs and hermatypic corals of Japan. Number means total species complemented by Veron (1992).

The coral reef ecosystem can only exist in clear, oligotrophic, warm waters with low nutrient input. In contrast to temperate marine communities, initial photosynthetic carbon fixation in coral reefs is carried out predominantly by the symbiotic zooxanthellae. Metabolites are exchanged between zooxanthellae and corals, and nutrients are conserved in an otherwise nutrient-limited environment. Changes in the environment such as nutrient levels, light and temperature, which affect the symbiotic association, will influence the life of corals and hence the entire reef community.

Global warming and various local stresses from human activities are of greater concern among coral reef scientists and administrators today. According to Williamson (2008), 19% of the world's coral reefs have been effectively destroyed and show no immediate signs of recovery, and a further 15% are under imminent risk of collapse within 10-20 years. Some scientists warn that if we fail to act to the looming situation soon, almost all coral reefs on the planet will become extinct by the year 2100.

Japan is one of few developed nations with coral reefs in their surrounding waters. The distribution of Japanese coral reefs is restricted mainly to the Ryukyu Islands (including Okinawa) and the Ogasawara Islands, both ranging between 24^{o} N and 30^{o} N. This range is the northern limit of the global coral reef distribution. Some hermatypic coral communities are distributed further north along the Pacific coast, up to the entrance of Tokyo Bay (35^{o} N), owing to the influence of the warm Kuroshio Current (Figure 2). However, similar to coral reefs around the globe, the corals of Okinawa have been on the decline. Coral reefs around these populous islands have become particularly degraded during the last 40 years. In order to prevent the decline of coral reefs, it is imperative that the correct decisions are made, and the right actions are taken.

Figure 2. Coral reefs and zooxantella (Akajima Island).

At present, the environmental condition in Okinawa is not always favorable for coral reefs. After the return of administrative rights over Okinawa to Japan in 1972, coral reefs have been repeatedly damaged by red soil run-off and eutrophication caused by severe soil erosion that accompanies land development projects. An outbreak of the large, coral-eating, crown-of-thorns starfish, *Acanthaster planci*（Linnaeus）in the 1970s once wiped out almost all of the corals on the reefs off Okinawa Island (Figure 3). Additionally, another major outbreak in 2000 extended into the surrounding islands, causing serious damage. The worldwide increase of sea surface temperatures in 1998 (rising above 30 ℃), including the Ryukyu Islands. This caused the temporary or permanent loss of the symbiotic algae (zooxanthellae), leading to a large-scale coral-bleaching event that caused serious deterioration of coral communities.

Figure 3. Crown of thorn starfish predating corals in Okinawa.

Development of coral mass culturing techniques at Akajima Marine Science Laboratory

The primary focus of coral conservation must be the reduction of regional human interference such as sedimentation, pollution, eutrophication, overfishing and indiscreet coastal development to facilitate natural and long-term recovery. Unless chronic stressors are reduced, propagation of corals is retarded and the reefs will continue to degrade. A successful effort will rely on political support, scientific information and stakeholders' opinion. However, if the reduction of chronic stressors is not sufficient or in cases where extensive habitat and natural recruitment sources have been lost, effort should be taken toward reef rehabilitation through improvement of coral habitats as well as underwater silviculture and transplantation approaches.

What can we do to stop corals from dying? Japan, which has been blessed with coral reefs, should play a greater role answering this question through the conservation and rehabilitation of coral reefs. Driven by such aspiration, a small private research institute, the Akajima Marine Science Laboratory (AMSL), was established on Akajima Island, Okinawa in 1988. Since then, AMSL has received international recognition through their research on the ecology, reproduction and evolution of corals. Utilizing the knowledge that they have gained over the years, the laboratory is now developing techniques that assist in the rehabilitation of coral reefs.

Mass spawning of *Acropora* corals occurs in Okinawa near the full moon during early summer nights (Figure 4). Countless sperm/egg bundles are released from the corals into the sea. Aggregates of fertilized coral eggs known as slicks, drift on the water surface following the mass spawning. In order to culture corals, the necessary eggs and embryos may be collected from such slicks. Alternatively, the corals are fertilized in the laboratory by gentle mixing of sperm/egg bundles collected from a number of donor colonies of the same species. The embryos are then bred in a large water tank on land or a floating pond in the sea, where they develop into planula larvae. Four to seven days later, the planulae swim down to the bottom in search for a suitable substratum to settle on.

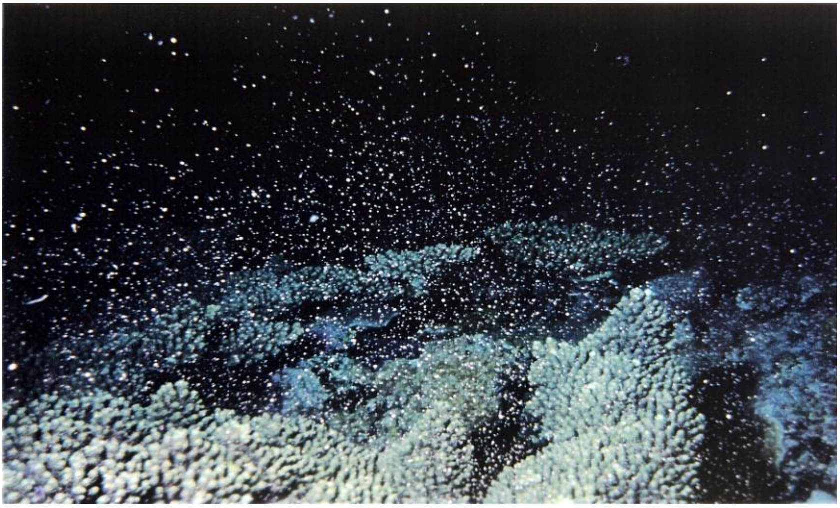

Figure 4. Mass spawning of hermatipic corals at Akajima Island.

The planulae follow special chemical signals emitted by certain bacteria and crustose coralline algae. In other words, they neither settle nor metamorphose into polyps (juvenile corals) on substratum where these organisms are not present. When more than 80% of planulae are competent to settle, artificial larval settlement is conducted in a large water tank in the laboratory or in a mesh enclosure in the sea. The larvae may settle onto the substratum after two nights. It is possible to induce settlement of up to 1000 polyps onto a tile (10 cm x 10 cm) made of concrete or unglazed potter's clay that has been placed in the sea for over one month in order to develop a bacterial biofilm and coralline algae on the surface (Omori 2008). A novel substrate called the "coral peg" (Omori and Iwao 2009) may be used in addition to the square tile.

The polyps, each measuring about one millimeter in diameter, increase in number by producing clones to form a large colony on the substrate. They are cultured in cages suspended at 1.5 to 5.0 m depths in the sea. However, if seaweeds propagated on the tile and deprive the juvenile corals of sunlight, the corals die, resulting in low overall rates of survival. In order to decrease coral mortality, algae-eating juvenile top-shell snail *Trochus niloticus* (Linneus) (5 to 10 mm in shell diameter) were grown together with the juvenile corals. This mixed culture of *Acropora* corals and juvenile top-shell snails in the same cage led to a dramatic reduction in coral mortality. In late 2006, 18 months after fertilization, colonies of *Acropora tenius* (Dana) grew to an average size of 6 cm in diameter (Figure 5). We transplanted 2,000 colonies onto the seabed off Akajima. In June 2009, some of these 4-year-old colonies, as well as 5-year-old ones, had grown to 20-25 cm in diameter and spawned for the first time, showing the possibility of using this technique to assist coral reef rehabilitation. Since then, the mass spawning of the transplanted corals has occurred every year. The colonies are over 30 cm in diameter and many fishes and crustaceans are living in and around the colonies (Figure 6). Furthermore, we were recently successful in producing a second generation of juvenile corals using the eggs and sperm obtained from the transplanted corals.

Figure 5. Eighteen month-old *Acropora tenuis* colonies in cage culture (Omori 2005).

Figure 6. *Acropora tenuis* colonies that cultured from eggs and transplanted at Akajima Island (Courtesy of Akajima Marine Science Laboratory).

Discussion

Rehabilitation of coral reefs has proven difficult, with results lagging in comparison to restoration of other ecosystems such as coastal wetlands and riparian habitats. There is still no guarantee that coral reefs will resume its original function through the present rehabilitation approach. It is depressing to compare the small scales of active rehabilitation projects relative to the worldwide scale of coral reef degradation. There is still much debate among scientists about the effectiveness and value of artificial coral reef rehabilitation.

However, we believe that coral reef rehabilitation efforts should be pursued in the future. In Japan, 67% of the country is forested and nearly 27% is artificially planted forest, an outcome of the people's continuous effort since 500 AD. If we could facilitate coral reef rehabilitation in a few key locations, its cascading effect as neighboring reefs are provided with a new source of eggs and larvae, will lead to a gradual increase in biodiversity over a time scale of years.

Past attempts to rehabilitate coral communities have mainly utilized transplanted coral fragments using asexual propagation, due to its relative ease. However, use of fragments from a limited number of donor colonies may reduce genetic diversity. This is confounded by difficulties in sampling from a large number of coral fragments in areas where coral density is low. Furthermore, if growth and life span of corals are affected by the age of the colonies, as suggested in *Pocillopora damicornis* (Linnaeus) (Permata and Hidaka 2005), selection of young coral fragments for transplantation may add to the problem. Therefore, the present technique by means of sexual propagation can increase genetic diversity in coral communities and while conferring a greater advantage in comparison to asexual propagation.

Silviculture on land has a long history of over 1600 years, but rehabilitation of coral reefs by artificial efforts began after the 1980s. We must learn more from ecological studies on restoration of terrestrial habitats. Science and technology for coral cultivation and transplantation will develop even further and I hope their fruits may help large-scale rehabilitation of coral reefs in the near future.

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