Coral Reefs of Japan

Ministry of the Environment
Japanese Coral Reef Society

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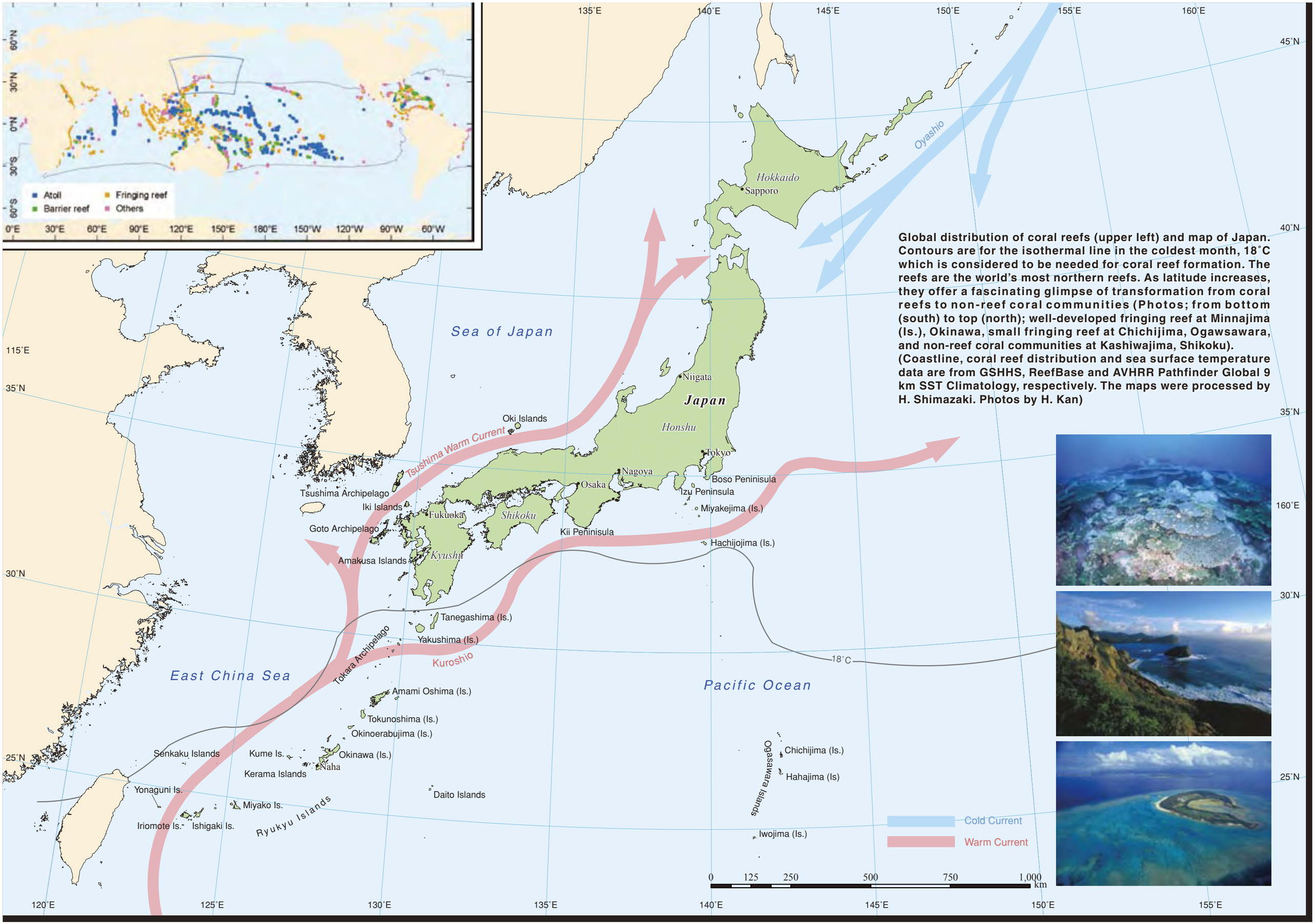

Global distribution of coral reefs (upper left) and map of Japan. Contours are for the isothermal line in the coldest month, 18°C which is considered to be needed for coral reef formation. The reefs are the world's most northern reefs. As latitude increases, they offer a fascinating glimpse of transformation from coral reefs to non-reef coral communities (Photos; from bottom (south) to top (north); well-developed fringing reef at Minnajima (Is.), Okinawa, small fringing reef at Chichijima, Ogawsawara, and non-reef coral communities at Kashiwajima, Shikoku). (Coastline, coral reef distribution and sea surface temperature data are from GSHHS, ReefBase and AVHRR Pathfinder Global 9 km SST Climatology, respectively. The maps were processed by H. Shimazaki. Photos by H. Kan)

Coral Reefs of Japan

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Foreword

The sea that surrounds the islands of Japan, an archipelago of some 3,000 kilometers along the eastern edge of the Eurasian continent, encompasses a tremendous range of conditions, with sea ice in its northernmost regions and one of the world's most famous warm currents, the Kuroshio, running through its southern end. The Kuroshio Current is what makes possible coral in these waters. Despite being the northernmost range of coral in the world, the coral reefs which extend south from the Tokara archipelago in the southern part of Japan are particularly renowned for their great diversity in coral species as well as for their beauty.

Coral reefs attract a variety of living creatures, including coral, fish, and benthic organisms, among others. Their workings create a veritable tapestry of complex and rich ecosystems that rival those of rainforests. People living on waters with coral reefs have used the rich resources of the ocean wisely for generations and generations.

In recent years, the number of people taking part in diving has increased, making coral reefs things of interest to many people. Yet at the same time, coral reefs are endangered by landfills, soil flows from the nearby continent, and extraordinary explosions in the populations of crown-of-thorns starfish, among other threats.

In order to preserve the coral reefs, the Ministry of the Environment established in 1970 a marine park system within the national park system and has been working to capture crown-of-thorns starfish for many years. In addition, in 1994, in conjunction with other relevant nations, Japan helped to establish the International Coral Reef Initiative (ICRI), and Japan has been advancing its efforts actively both domestically and abroad with regard to coral reef monitoring and restoration, public awareness, and capacity building.

"Coral Reefs of Japan" has been published on the occasion of the 10th International Coral Reef Symposium through the cooperative efforts of researchers from the Japanese Coral Reef Society and others. It introduces to people both in Japan and around the world the coral reefs of Japan and the current state of Japan's efforts to protect them.

I extend my personal thanks to the many people who worked to make this publication possible.

I very much hope that this book provides insights to the many people around the world who are interested in the protection of coral reefs and hope that it assists in promoting the protection of coral reefs and their sustainable use.

Yuriko Koike
Minister of the Environment

Preface

Objectives and backgrounds

Coral reefs, including non-reefal hermatypic coral communities, are distributed over almost entire southern half of the coast line of the territory in Japan. In spite of this, most Japanese people are not aware of this fact and have been caught by an illusion that coral reefs belong to more tropical areas. Even Japanese scientists seemed to have believed the same way until recent and thought that coral reef studies could be performed only in the mandated territory of Micronesia and overseas territory of Taiwan. For this reason, when these territories were lost after World War II, they thought that they could no longer carry out coral reef research. This caused a blank period of over 30 years and not a single textbook on the Japanese coral reefs published after even nearly 60 years from the end of World War II. Under such a context, the 10th International Coral Reef Symposium (ICRS) was held on Okinawa where it is the central coral reef distributed area in the country. Taking this perfect opportunity, this book was published by the Ministry of the Environment, government of Japan and the working group which mostly consisted of members of the JCRS (Japanese Coral Reef Society). The primary purpose of this book is to introduce the Japanese coral reefs to both home and abroad. I also expect this book to serve as a good textbook for the better understanding of Japanese coral reefs.

History of research on the Japanese coral reefs

The history of coral reef research by Japanese scientists can be traced to early 1930s. These early researches, made between 1930s and the end of World War II (1945) are almost exclusively made on the coral reefs of the oversea territories, and only few studies were in the home territory.

In 1950, the University of the Ryukyus was established on Okinawa and studies on the coral reefs of the Ryukyu Islands started. But it was only after the administrations of the Amami Archipelago (1963) and the Okinawa Islands (1972) were returned to Japan when the reefs of these islands became fully accessible to the Japanese scientists. Since then, particularly after the last half of 1970s, the coral reef researches became very active.

The Japanese Coral Reef Society

In 1980s, many Japanese coral reef scientists started to express their desire to organize some research organization. JCRS was established in November 1997 with the initiatives of those who attended the 8th ICRS in Panama. The JCRS started with 220 members at the time of establishment and has now increased to 399 (as of May 2004). The fields of specialization of the members are various including; biology and fisheries (144 members), environment and conservation (122), geology and geomorphology (72), sociology and humanity (21), and others (40). Through establishment of domestic organization and expansion of coral reef research in Japan, it was successfully achieved to get nominated to host the 10th ICRS in Okinawa, which had been one of the objectives for the establishment of the JCRS.

Distribution of coral reefs in Japan

The distribution of major coral reefs is now restricted mainly to the Ryukyu Islands (Okinawa and Kagoshima prefectures) and the Ogasawara Islands (Bonin Islands, Metropolis of Tokyo), both ranging between 24°N and 30° N. This range is the northern limit of the World coral reef distribution. In addition, smaller scale coral reefs are found in Senkaku Islands, Daito Islands, Iwojima

(Is.), Minamitorishima (Marcus) (Is.) and Okinotorishima (Parece Vela) (Is.). Okinotorishima (20°N) is the southernmost coral reef in Japan. The northernmost coral reefs in Ryukyu Islands are found at Tanegashima (30° 43' N) (Nakai 1990) in Kagoshima Prefecture and non-reefal herlmatypic coral communities are distributed beyond north of Tanegashima except at Iki Islands (33° 48′ N) in Nagasaki Prefecture where the highest-latitude coral reef was discovered recently (Yamano *et al.* 2001). These High-latitude coral communities along the Pacific coast can be seen up to Tateyama Bay (35°N) (Nishihira and Veron 1995) which is located at the entrance of Tokyo Bay, owing to the influence of warm Kuroshio Current. These high-latitude non-reefal communities do not develop coral reefs but have similar function and characteristics as coral communities on coral reefs. Therefore, we also included them in this book.

According to Veron (1992), the coral fauna of Japan (400 species) is essentially similar to that of the Philippines (414 species.), which is situated in the center of coral distribution in the West Pacific. Moreover, community structure of the coral reefs of Ishigaki Island, one of the southernmost islands of the Ryukyu Islands, is also similar to those of the central West Pacific (Nakamori 1986).

The characteristics of the Japanese coral reefs

Most of the Japanese coral reefs are the fringing type while Daito Islands are the raised atolls. The deep bore hole made at Kitadaito Island by H. Yabe and his group proved that the reef limestone accumulated over 432 m in thickness and was assigned to the period from lower Miocene to upper Oligocene (Aquitanian to Chattian) (Hanzawa 1941). This showed that the coral reefs on Daito Islands are different in origin from those of the Ryukyu Islands. The ages of the recent coral reefs were 7,000 years in Kume Island (Kan *et al.* 1991) and 8,000 years in Kikaijima (Konishi 1980) both belonging to Holocene in origin.

Coral reef degradation

The Japanese coral reefs are facing with various disturbances both natural and anthropogenic causes in recent years. Accordingly, subjects such as disturbance, monitoring, conservation, restoration, and related legal laws on conservation are dealt as important subjects in this book. The major degrading factors of coral reefs in Japan are reclamation of coastal areas, construction of shore protection and roads, terrestrial outflow of soils, crown-of-thorns starfish (*Acanthaster planci*) outbreak, and mass coral bleaching event due to recent high water temperature trends.

On Okinawa, the first recorded outbreak of *A. planci* occurred in 1969, and by 1980s, the whole coastline of Okinawa Island experienced devastation of coral communities. While the outbreak seemed to be terminated in 1990s, it again occurred at many locations in 2000. The first recorded coral bleaching event took place in Okinawa in 1980, and it had occurred almost in every El Niño years subsequently. The most extensive bleaching event took place in 1998, when a high seawater temperature of 31°C extended as deep as 50 m, many corals bleached and died out from the surface to this depth. The mean live coral coverage decreased to 18 % on Okinawa Island, 8 % on Kume Island, and 62 % on Kerama Islands after this event, indicated large variation among islands (Research Institute for Subtropics 1999).

Conservation and recovery of coral reefs

One of the most effective ways to protect coral reef communities and restore from damages is said to establish marine protected areas. The Japanese Government established marine park zones inside the national parks and quasi-national parks at coastal areas including coral reef areas. These parks have been effective in protecting coral communities from various direct human impacts, but not for the *A. planci* predation and bleaching event.

National and local governments have been conducting extermination of *A. planci* for long time in and near the marine parks. These activities have been effective in removing particular starfish populations, but have not functioned as complete control. The effective countermeasures to control the starfish population are expected to be developed by the new projects supported by national and local government. For controlling coral bleaching, one effective measure must be to establish a larger marine park zones in which a variety of habitats with different sets of environmental factors are included. Among different habitats, there may be some favorable factors for preventing bleaching.

Okinawa Prefecture has established regulations which prohibit collection of corals and controls discharges of sediments to the sea. These are expected to conserve coral reefs on Okinawa. Coral communities can be artificially rehabilitated by culturing the seedlings produced from larvae and transplanting parts of the stock colonies. However, there remains possibility of genetic disturbances and these techniques should not be practiced unless there is no possibility for natural recovery.

The national government has formulated the 'Law for the Promotion of Nature Restoration' in 2003 which is to promote recovery of lost natural environments. Under this law, national government is initiating a coral reef recovery project in the Yaeyama Archipelago. The success of this project is highly expected.

Last remarks

This book gives the first comprehensive description of the Japanese coral reefs including above mentioned disciplines, such as; biology, geology, geomorphology, physico-chemistry and socieology. I truly hope this book will afford a clue to readers a better understanding on Japanese coral reefs, and contribute to succeed beautiful coral reefs to the future generations.

Kiyoshi Yamazato
President of the Japanese Coral Reef Society

Table of Contents

Preface 4

1 **Distribution of coral reefs** 9

1 - 1 Hermatypic corals of Japan 10
1 - 2 Coral reef landforms in Japan 14
1 - 3 Distribution of coral reef communities 23

2 **Coral reef disturbances** 41

2 - 1 Global environmental change and coral bleaching 42
2 - 2 Predation damage to corals 49
2 - 3 Coral diseases 56
2 - 4 Direct impacts of coastal development 60
2 - 5 Terrestrial inflow of soils and nutrients 64
2 - 6 Inappropriate activities around coral reefs 69
Coral reef degradation and sustainable use in the Yaeyama Archipelago, Okinawa: A Study of Lift-Net Fishery and Fishermen's Perspectives and Opinions

3 **Coral reef monitoring** 77

3 - 1 Coral monitoring in Japan 78
3 - 2 Remote sensing of coral reefs in Japan 89

4 **Sustainable use and conservation of coral reefs** 105

4 - 1 Coral reef conservation and management in Japan 106
4 - 2 Legal systems 110
4 - 3 Environmental education related to coral reefs 113
4 - 4 Fishery 117
4 - 5 Tourism 122
4 - 6 International cooperation 129

5 Coral reef restoration 137

5 - 1 Restoration techniques 138
5 - 2 Approaches for restoring coral reef ecosystems 146

6 Status of coral reefs around the country ... 153

6 - 1 - 1 Ogasawara Islands 158
6 - 1 - 2 Osumi Islands and Tokara Archipelago 164
6 - 1 - 3 Amami Archipelago 170
6 - 1 - 4 Okinawa Islands 178
6 - 1 - 5 Daito Islands 198
6 - 1 - 6 Miyako Archipelago 202
6 - 1 - 7 Yaeyama Archipelago 210
6 - 2 - 1 Boso Peninsula, Izu Peninsula and Izu Islands 230
6 - 2 - 2 Sea of Japan 240
6 - 2 - 3 Kii Peninsula 250
6 - 2 - 4 Shikoku 258
6 - 2 - 5 Kyushu 270

Appendix 287

Appendix 1 Related statistic data of coral area
- 1 - 1 Meteorological Data
- 1 - 2 Population and Number of Households
- 1 - 3 Number of employed in each industry
- 1 - 4 Number of tourists visited
- 1 - 5 Fishery Statistics
- 1 - 6 Protected Areas
- 1 - 7 Additional information on the Daito Islands and Sea of Japan

Appendix 2 The 5th National Survey on the Environment
Appendix 3 Spot Check method for coral reef survey
Appendix 4 A list of Hermatypic corals in Japan
Appendix 5 Japanese Organizations related to coral reef study and conservation
Appendix 6 Cited References
Appendix 7 Authors

Column

Coral reefs on the border 20
Unique genetic properties of acroporids 40
Toward the revival of Miyakejima after the latest volcanic eruption 103
Spawning behavior of brooders 134
Mass spawning of acroporids 150
Living on coral reef atolls - Human induced vegetation changes 176
Coral reef development near cities 194
Folkcraft of Okinawan coral reefs 196
Geographical features and use of Ryukyu limestone 209
A glimpse of coral reef studies in pre-westernized Japan 282
Reef Check in Japan 284
International Coral Reef Research and Monitoring Center —For conservation of coral reefs in Japan and the world ... 286

Chapter 1

Distribution of coral reefs

Coral reefs are characterized by its beautiful spectacle, where tropical fishes swim around on colorful corals in crystal-clear waters shining in emerald blue. This wonderland is created, taking long-long period, by innumerable living organisms that inhabits on the reefs as their home. Japanese Archipelago stretches long from southwest to northeast resulting to have well developed coral reefs at south and non-reefal coral communities at higher latitudes. These habitats express various different characteristics which never disinterests us. This chapter introduces such characteristics in coral fauna and geological formation of coral reefs including non-reefal coral communities in Japan, and further takes a close look on the wonderland of organisms on the reefs.

1-1 Hermatypic corals of Japan

Moritaka Nishihira

1 Introduction

There are ~800 species and ~110 genera of hermatypic (zooxanthellate) corals, mostly within the Order Scleractinia. In addition to members of this order, zooxanthellate corals include single monospecific genera of Order Coenothecalia and Order Stolonifera, plus ~10 species of the single genus of Order Milleporina. Scleractinian corals are widely distributed from tropical to boreal regions, whereas the other three groups are mostly restricted to low-latitude coral reef environments.

The taxonomy and biogeography of Japanese coral fauna have been clarified by extensive, intensive field studies by Veron (1992, 2000). Only a general account of corals of Japanese waters will be given here, concentrating mainly on species from coral reef areas. We follow the taxonomic classifications of Veron (1992, 2000) and Nishihira and Veron (1995). For more details, please refer to these publications.

2 High species diversity and biogeographic distribution

Japanese seas range from sub-tropical to temperate regions. The south-western half of the total area includes the Ryukyu Islands. The Ryukyu Islands are further divided into three major groups of islands, the South Ryukyus (the Yaeyama and Miyako islands), the Middle Ryukyus (the Okinawa and Amami islands), and the North Ryukyus (the Tokara Archipelago). Especially in the South and Middle Ryukyus, there are well developed coral reefs that support high coral species diversity. Although coral reefs are not developed in the area north of the Satsunan Islands, towards the central Japanese mainland, well-developed coral communities are observed in these areas. Further north, from the Izu Peninsula to Tateyama in Tokyo Bay, only low diversity coral communities occur. Coral communities in these three areas may be called coral reef communities, non-reefal communities, and outlying communities (Veron, 2000).

Although Japanese coral fauna has not been fully elucidated, ~380 species are estimated to occur in the Yaeyama Archipelago, ~340 in the Okinawa Islands, ~220 in the Amami Archipelago, ~150 in the area from Tanegashima Island to Shikoku Island, ~100 from Kyushu Island to the Kii Peninsula in middle Japan, and ~25–40 species in the Izu Peninsula and Tokyo Bay areas. Veron (2000) added ~35 species to the Japanese fauna. Including these species, the total number of Japanese corals may be estimated at ~415 species for coral reef areas (from the Yaeyama Archipelago to the Amami Archipelago), ~200 species for non-reefal communities (from Tanegashima to the Kii Peninsula), and ~55 species for outlying coral communities (from Izu Peninsula to Tokyo Bay).

This species richness may change, depending on future field studies in various areas or following future taxonomic reviews. At present, we may say that the Japanese coral fauna consists of ~415 scleractinian species belonging to 78 genera, plus ~10 species of three non-scleractinian genera. These figures show that despite their high latitudes, Japanese waters support a high diversity of coral fauna. Of 78 scleractinian genera, 28 are mono-specific, while nine genera include more than 10 species. The genus *Acropora* is most speciose (82 species), followed by *Montipora* (38), *Porites* (25), *Favia* (16) and *Fungia* (15).

Japanese corals show a distinct latitudinal pattern to their biogeographic distribution. Species richness is highest in the coral reef areas of the Ryukyu Islands, and it decreases in a northward direction. In the Ryukyu Islands, the southernmost Yaeyama Archipelago support the richest fauna. This observed high species richness may be attributed to their location and geography.

The Ryukyus consist of many islands scattered over a wide area, far from the mainland coast of China, and thus clear of turbid terrestrial waters. In the South and Middle Ryukyus, relatively large islands are found, with rivers and long, irregular coastlines that create diverse habitats in shallow coastal waters. Northward reductions in coral biodiversity occur through the gradual differential disappearance of low-latitude species, not by displacement of tropical fauna with subtropical and temperate coral species. The northward latitudinal decrease in coral species' richness through the Ryukyu Islands and along the Pacific coast of the Japanese mainland occurs in parallel with a negative gradient in surface sea water temperatures (upstream to downstream in the north-flowing Kuroshio Current). The Kuroshio Current is considered to be the most important factor producing the high species richness of Japanese coral fauna.

3 Characteristic corals

Wide-ranging distributions (from the Ryukyu Islands to the central Japanese mainland) are known for ~45 species of coral, while ~230 species are restricted to coral reef areas. *Acropora tanegashimensis* (Photo. 1) and four other species occur only in non-reefal temperate waters. About 130 species have been reported from non-reefal to coral reef areas, but are not known to occur in temperate outlying communities. *Alveopora japonica*, *Acropora japonica* and *Acropora pruinosa* have not been identified from coral reef areas.

Some species have interesting distributions, including discontinuous distributions in some wide-ranging species. *Catalaphyllia jardinei* (Photo. 2) is found in temperate Japan and tropical areas, yet it has not been identified around the Ryukyu Islands. *Porites heronensis* has been reported from Australian waters and the Japanese mainland, but not from the Ryukyu Islands.

Currently, corals thought to be endemic to Japan include *Euphyllia paraglabrescens* (Photo. 3), *Acropora tanegashimensis* (both endemic to Tanegashima Island) and *Porites okinawensis*. *Alveopora japonica* has been reported from the Japanese mainland and Korean waters, but not from the Ryukyu Islands.

Among those corals that have been reported as being restricted to Japanese waters are many species that have been identified in the more southern seas, such as around the Philippines. *Boninastrea boninensis*, once thought to be endemic to the Ogasawara Islands, is now recognized as being widely distributed in the Philippines. *Leptoseris amitoriensis* (Photo. 4) has been regarded, in the past, as endemic to Iriomote Island, but is now known

Photo.1. *Acropora tanegashimensis* (Tanegashima Is., Kagoshima).

Photo. 2. *Catalaphyllia jardeni* (Kushimoto, Wakayama).

Photo. 3. *Euphyllia paraglabrescens* (Tanegashima Is., Kagoshima).

Photo. 4. *Leptoseris amitoriensis* (Photo by H. Yokochi, Iriomote Is., Okinawa).

Photo. 5. *Goniopora cellulosa* (Tanegashima Is., Kagoshima).

Photo. 6. *Goniastrea deformis* (Shirahama, Wakayama).

to be distributed across a wide range of locations to the south of Japan. In Philippine field surveys, Licuanan and Capilli (2003) found *Goniopora cellulosa* (Photo. 5), *Goniastrea deformis* (Photo. 6), and *Hydnophora bonsai*, which had all previously been reported only around the Amami Archipelago and northern non-reefal areas of Japan. *Madracis kirbyi* had been reported from the Ogasawara Islands, but subsequently was also found in the Ryukyu Islands. It is likely that more range extensions will occur with further species identification in the Ryukyu Islands. As these examples illustrate, it is safe to say that other species will be added to the Japanese coral fauna inventory in the future.

4 Further studies

Japanese coral fauna has been clarified by a series of studies conducted at certain localities by Veron (1992, 2000) and by others, but further intensive fieldwork at other locations is needed if the area's biodiversity and biogeography are to be understood. For example, further detailed study has shown that *Madracis asanoi* does not harbor zooxanthellae; therefore, the species should not be listed amongst Japan's zooxanthellate coral fauna. In the Ryukyu Islands, unexpectedly abundant populations of *Heterocyathus aequicostatus* (Photo. 7) have been observed growing on soft bottoms at >10 m depth. Close examination of the reef flat off Iriomote Island revealed the world's smallest sessile colonial zooxanthellate coral, *Stylaraea punctata* (Photo. 8). In this way, future detailed studies are expected to add more species to the catalogue of Japanese fauna. In addition, future detailed taxonomic and systematic studies may change the rational treatment of species. Veron (2000) tentatively established many new species, or split single species in two.

Corals have been identified using traditional methodologies based on skeletal morphology, as well as by the morphological characteristics of their soft tissues, using ecological, behavioral, and reproductive features. Modern genetic approaches have also proved useful for species recognition and for gauging variations within and between local populations. Many species show discontinuous geographical distributions and/or local variations in key morphological characters. Comparative studies of corals between different habitats (coral reef areas and the Japanese mainland, or the Ryukyu Islands and other tropical coral reef areas) are likely to be productive in this regard.

Insufficient field studies have been conducted in the Ryukyu Islands, especially in the Miyako and Amami Archipelago. Particularly necessary are studies of *Acropora*, *Montipora*, and species that are difficult to identify. Field studies of coral communities off the

Japanese mainland have mostly concentrated on the Pacific coast. Extensive studies are needed in areas along the coast of the Sea of Japan. Information about this coral fauna is quite limited, but in terms of coral species, the coastline of the Sea of Japan appears less rich than that of the Pacific coast.

5 Importance of diversified habitat

Corals are vulnerable to various disturbance agents, and coral communities, especially in coral reef areas, have been seriously damaged. Coral communities may be degraded through mass predation, bleaching, and environmental destruction. Since the early 1970s, mass mortality of corals has been caused by intermittent outbreak populations of the crown-of-thorns starfish, *Acanthaster planci*. Outbreaks of this starfish remain a localized threat to coral communities. The 1998 mass bleaching events have so far been the most wide-ranging disturbance for corals and coral reefs in Japan. Red soil runoff, derived from erosion of terrestrial development sites, causes continuous environmental pollution. Many local coral communities have disappeared owing to nearby local construction work.

In many places, a drastic decrease in living coral coverage has occurred. While, in general, this trend continues, some places do show signs of recovery. There is no information about the number of species that have become locally extinct or vanished entirely from Japanese waters. Special attention should be focussed on rare species, those species that are restricted to a particular habitat, and species with low growth rates and/or low reproductive potential.

Diversified habitats occur repeatedly, due to the complex coastal and underwater geomorphology. Wave exposure and turbidity conditions change with other environmental gradients from the tip of a cape to a bay bottom, or from windward to leeward locations. Light and water movement vary with depth, and substrates may change from rocks to mud. All of these abiotic factors are important for coral distribution. For the long-lasting maintenance of coral diversity, it is important to maintain this variety of habitats in a healthy condition, free from pollution and mechanical disturbance. *Oulastrea crispata*, *Pseudosiderastrea tayamai*, *Heteropsammia cochlea*, *Heterocyathus aequicostatus*, *Diaseris distorta* (Photo. 9), and *D. fragilis* inhabit muddy or sandy bottoms. Minimization of environmental disturbance and legal protection of various habitats is important if the high diversity of Japanese coral fauna is to be saved. This is fundamental for the conservation of coral reef communities, as well as for that of the many organisms that are directly or indirectly dependent on corals and coral communities.

Photo. 7. *Heterocyathus aequicostatus* (Okinawa Is., Okinawa).

Photo. 8. *Stylaraea punctata* (Iriomote Is., Okinawa).

Photo. 9. *Diaseris distorta* (Okinawa Is., Okinawa).

1-2 Coral reef landforms in Japan

Hajime Kayanne, Chuki Hongo, Hiroya Yamano

1 Introduction

The landform represented by a coral reef is defined as 'a breakwater structure formed by corals and other calcifying organisms, with its surface reaching sea level (Yasugi *et al*. 1996)'. Coral reefs are present in the Ryukyu Islands from latitudes 24° to 31° N, and in the Ogasawara Islands south of 27° N. Most are 'fringing' reefs, with their reef-flats attached directly to the islands' shorelines. From a global perspective, these buildups occupy what is defined, on the basis of sea surface temperature (SST) gradients, as a marginal zone for reef growth. Kyushu, Shikoku and southern Honshu are located in non-reef-building areas; coral communities are present, but do not form reefal buildups. Coral patch reefs were recently discovered in the Iki Islands, at 33° 45' N (Yamano *et al*. 2001c), although no coral reefs are known to exist between these islands and Tanegashima (Is.) (30°30' N), formerly regarded as the northern limit of coral reefs.

Coral reefs about 1 km wide fringe the coastlines of the Ryukyu Islands, south of 27° N. In the Ryukyu and Ogasawara islands, between 27° and 31° N, reef distribution is patchy and reef flats become narrower to the north. The Ryukyu Islands are located in the Kuroshio Current, in a monsoon region, and are frequently affected by typhoons, all of which are well known to affect reef formation and distribution.

This chapter presents an overview of the geological, tectonic, meteorological, and oceanographic factors that constrain coral reef formation, as well as a summary of reef zonation, its development, and its geographical variation, in addition to a discussion of the importance of these factors, including the intrinsic characteristics of coral reefs, in planning coral reef preservation and management.

2 Geographical background of coral reef formation

1. Geology and tectonics

Japan is an active volcanic island arc, located along the subduction zone of the Pacific plate. In the southern half of the country (southern Honshu, Shikoku, Kyushu and the Ryukyu Islands), the Philippine Sea plate, formed by back-arc opening of the Izu-Ogasawara arc (Fig. 1), is currently being subducted. The Nansei Islands (Southwest Islands), at the southwestern limit of the Japanese Archipelago, are divided into the Satsunan Islands in the north and the Ryukyu Islands in the south, but in common practice, and in this book, the whole island group is called the Ryukyu Islands.

The Ryukyu Trench, Ryukyu Islands, and Okinawa Trough parallel the boundary of the Philippine Sea

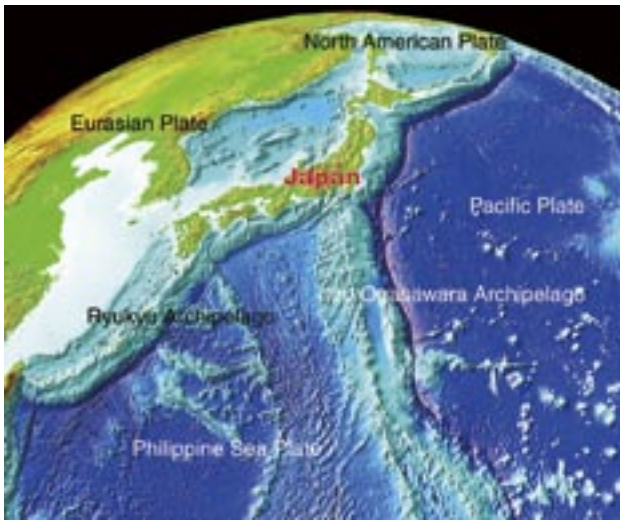


Fig. 1. Japan and surrounding ocean area.
Provided by Hydrographic and Oceanographic Department, Japan Coast Guard.

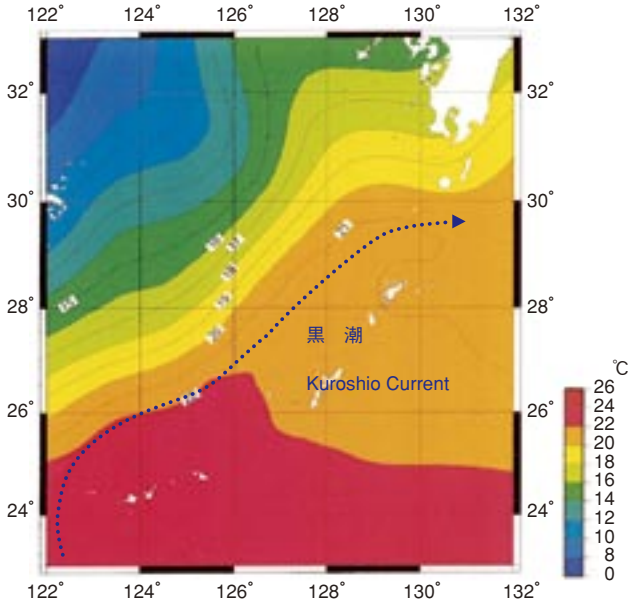


Fig. 2. Distribution of sea surface temperatures (SSTs) in February and the Kuroshio Current flow path in the Ryukyu Islands (from the Oceanographic Normals and Analyses for the period 1971-2000, Japan Meteorological Agency).

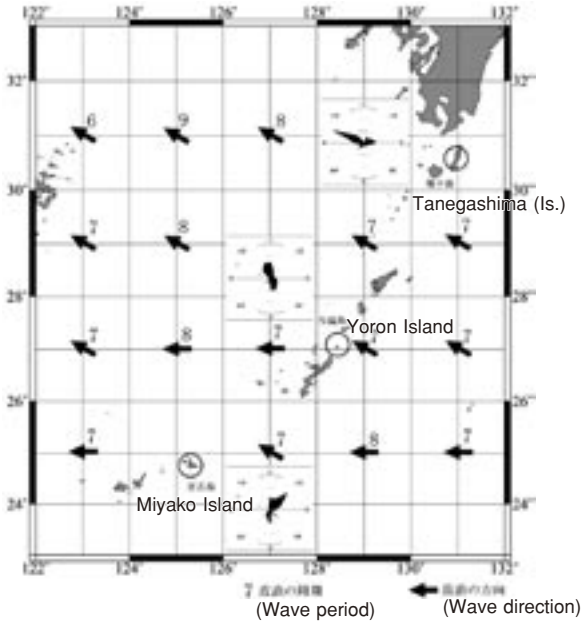


Fig. 3. Mean wind rose and wave direction around the Ryukyu Islands.
The synoptic wave chart was figured in reference to the mean synoptic wave chart in 2002 from the Japan Meteorological Agency website (http://www.data.kishou.go.jp/marine/wave/chart/mean/jpmean/html). The wind rose was drawn with reference to the wind direction of the mean daily maximum wind speed in 2002 from the Electronic Reading Room of the Japan Meteorological Agency (http://www.data.kishou.go.jp/).

plate. The Izu-Ogasawara trench, Izu-Ogasawara arc, and Ogasawara Trough are parallel to the boundary of the Pacific plate. Coral reefs are present on the islands of Minamidaitojima and Kitadaitojima (raised atolls), Okidaitojima (a raised table reef), and Okinotorishima (a table reef), which are located on ridges on the Philippine Sea plate. They are also present on Minamitorishima (a table reef) on the Pacific plate.

Prior to the Pliocene, the Ryukyu Islands constituted the locus of terrigenous mud deposition (now the Shimajiri Group) at the margin of the Asian continent. The Okinawa Trough began to form about 10 million years ago, and has been subsiding conspicuously for the past 2 million years (Kimura 1985). As a result, the Ryukyu Islands became separated from the continent, and deposition of calcareous sediment began, creating what is now known as the Ryukyu Group (Nakamori *et al.* 1995; Iryu *et al.* 1998).

Uplift over the past several hundreds of thousands of years has resulted in the raising of coral reef terraces. Terraces that formed in the Last Interglacial, 120,000 years ago, are now located at altitudes of 220 m above sea level on Kikaijima (Is.), 35 m on Hateruma Island, and 24 m on Yonaguni Island (Ota and Omura 1992). Uplift continued in the Holocene (until a few thousand years ago), such that comparatively young raised coral reefs (a few thousand years old) are also present on many islands (Koba *et al.* 1982).

The Ryukyu Islands consists of three types of island: 'low islands' that are overlain with coral reef terraces; 'high islands', where the Shimajiri Group is exposed (Mezaki 1995); and 'volcanic islands'. Reef characteristics, outflow characteristics of precipitation, soil type, and land-use vary, according to the island type.

2. Climate and Oceanography

Sea surface temperatures (SSTs) decrease to the north with latitude. The SST in the coldest month is 24℃ in the Yaeyama Archipelago and 19℃ in the Satsunan Islands (Fig. 2). The Kuroshio Warm Current flows along the Ryukyu Islands, raising SSTs to higher than

in other regions at the same latitude, and supplies coral larvae from a more southern core zone of reef development. It is because of this that the Ryukyu Islands maintains high coral diversity and well-developed coral reefs.

The Ryukyu Islands is situated in an Asian monsoon region, with southern winds predominating in summer and stronger northern winds during winter (Fig. 3). The island group faces the open ocean to the east, from which direction it receives major ocean swells. Typhoons, with wind speeds commonly over 30 m/sec, pass through the islands, on average, seven times per year (Yamano *et al.* 2000).

3 Characteristics of coral reef landforms in Japan

1. Zonation

Coral reefs in the Ryukyu Islands typically have a reef flat just below sea level, and a reef slope seaward of the reef flat (Fig. 4). These areas are separated by a breaker zone that separates the calmer landward environment from the open ocean on the seaward side (Photo. 1). The reef flat is generally a level surface, but many have a seaward rise, called the reef crest, with a shallow landward depression 1 to 3 m deep, called a moat. The reef slope, extending from the reef crest down to a depth of 20 m, consists of parallel ridges perpendicular to the coastline, which are called spurs and grooves (Photo. 2). Below a depth of 20 m, a steeper slope descends to a depth of 50 m, below which the gentler slope of the island shelf extends (Fig. 5, Photo. 3).

The use of coral reef geomorphological terms is confounded by the fact that researchers commonly use different words for a single phenomenon; this, in turn, hinders effective communication, management, and preservation. This work employs the following standard usage: the reef flat and reef slope are first-order geomorphological units; the reef-flat can be subdivided into the reef crest and (back-reef) moat, and the reef slope can be subdivided into the spurs and grooves and outer slope (Fig. 4).

2. Formation process

Extensive shallow drilling research, investigations of raised reefs on land, and comprehensive soundings in the Ryukyu Islands have illuminated the process by which coral reefs have formed in this region (Konishi *et al.* 1983; Takahashi *et al.* 1988; Kan and Hori 1993; Yonekura *et al.* 1994; Kan *et al.* 1995, 1997; Yamano *et al.* 2001a, 2001b). Like coral reefs in other parts of the world, reefs in Japan grew during the postglacial rise in relative sea-levels, and ensuing still stand. Sea-levels dropped to 130-140 m below the present level in the last glacial maximum, 20,000 years B.P. During deglaciation, sea-levels rose rapidly, up until 6,000 years ago, at a rate of approximately 1 m/100 years, but with a brief still stand at about 50 m depth, 12,000 years ago (Fairbanks 1989; Chappell and Polach 1991).

Coral reefs formed in response to relative sea-level rises. In the tropics, some coral reefs started to form when the local sea-level was 120-140 m below the present level, but in the Ryukyu Islands, no coral reefs are present below 50 m (Hori and Kayanne 2000). In the Ryukyu Islands, coral reef growth began about 10,000 years B.P., before which time the SST in the region had not reached the critical average temperature of 18 ℃. Formation of all reefs between 27° and 21°N began at 50 m depth, which records reef formation that postdated the still stand in relative sea-level rise at 10,000 years B.P.

From 10,000 to 6,000 years B.P., coral reefs were in catch-up mode with a rapidly rising sea-level. Reef facies during this stage consisted of *in situ* massive and branching corals, and interstitial coral rubbles that formed a bank 5 m below sea-level. The first parts of the reefs to reach sea level were the reef crests. Their robust framework consists of branching *Acropora* (e.g., *A. digitifera* and *A. gemmifera*) that accumulate at a rate of 0.1 to 0.4 m/100 years. The emergence of the reef crest effected a division of the fringing reef into landward and seaward zones, and was accompanied by development of the backreef, or back-reef moat, in which coral and foraminiferal debris accumulated (Yamano *et al.* 2001a; Fig. 6). Just landward of the reef crest, an accumulation of coral rubbles formed a mound called the reef pavement (Yonekura *et al.* 1994).

In the Ryukyu Islands, postglacial coral reefs were commonly tectonically uplifted into the subaerial realm. Where uplift exceeded tidal range (e.g., Kikaijima), large parts of reefs became emergent, new coral reefs developed atop the spurs of the uplifted reef, and the locus of reef growth migrated seaward, relative to zonation of the underlying reef. Where the scale of

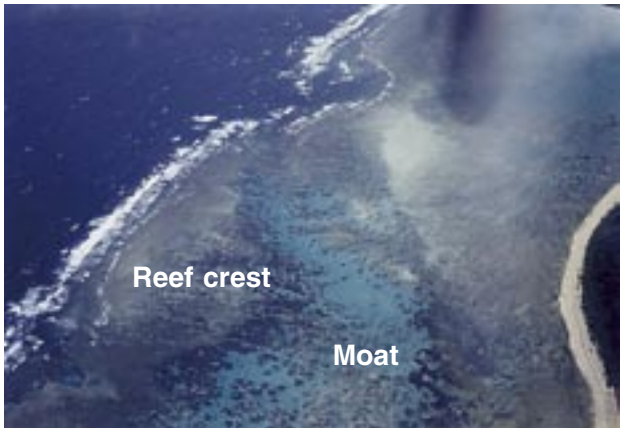


Photo. 1. Typical constitution of fringing reef zonation.

Photo. 2. Spur and groove systems at 5 m depth on northeastern part of Yoron Island.

Photo. 3. Inner break point at 52m depth on the south of Yoron Island.

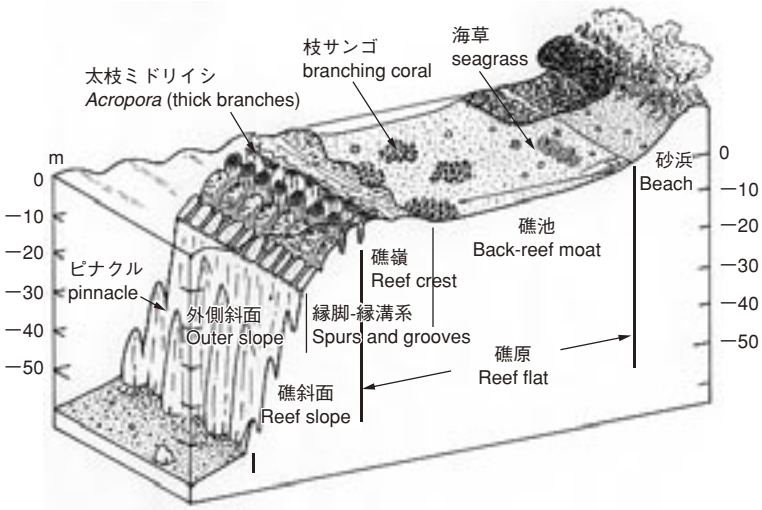


Fig. 4. Constitution of coral reef zonation. Reef crest and moat at Shiraho, Ishigaki Island.

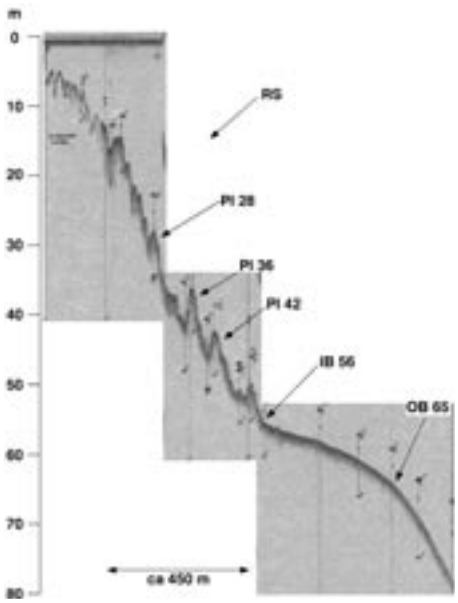


Fig. 5. Echo-sound profile of reef slope topography at the offing of Hirakubo, northern tip of Ishigaki Island (from Hori and Kayanne 2000).
RS: Reef Slope, PI: Pinnacle, IB: Inner Break, OB: Outer Break. Numbers represent depths (m).

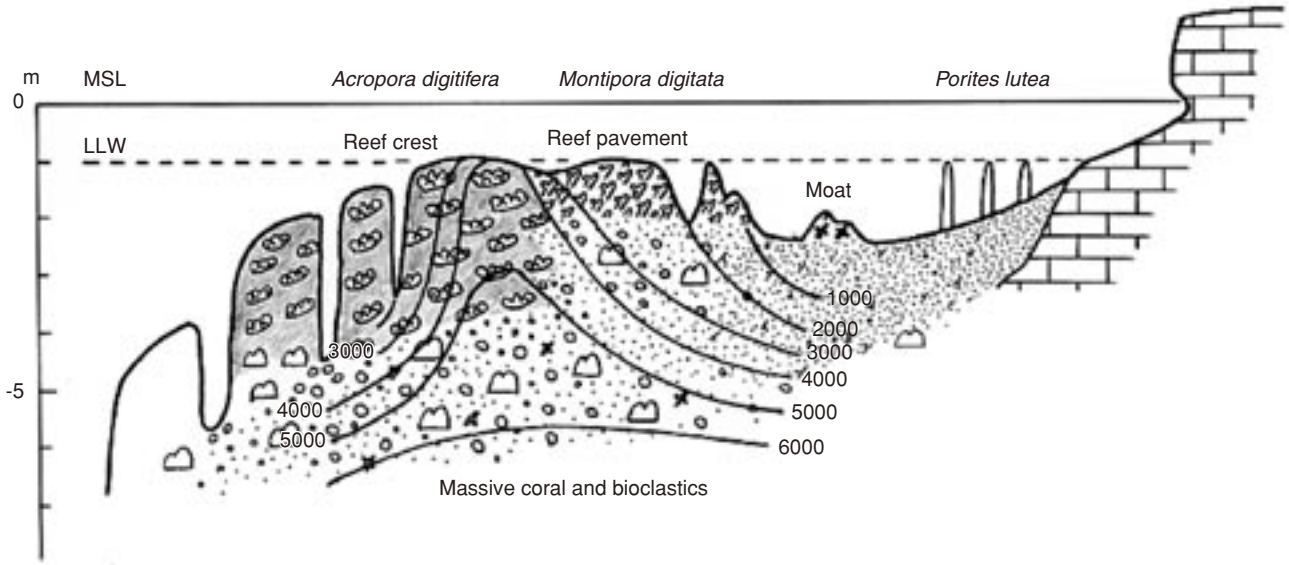


Fig. 6. Schematic diagram of formation process of a fringing reef in the Ryukyu Islands (modified from Yonekura *et al.* 1994; Kan *et al.* 1997; Yamano *et al.* 2001a). 1000-6000: cross section at 1000-6000 years ago.

uplift was less than the local tidal range (e.g., Shiraho Reef at Ishigakijima Island), the surface of the reef crest remained below high-water level, and the location of reef zones remained unchanged, but corals no longer lived on the subaerially exposed rock of the reef crest. In such locations, exposure of the reef crest during low tide limits the mixing of water between the open ocean and the reef flat.

3. Geographical variation

Coral reefs throughout the Ryukyu Islands all formed under the same conditions: catch-up growth during relative sea-level rise was followed by lateral extension once the reef crest attained sea-level. For this reason, all of the reefs exhibit the same basic geomorphological zonation. Local variations superimposed upon this pattern are the result of minor differences in temperature and wind conditions; these slight differences are manifested latitudinally as well as at the scale of a single island.

Between 24° and 27° N, modern coral reef growth began when the sea level was about 50 m below the present level, and thus the reef flats fringe the islands in an almost uninterrupted fashion, with widths corresponding to those of the islands' shelves (Photo. 4). At latitudes higher than 27° N, reef flats are patchily distributed and narrow in width as a result of being younger, and because of the shallower depths of reef nucleation (Photo. 5). Variation in reef expression at the scale of a single island corresponds with coastline orientation. Winter monsoon winds are from the north, and swells come from the open Pacific Ocean to the east, both of which result in high waves on northern and eastern coasts, where correspondingly well-developed reef crests and moats, and continuous reef flats, are characteristic. In contrast, on west-facing coasts, reef flats are discontinuous, and reef zonation is poorly developed (Fig. 3).

4 Landform characteristics and preservation

The features of coral reef landforms in the Ryukyu Islands must be taken into consideration in planning their management and preservation. Fringing reefs are, by definition, directly linked to and affected by adjacent landmasses. This makes for easier land-based management than is possible for barrier and atoll reefs. Coral reef resources have long been exploited by local people in the coastal fishery. It also means, however, that fringing reefs receive direct effects from land-based human activity. Harmful silt and nutrients

Photo. 4. Reef flat of Sekisei Lagoon in Yaeyama Archipelago. (photo by H. Hasegawa)

Photo. 5. Patchily distributed and narrow coral reefs at Tokunoshima (Is.) in Amami Archipelago.

flow directly onto the reefs from land. The tectonic uplift in the Ryukyu Islands, and resultant emergence of reef crests into the intertidal zone, mean that water exchange between the reef flat and the ocean is limited; this, in turn, creates a closed environment on reef flats, which enhances the land effect, and creates a stressful environment for reef-flat corals. It also means that run-off from the land is trapped on the reef flat and does not significantly affect the reef front, exaggerating the environmental and biological contrasts between the two. Monitoring and assessment of the reef flat and reef front must be conducted separately.

The location of the Japanese islands, in a monsoon area that is affected by typhoons, means that reef crests are especially robust, and that coral community turnover after typhoons is frequent. For this reason, the extant coral communities in the Ryukyu Islands could presently be in a comparatively early and non-equilibrium stage of development, such that baselines established now may well be meaningless, regardless of anthropogenic influence.

Coral reefs act as natural breakwaters that protect coastlines from erosion. Only a subtle natural balance between reef growth and erosion maintains their respective properties. The death of entire coral communities results in reef collapse and loss of the natural breakwater function. For this reason, the maintenance of coral reef health is critical to retaining the natural landforms that they form, landforms that humans rely on for coastline protection.

Column

Coral reefs on the border

Hajime Kayanne

Japan extends from 20°25' to 45°33' N and from 122°56' to 153°59' E; the western, eastern and southern most localities support coral reef islands. The western-most island is Yonaguni Island, which consists of reef limestone terraces surrounding Tertiary sedimentary rock. Contemporary coral reefs are mainly fringing reefs, often 50 to 200 m wide (refer to Chapter 6-1-7c). The eastern-most island, Minamitorishima (Fig. 1), is the only island on the Pacific plate east of the Izu-Ogasawara trench. Coral reefs were formed around a volcanic island, which eventually subsided because of gradual subsidence of the western Pacific plate beneath the Philippine Sea plate. The island was formerly an atoll that became a landform of table reef due to the subsidence. The island consists of a 5 to 8 m high rim with a central depression 1 m below sea level. The contemporary reef that fringes the island is 50 to 300 m wide. The rim is considered to be an emergent reef, based on its karst landforms (Nagaoka 1987), or an island formed by consolidated bioclastic sand and gravel (Yagi *et al*. 1992). Officers from the Meteorological Agency and the Defense Agency reside on the island.

The southern-most island is Okinotorishima (Fig. 2). It is on a submerged arc comprising the Kyushu-Palau ridge. A volcanic island, formed on the ridge before the Miocene (24 million years ago) and subsequently submerged, allowed coral reef to grow. The reef is a table reef, with its long axis running 4.5 km east-west and 1.7 km wide (north-south); its central depression is 5.5 m deep at its maximum. There are two islands on the reef flat 1.5 m above mean sea level. The islands have been described as foraminifera and coral limestone (Tayama 1952), which implies they are Pleistocene limestone remnants. These islands are now protected from waves by an artificial bank. Three other islands have been described, but appear to be boulders thrown onto the reef by heavy storms.

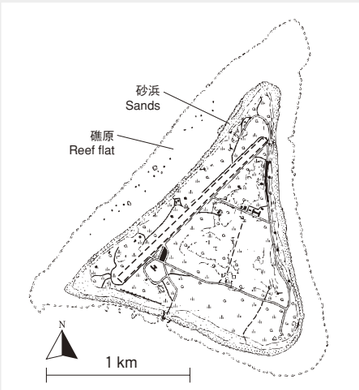


Fig. 1. Topographic map of Minamitorishima (Is.).

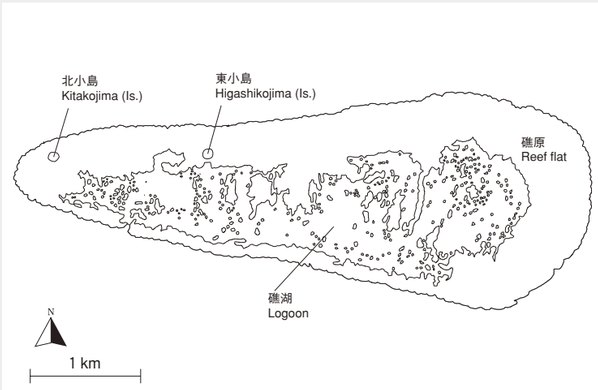


Fig. 2. Topographic map of Okinotorishima (Is.).

The coral reef islands on the border are highly regarded because they define the territory of Japan. In particular, after the 200-nautical-mile exclusive economic zone was determined by the 'U.N. Convention on the Law of the Sea', one island has an economic zone of 430,000 km square (Fig. 3). The Senkaku Archipelago, 150 km to the north of Iriomote Island, has uplifted Holocene coral reefs (Konishi *et al*. 1979). There are territorial issues with China over this archipelago (Fig. 4).

Despite their importance in identifying Japan's territorial boundaries, there is little information on how these reefs formed and on the present status of the reefs. The islands on the table reefs of Minamitorishima and Okinotorishima are either remnant limestone deposits and/or consolidated bioclastics. To preserve these islands and protect them from storms and sea level rise, it is necessary to conduct research on their present status and understand how they were formed, which may in turn lead to eco-technology that elucidates island forming processes.

Fig.3. Exclusive Economic Zone of Japan
Okinotorishima, a solitary island at the southernmost of Japan, covers larger Economic Zone than the land area of Japan (more than 370,000 km^2).
Original Map is from Japan Coast Guard's official home page.

Fig. 4. Satellite image (Landsat ETM+) of Uotsurijima (Is.) in Senkaku Islands.

1-3 Distribution of coral reef communities

Makoto Tsuchiya
Illustrations by Moritaka Nishihira

Introduction

Coastal ecosystems often occurring in association with coral reefs include rocky coasts, sandy beaches, tidal flats and seagrass meadows. Mangrove forests are also frequently found around river mouths. In this chapter, coral reef communities and their distribution are diagrammatically illustrated, and their geographical and ecological distribution patterns are outlined.

In Japan, coral reefs are relatively widely distributed over latitudes spanning more than 1,000 km; these reefs exhibit a range of reef communities. In the past, comprehensive surveys of coral reef communities have been conducted at several reefs, for example in the Senkaku Islands, Sesoko Island and Kabira Bay. There is a shortage of up-to-date quantitative research on community structure, although qualitative descriptions of the distributions of certain reef organisms, such as mollusks and crustaceans, have been published in many illustrated encyclopedias in Japan.

Habitats such as sandy beaches, rocky coasts with characteristic notch morphology, reef flats, backreef lagoons, reef edges, and reef slopes harbor different characteristic communities. In the backreef lagoon for example, there are places covered with rocky carbonate or with sandy particles. Common species observed in this habitat include the seagrasses *Thalassia hemprichii* and *Cymodocea serrulata*, the sea urchins *Echinometra mathaei*, *Tripneustes gratilla* and *Diadema setosum*, and the sea cucumbers *Holothuria leucospilota*, *H. atra*, *Synapta maculata* and *Bohadschia argus*. Corals are also frequently patchily distributed. However the densities of acroporid and pocolloporid corals have decreased in recent years, owing to disturbances such as the discharge of terrigeneous fine particles (e.g., red soil), high predation pressure by the crown-of-thorns starfish (*Acanthaster planci*), and bleaching events. Reports on the distribution of these species are freely available (JCRS 2002).

Cadret *et al.* (1999) studied the distribution of butterflyfish communities at 45 stations on the reefs of five islands within an area of 500 × 300 km (24–27°N; 124–128°E). A total of 30 species were recorded, and the overall species composition of communities from the various reefs was rather similar; it did differ, however, in a number of different habitats, such as the reef slope and backreef lagoon. It has been suggested that habitat heterogeneity and the abundance of coral species may affect community structure. Tsuchiya and Fai (in press) reported that the number of species of the xanthid crab *Trapezia*, which are obligate symbionts on pocilloporoid corals, did not differ significantly across several sites of similar area. However, the number of species was lower in Kumamoto (33°N; 130°E), ca. 800 km north of Okinawa, where the host coral *Pocillopora damicornis* is very abundant. The brooders *P. damicornis* and *Stylophora pistillata*, which are widely distributed in the Ryukyu Islands, showed genetic differences in different localities (Adjeroud and Tsuchiya 1999; Nishikawa *et al.* 2003), while the spawner *Acropora tenuis* did not show any such differences (Nishikawa *et al.* 2003).

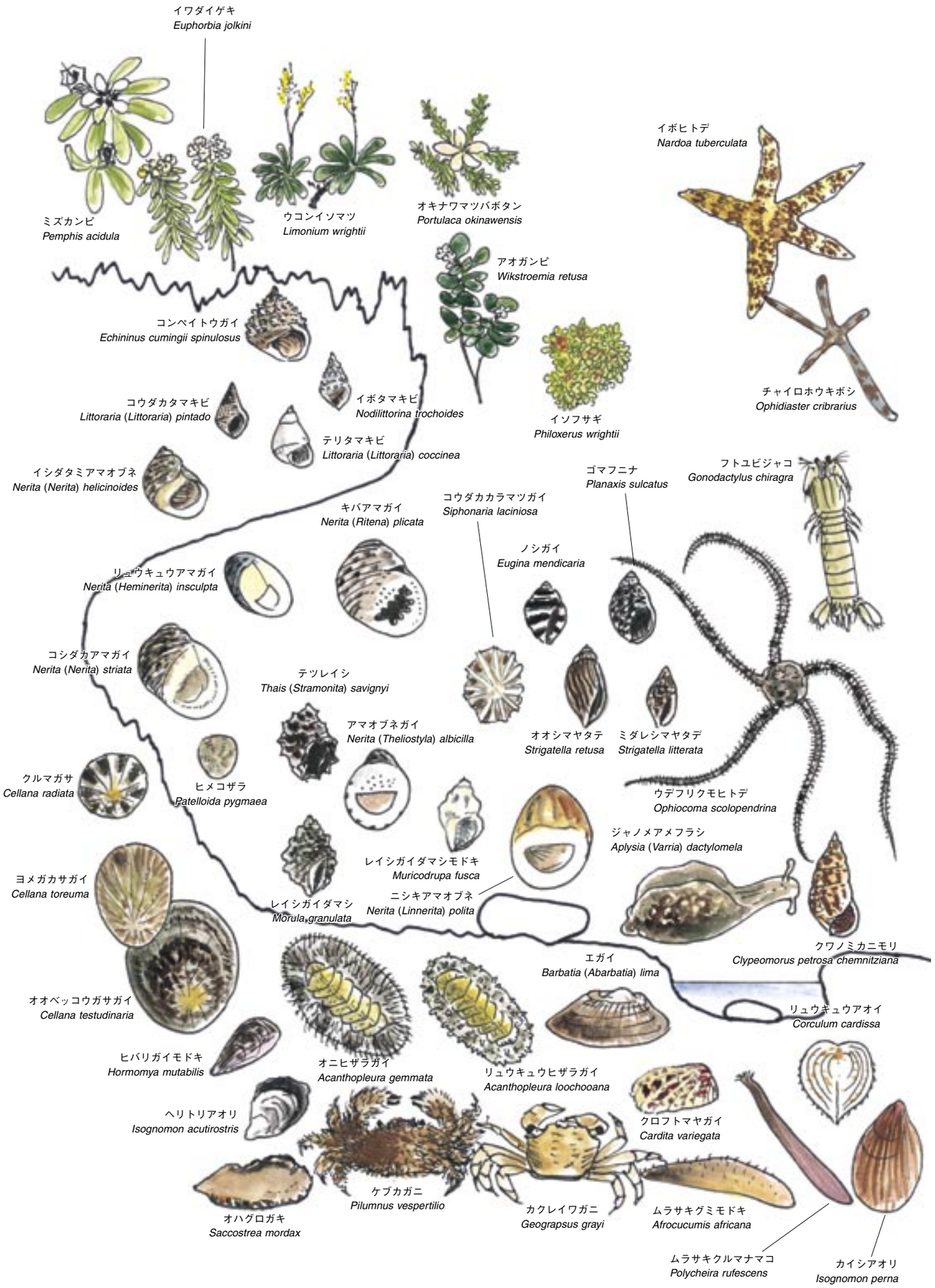
The zonation, growth, and habitat use of the calcareous algae of the Okinawan coral reefs has been the subject of ecological and reproductive research (Matsuda 2002). Ten species of seagrass were reported in the Ryukyu Islands (Yokochi 2002), with only three species occurring in the northern part of the archipelago, e.g., in the coastal area of Tanegashima Island. Their distribution and reproductive traits have also been well-researched. A list containing seaweeds of 548 species in 209 genera has been produced by Tsuda (1991), but the analyses of their overall distribution patterns are inadequate.

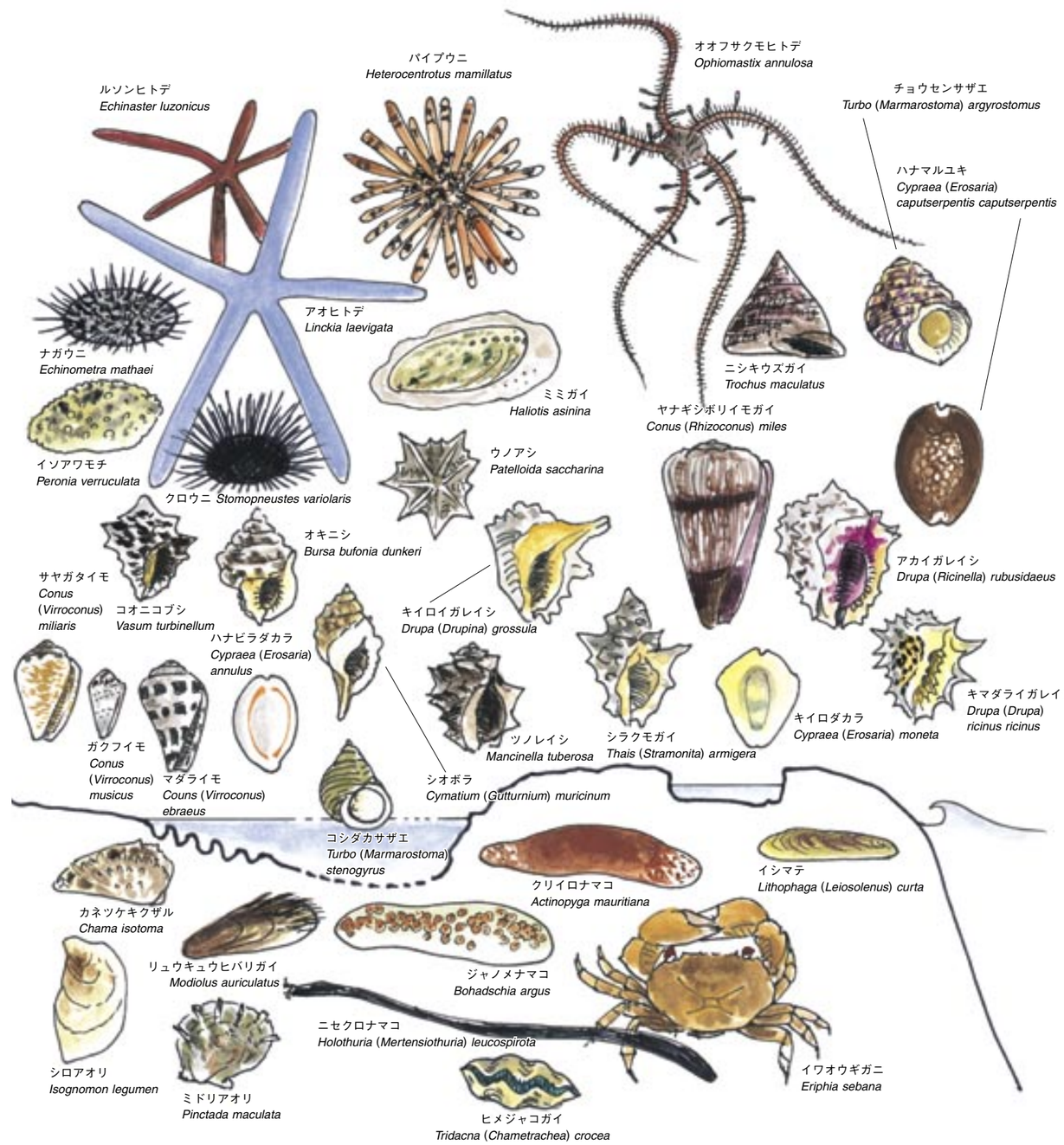
Biodiversity and ecosystem issues are currently widely discussed topics. Coral reefs, with their wide variety of biotic and abiotic interactions, constitute appropriate examples for the discussion of mechanisms that promote the coexistence of diverse species. Information on the geographical and ecological distribution of various species is essential for these analyses.

Communities in rocky intertidal zones. Part I

The vertical tidal range in Okinawa is about 2 m during spring tides and 25 cm at neap tides. Diverse species inhabit this heterogeneous environment.

As the rocky intertidal zone is quite flat in coral reef areas, there is no conspicuous zonation of organisms. However, distinct distribution patterns of intertidal organisms can be observed by walking across the reef from the land towards the reef edge. A variety of intertidal animals and plants can be seen, including, mobile species, sessile species, fishes in tidal pools, animals associated with other organisms, and seaweeds, showing seasonal variation. The mechanisms by which they have adapted to the diverse intertidal environment, their feeding habits, species interactions and so on, help us to understand why coral reef organisms are so diverse.





Communities in rocky intertidal zones. Part II

1. Littoral fringe

This zone is categorized as the area located between the upper limit of littorinid gastropod distribution and the area of barnacle distribution, the latter being the upper limit of the eulittoral zone (Lewis 1964). In the Ryukyu Islands, this zone is also the habitat for terrestrial plants such as *Limonium wrightii* and *Piloxerus wrightii*, which coexist with the littorinid *Echininus cumingii spinulosis*. This species usually inhabits the inside of rock crevices, but leaves this shelter during sunny days in the summer. Individuals often overlap to form double or triple layers, a behavior which seems to be designed to prevent over-heating on the rock surfaces (Photo. 1). This behavior is more conspicuous in another littorinid species *Nodilittorina pyramidalis*, which is abundant in the upper part of the eulittoral zone (Photo. 1-2). The gastropod, *Ritena plicata*, is commonly seen in the lower part of the littoral fringe. Vertical migrations of *R. plicata* are often associated with environmental changes; for example, their distribution zone is sometimes 1–2 m higher than normal just after a typhoon passes.

2. Eulittoral zone

The upper limit of the barnacle zone in coral reef areas is not as conspicuous as it is in temperate zones, due to the scarcity of barnacles. The lower limit of the eulittoral zone in the temperate intertidal zone is defined as the upper limit of the habitat of macroalgae such as *Laminaria* and *Undaria*, but in coral reef areas it should instead be defined by the upper limit of the habitat of coral species (Nishihira 1974).

The eulittoral zone of coral reef areas in Okinawa consists mostly of reef flat. The gastropod *Planaxis sulcatus* (Photo. 2-1), the small bivalve *Isognomon* (*Parviperna*) *acutirostris*, and the oyster *Saccostrea mordax* (Photo. 2-2), are abundant on the landward side, where they frequently aggregate densely. During the cold season (January to March), the green algae *Ulva, Monostroma* and *Enteromorpha* cover the rock surface, and provide large quantities of nutrients to coral reef organisms as they decompose in the summer months. *Monostroma nitidum* is one of the most important food items in Okinawa, and is commonly harvested during the spring season. Small hermit crabs aggregate on rocks during high tides, chitons such as *Acanthopleula loochooana* and *A. gemmata* are found in rock crevices, and several species of carnivorous gastropod characterize the middle part of the eulittoral zone. The dominant species in the lower eulittoral zone is the sea urchin *E. mathaei*. Okinawan specimens have been well studied; recently, they were divided into four types, according to their morphological, ecological and developmental characteristics (Arakaki and

Photo. 1. Littorinids that inhabit rocky shores often overlap with other individuals to form double or triple layers, a behavior that seems to be designed to prevent over-heating on the rock surfaces.
(1) *Echininus cumingii spinulosis*
(2) *Nodilittorina pyramidalis*

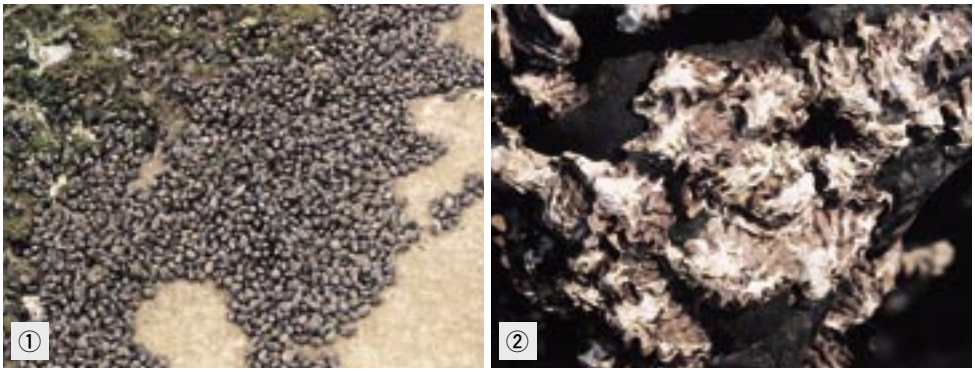


Photo. 2. Some gastropods (1) and oysters (2) frequently form dense aggregations on shore-side ledges in the eulittoral zone in Okinawa.
(1) *Planaxis sulcatus*
(2) *Saccostrea mordax*

Uehara 1991; Nishihira *et al*. 1991; Uehara *et al*. 1991). Of particular interest to researchers is the agonistic behavior of the urchins, which inhibit excavated burrows on the rock surface (Tsuchiya *et al*. 1991) (Photo. 3).

A variety of species are observed in tide pools, including the sea cucumber *Bohadshia argus* (Photo. 4-1) and *Holothuria leucospilota*, the brittle star *Ophiocoma scolopendrina* (Photo. 4-2), the urchin *E. mathaei*, and some species of coral. *Pavona frondifera*, a common species in backreef lagoons and tide pools, was affected by bleaching events in 1998 and 2001, after which some subsequently recovered. *Acropora* spp. were more seriously adversely affected, showing much higher mortality at certain sites.

Acetabularia ryukyuensis (Photo. 5), which is known as a living fossil among seaweed species, has recently declined in Okinawa. Large populations of *A. ryukyuensis* are found only in areas where anthropogenic impacts have been minimal. This species usually grows on boulders or coral rubble, and since these habitats are unstable, habitat disturbance may be too high for it to persist in areas that are frequently visited by humans.

Species richness is high in the tide pools near the reef edge. The fish and coral communities are also diverse, and lobsters are occasionally observed.

3. The lower intertidal or subtidal fringe

In coral reefs, this zone corresponds to the upper part of the reef slope, the lower part of the reef edge, and the backreef on the lagoon side. The decline of coral communities is also evident in this area. Fortunately, newly recruited colonies of *Acropora* are now appearing in some places, giving hope for future recovery.

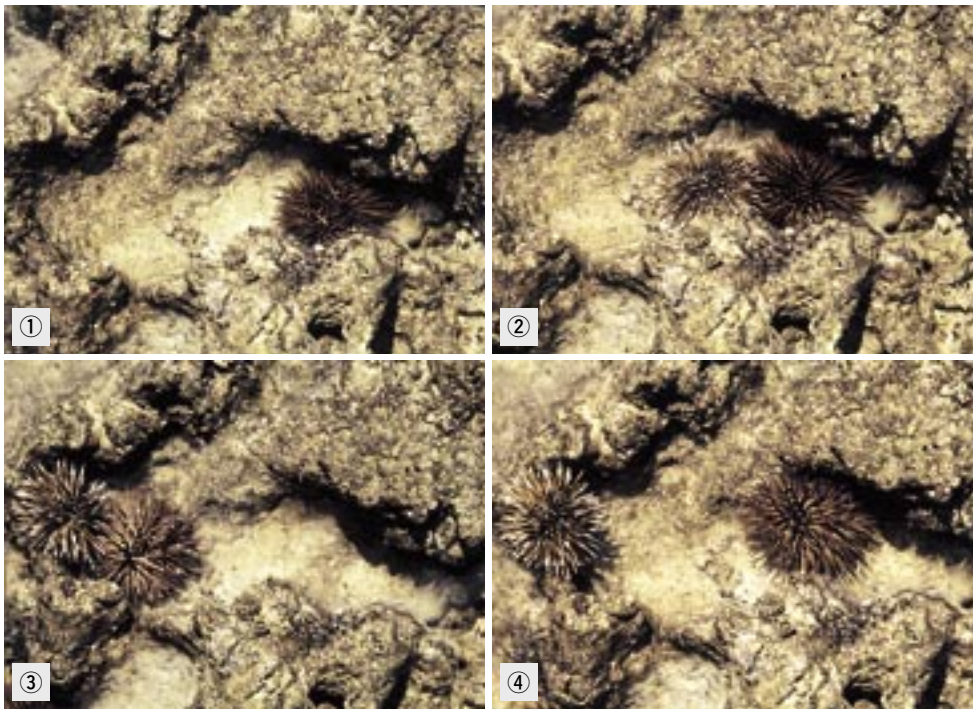


Photo. 3. Agonistic behavior of the sea urchin *Echinometra mathaei*, which inhabits excavated burrows on reef flat rocks in the eulittoral zone in Okinawa.
(1) Burrows occupied by E. mathaei type B.
(2) *E. mathaei* type A being introduced to type B's burrow.
(3) Type B driving type A out of the burrow.
(4) Type B subsequently returned to the original burrow. The behavior observed in
(1)-(4) took a total of about six minutes.

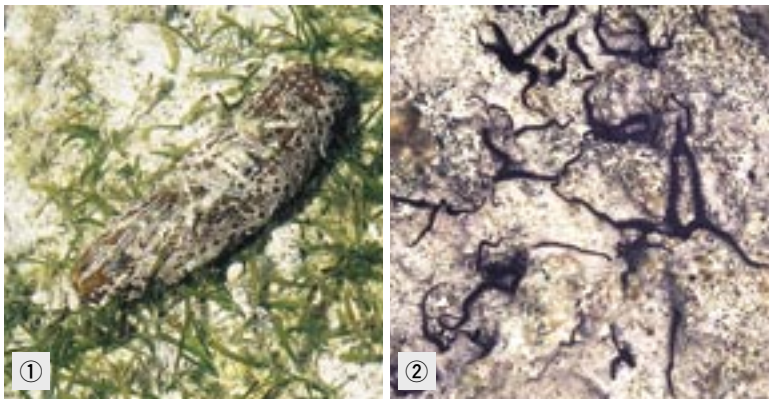


Photo. 4. Echinoderms observed in tide pools on Okinawan reefs:
(1) sea cucumber *Bohadschia argus*
(2) brittle star *Ophiocoma scolopendrina*

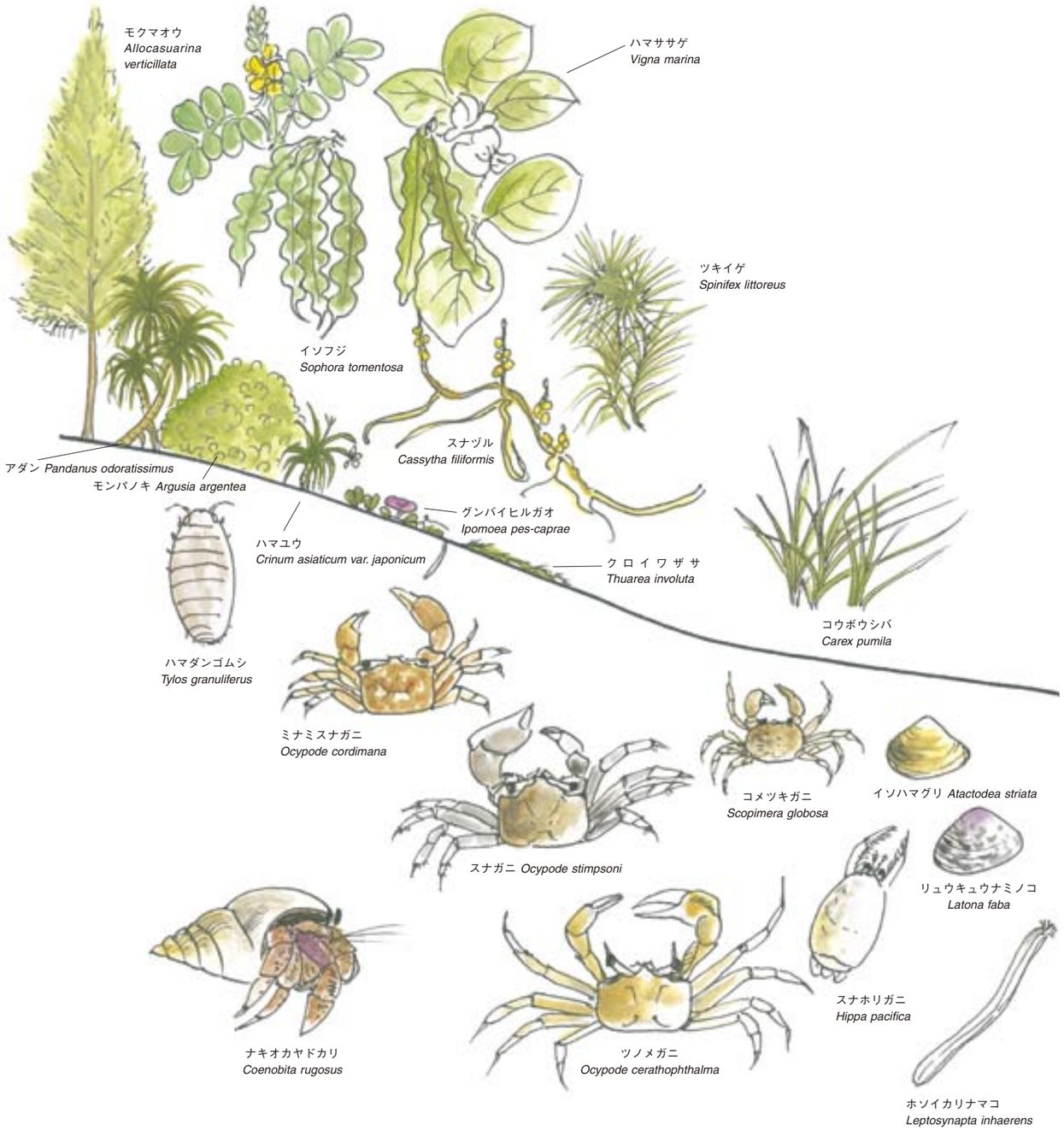
Photo. 5. *Acetabularia ryukyuensis* growing on boulders and coral rubble along the shore.

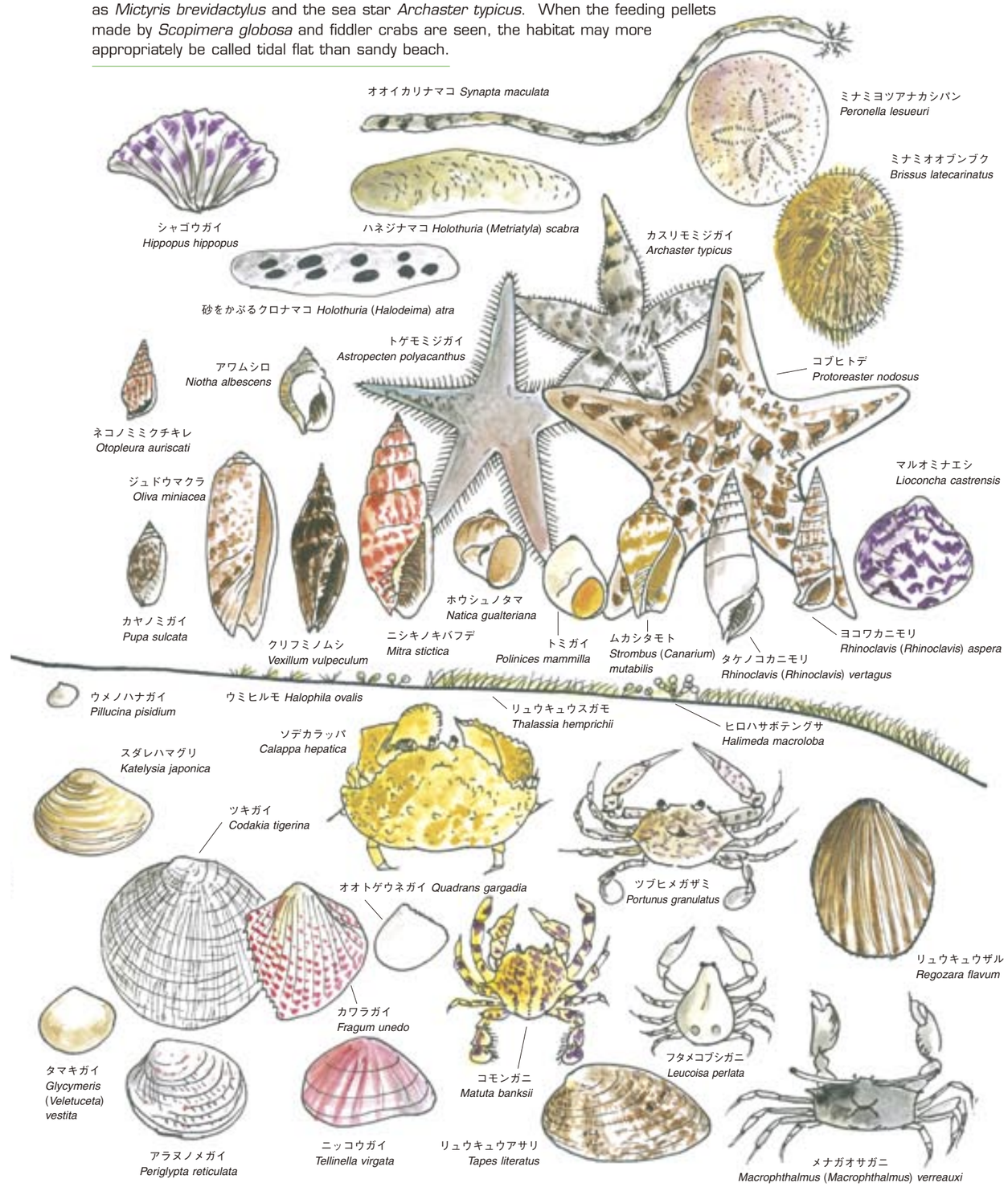
Communities on sandy beaches

Well developed sandy beaches are located along the coast on the landward side of the coral reefs. *Casuarina equisetifolia* functions as maritime forest along the back of the beaches and *Pandanus odoratissimus* and *Argusia argentea* also grow here. Herbaceous plants of the coastal plant community include *Crinum asiaticum*, *Ipomea pes-caprae* subsp. *brasiliensis*, and *Cassytha filiformis*, among which land hermit crabs *Coenobita* spp. are found. Land hermit crabs are essentially nocturnal; however, small individuals can be seen throughout the day, feeding on litter that has been left on the beach.

Typical sandy beach communities are also characterized by the rapidly moving ghost crab *Ocypode stimpsoni*, and the migrations of the hippod *Hippa pacifica* and the Pacific bean donax, *Donax* (*Latona*) *faba*.

The lower part of sandy beaches often functions as a tidal flat. Seagrasses are also often seen around the shallow subtidal zone. Sandy beaches in Okinawa usually contain elements of both sandy and tidal flat communities. Thus the flora and fauna include some species that are usually found on tidal flats but not typically on sandy beaches, such as *Mictyris brevidactylus* and the sea star *Archaster typicus*. When the feeding pellets made by *Scopimera globosa* and fiddler crabs are seen, the habitat may more appropriately be called tidal flat than sandy beach.



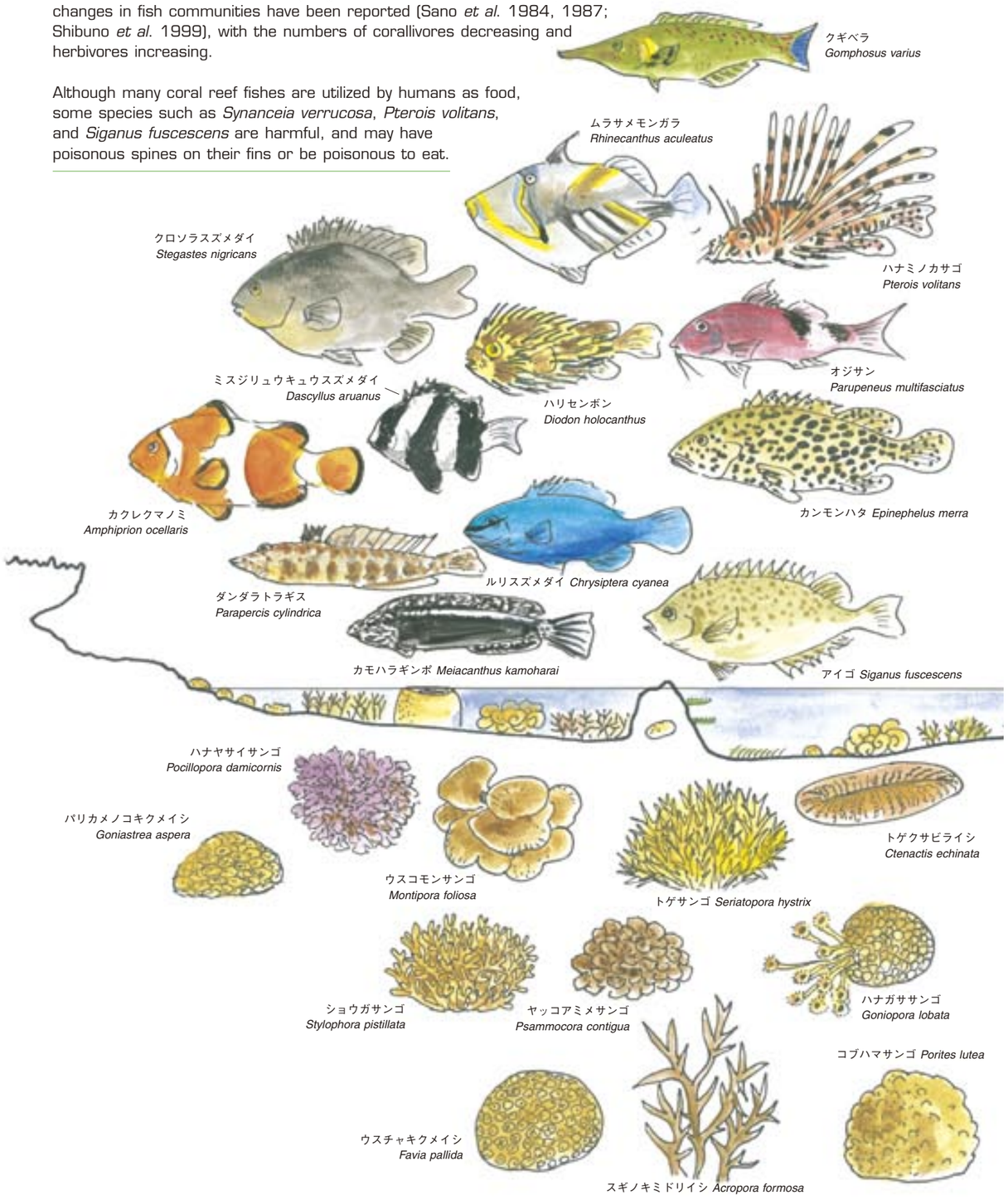


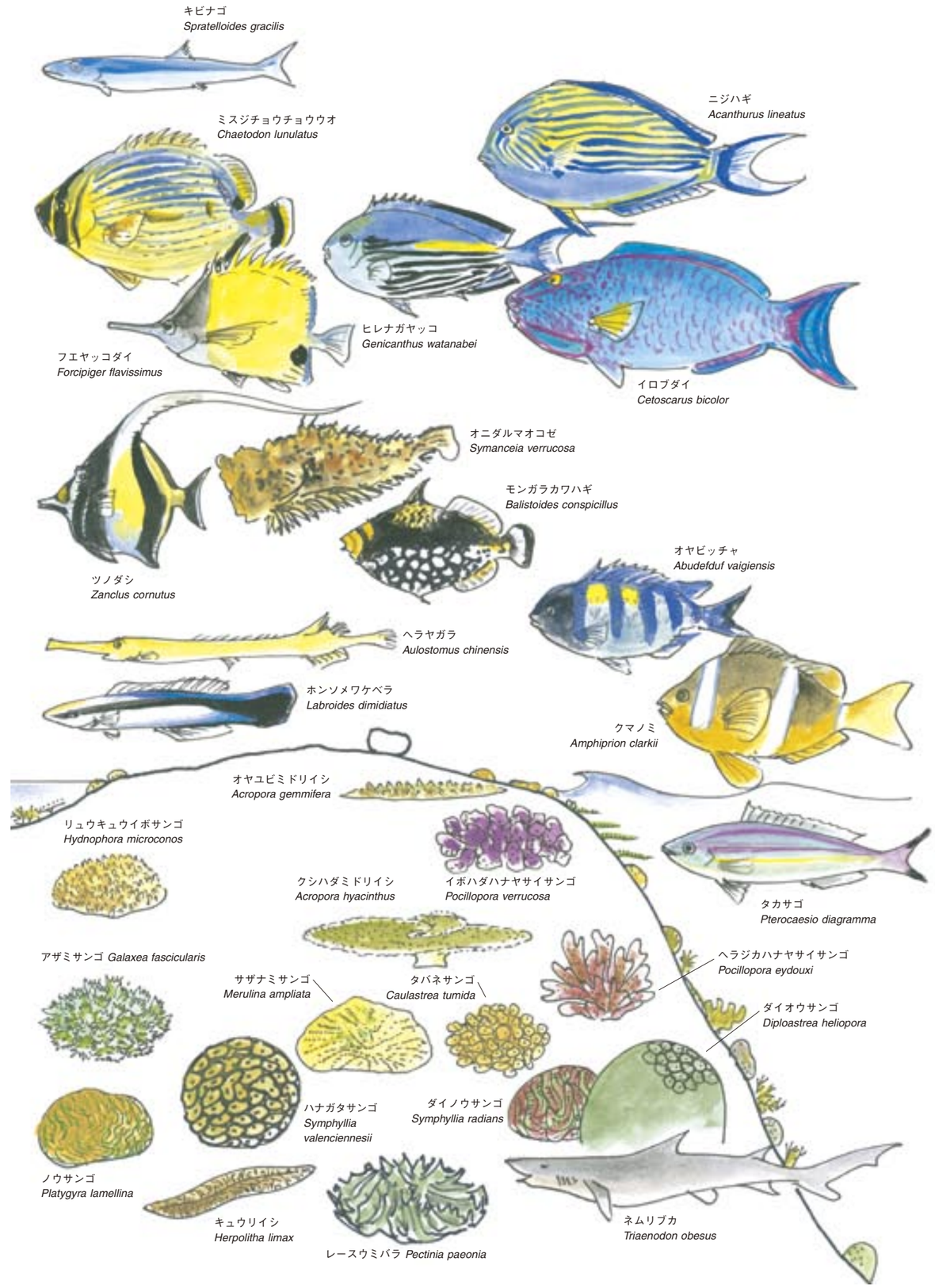
Coral reef organisms. Part I

The most typical of the organisms characterizing coral reefs are hermatypic corals. Different coral communities are observed among different habitats such as calm backreef moat, reef slopes, and high wave energy reef edges. Bleaching events have frequently occurred on many reefs and in many coral habitats; the recovery process has been observed to differ greatly among these different environments.

The life-history strategies of coral reef organisms are very diverse. They include: 1) small fishes and benthic animals using coral as shelters, 2) animals feeding on the coral, 3) animals that have symbiotic relationships with coral, and 4) other strategies. Since many reef organisms rely on coral either directly or indirectly, the physical condition of the coral is very important to the well being of many organisms. After outbreaks of *A. planci* or severe bleaching events, drastic changes in fish communities have been reported (Sano *et al.* 1984, 1987; Shibuno *et al.* 1999), with the numbers of corallivores decreasing and herbivores increasing.

Although many coral reef fishes are utilized by humans as food, some species such as *Synanceia verrucosa*, *Pterois volitans*, and *Siganus fuscescens* are harmful, and may have poisonous spines on their fins or be poisonous to eat.





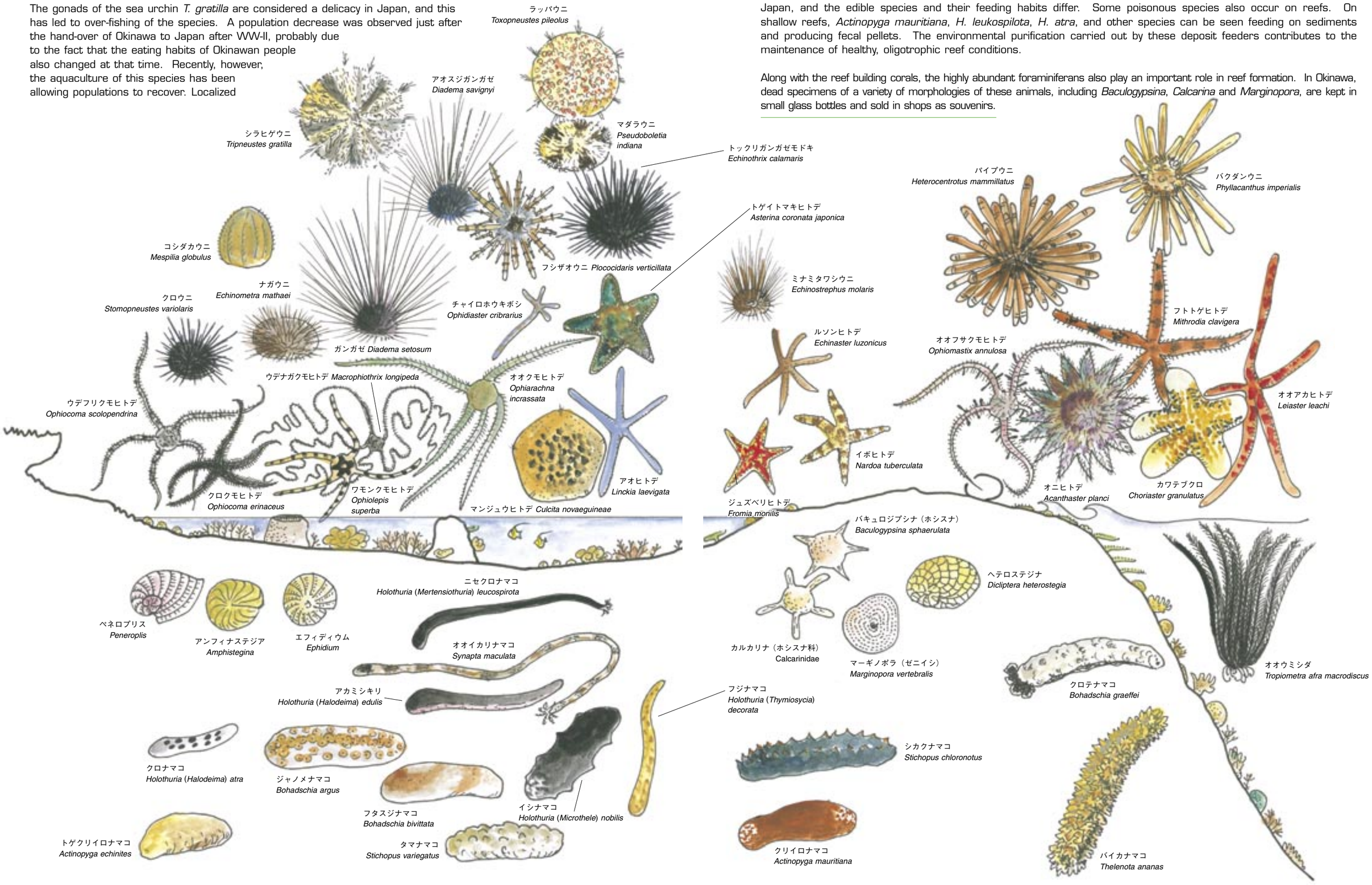
Coral reef organisms. Part II

Echinoderms, sea urchins, sea cucumbers, and ophiuroids are abundant in backreef lagoons and on the reef flat, and crustaceans, such as small crabs and shrimps, are the most abundant animals associated with pocilloporid or acroporid corals. Why do echinoderms and crustaceans flourish in the coral reef environment?

The gonads of the sea urchin *T. gratilla* are considered a delicacy in Japan, and this has led to over-fishing of the species. A population decrease was observed just after the hand-over of Okinawa to Japan after WW-II, probably due to the fact that the eating habits of Okinawan people also changed at that time. Recently, however, the aquaculture of this species has been allowing populations to recover. Localized aggregations of the sea urchins, *D. setosus* and *Heterocentrotus mamillatus*, which appear from crevices at night, also characterize the coral reef underwater scenery.

Okinawan people also eat sea cucumbers, although they are not as popular in Okinawa as they are in mainland Japan, and the edible species and their feeding habits differ. Some poisonous species also occur on reefs. On shallow reefs, *Actinopyga mauritiana*, *H. leukospilota*, *H. atra*, and other species can be seen feeding on sediments and producing fecal pellets. The environmental purification carried out by these deposit feeders contributes to the maintenance of healthy, oligotrophic reef conditions.

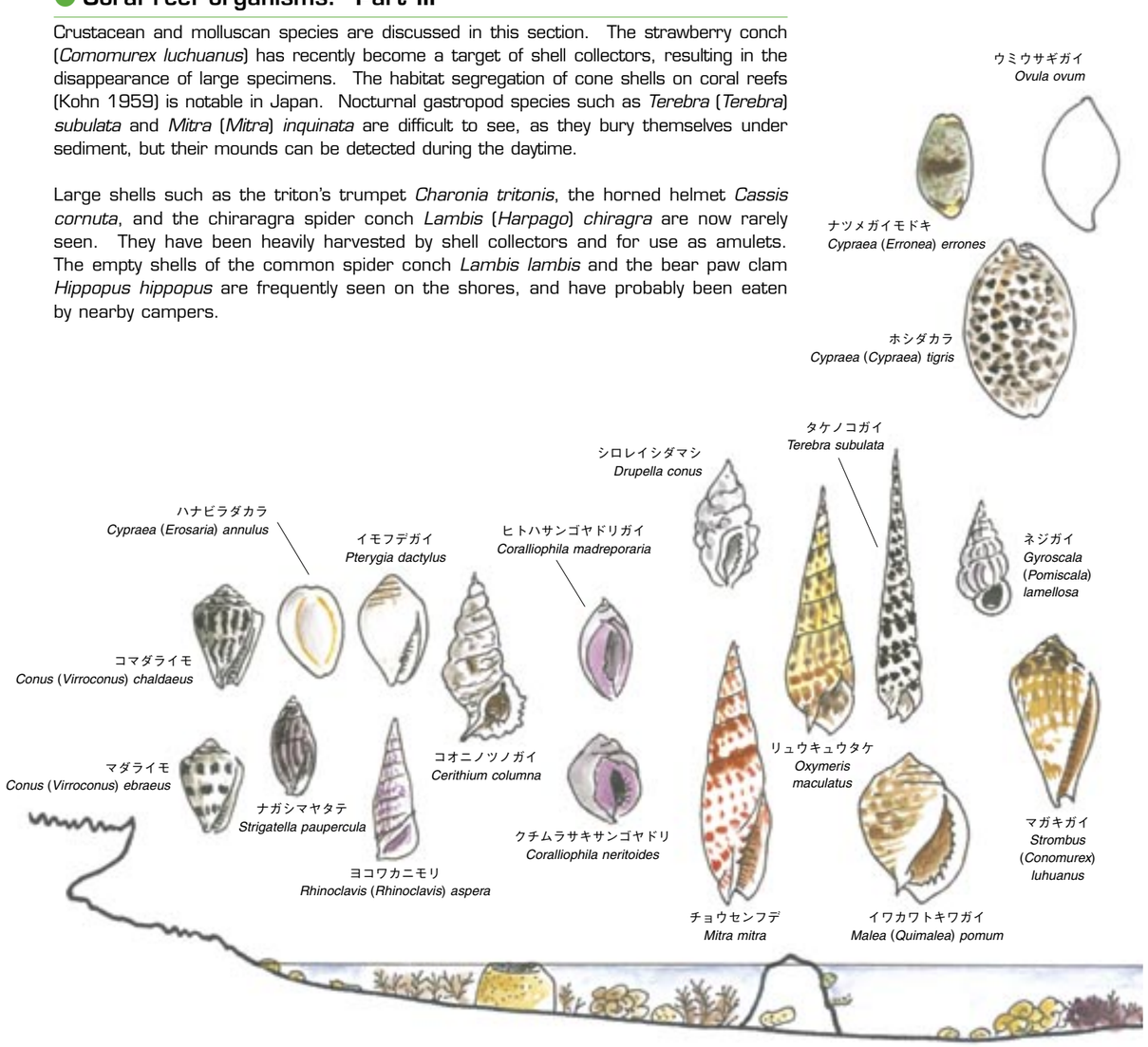
Along with the reef building corals, the highly abundant foraminiferans also play an important role in reef formation. In Okinawa, dead specimens of a variety of morphologies of these animals, including *Baculogypsina*, *Calcarina* and *Marginopora*, are kept in small glass bottles and sold in shops as souvenirs.



Coral reef organisms. Part III

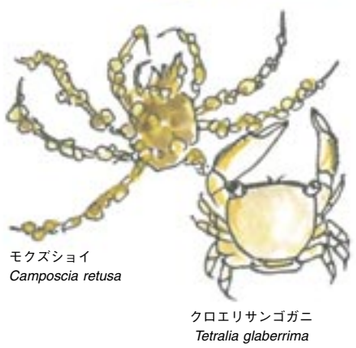
Crustacean and molluscan species are discussed in this section. The strawberry conch (*Comomurex luchuanus*) has recently become a target of shell collectors, resulting in the disappearance of large specimens. The habitat segregation of cone shells on coral reefs (Kohn 1959) is notable in Japan. Nocturnal gastropod species such as *Terebra* (*Terebra*) *subulata* and *Mitra* (*Mitra*) *inquinata* are difficult to see, as they bury themselves under sediment, but their mounds can be detected during the daytime.

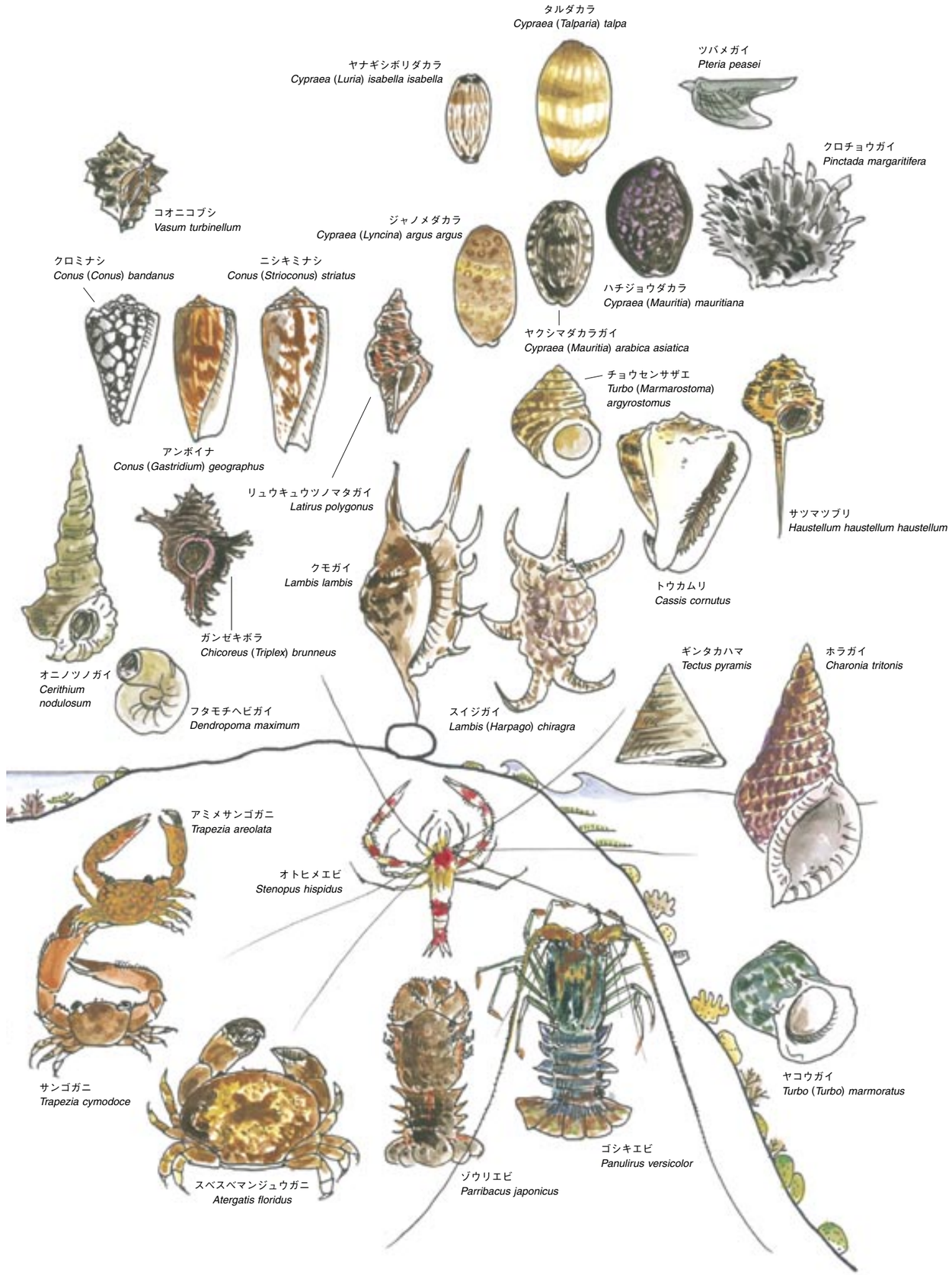
Large shells such as the triton's trumpet *Charonia tritonis*, the horned helmet *Cassis cornuta*, and the chiraragra spider conch *Lambis* (*Harpago*) *chiragra* are now rarely seen. They have been heavily harvested by shell collectors and for use as amulets. The empty shells of the common spider conch *Lambis lambis* and the bear paw clam *Hippopus hippopus* are frequently seen on the shores, and have probably been eaten by nearby campers.



Lobsters and *Scyllarides squamosus* occur on the reef slope and the reef edge. Living specimens are rarely sighted during the day, but are frequently caught along with other fishes and crabs in nets set at low tide near the reef edge.

The xanthid crab *Trapezia* spp., which is associated with the pocilloporid corals, has an interesting ecology. *Trapezia* spp. has been regarded as an obligate symbiont on pocilloporid corals, but the mechanisms of this symbiosis have not yet been clarified. Recently, specimens of *Trapezia cymodoce* were found on *Acropora* in the Kumamoto area (Tsuchiya and Nojima 2002), and other species of *Tetralia* have also been found on *Acropora* colonies. These interactions should be a topic for further research. Heterosexual pairs of *Trapezia* and of the shrimp *Alpheus lottini* have been observed on pocilloporid corals. Interactions among these obligate symbionts are interesting (Vannini 1985; Tsuchiya and Yonaha 1992). The obligate gastropod *Coralliophila neritoidea* and the goby *Paragobiodon* spp. are also commonly seen on pocilloporid corals.





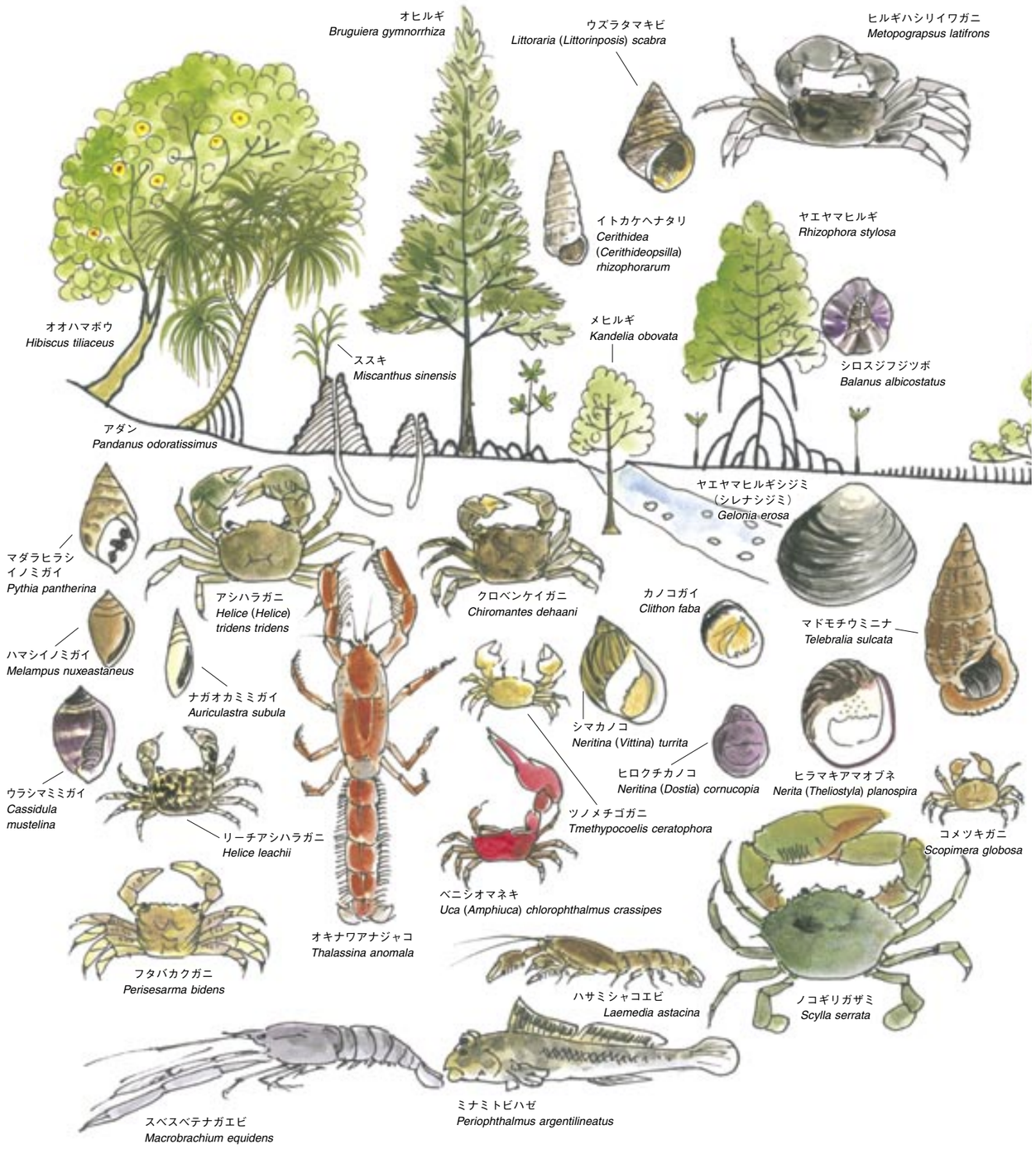
Communities in mangrove forests and neighboring tidal flats

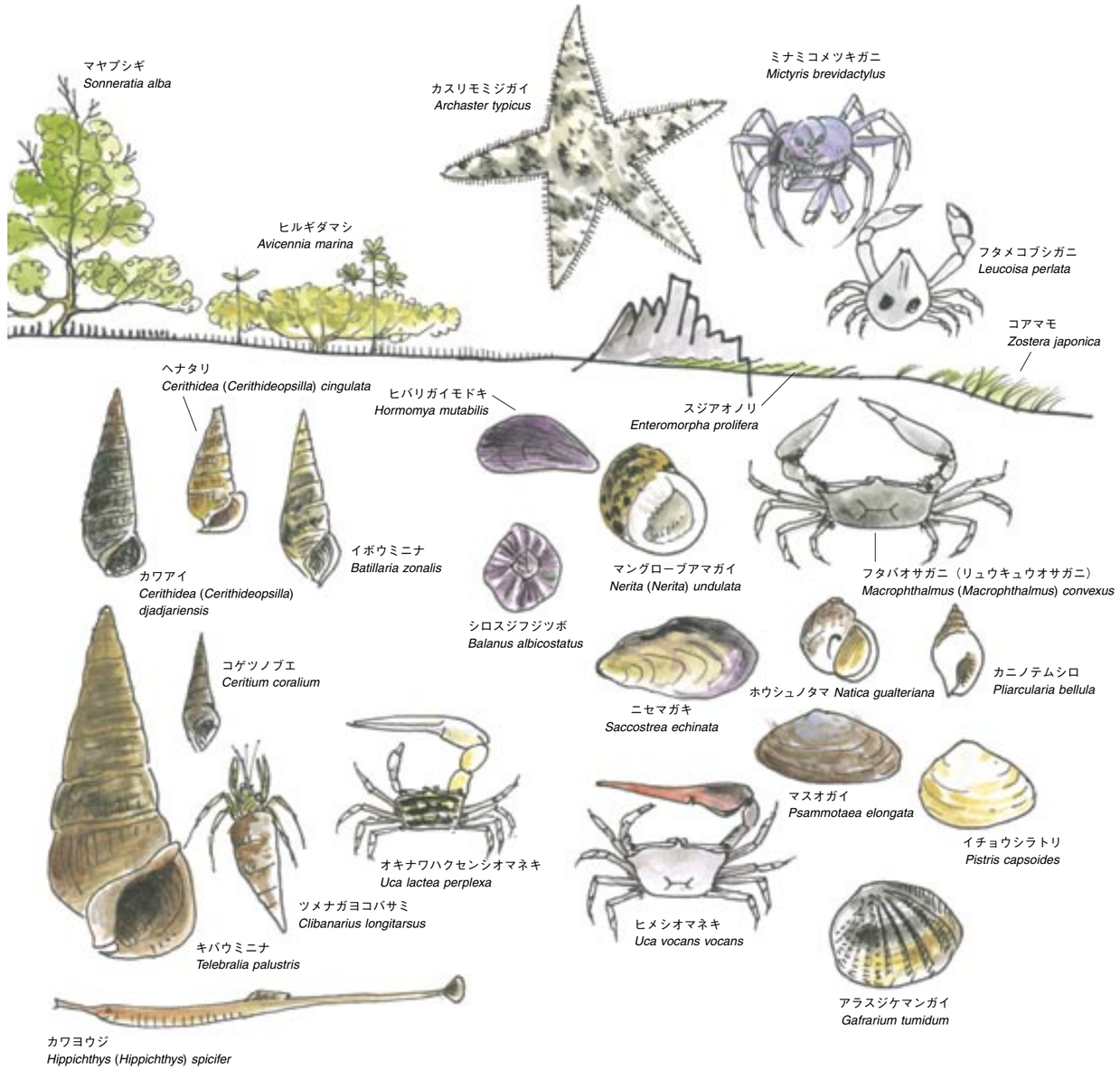
In Japan, mangrove forests typically consist of *Kandelia candel*, *Bruiguirella gymnorrhiza*, and *Rhizophora stylosa*. Recently, Japanese and Taiwanese specimens of *Kandelia*, the distribution of which was previously thought to extend as far as Kagoshima Prefecture (31°20'N), were re-examined morphologically and biochemically, and identified as a new species, *Kandelia ovobata* (Sheue *et al*. 2003). The true distribution of *K. candel* is now reported to include India, Thailand and Indonesia.

Several species of animal, including *Cassidula mustelina*, *Melampus castaneus*, and the littorinid *Littorinopsis scabra* inhabit mangrove trees, and the sesarmid crab, *Metopograpsus latifrons*, is found on the trunks. Sessile species, including the barnacle *Balanus albicostatus albicostatus* and the oyster *Crassostrea echinata*, attach their roots onto mangrove trunks. Large sandy-mud mounds, which can reach approximately 1 m in height, and are made by *Thalassina anomala*, can be seen around mangrove trees.

In the channels, the mud crab *Scylla serrata* is caught by traps, mainly for consumption. Some specialists use long rods with hooks to extract these crabs from their burrows. The gobies, *Periophtalmus vulgaris* and *P. cantonensis*, sometimes co-exist in Okinawa, making it the northern limit for the former species and the southern limit for the latter.

The mud creeper *Terebralia palustris* and large species of sesarmid crabs feed on the fallen leaves of mangroves. The feces that they produce are utilized as food by small benthic animals, such as fiddler crabs and small gastropods. Extraordinary aggregations of the fiddler crab *Uca perplexa*, and the soldier crab *Mictyris breridactylus*, can often be seen on tidal flats. The gastropods, *Batillaria zonalis* and *Cerithideposilla cingulata*, are also abundant.

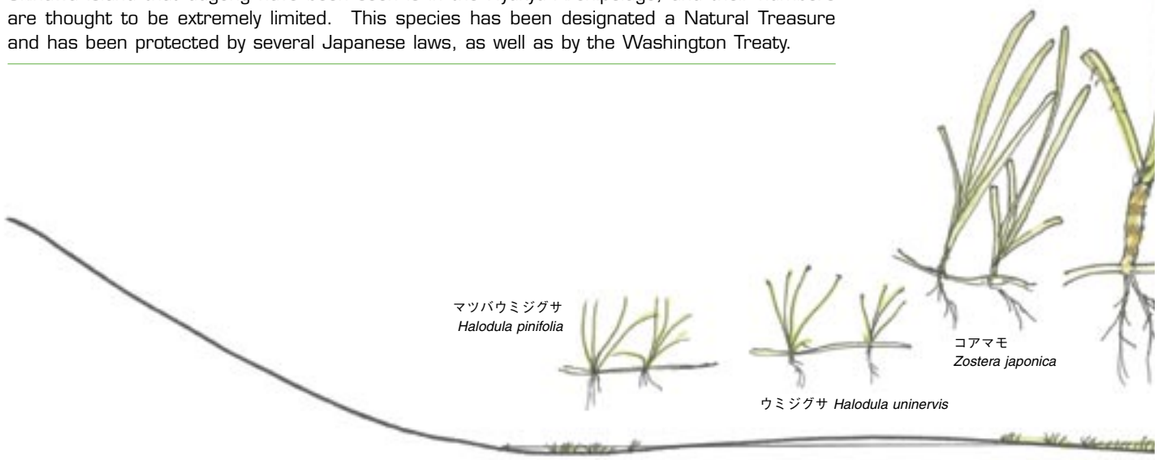


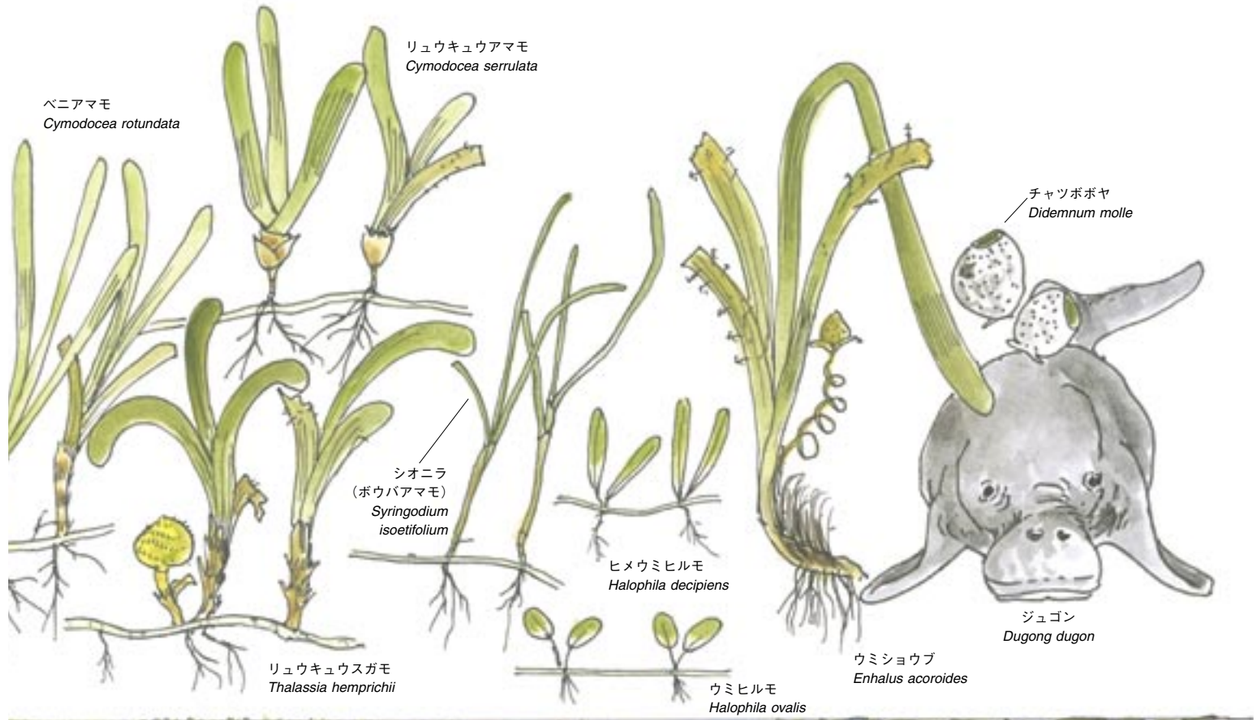


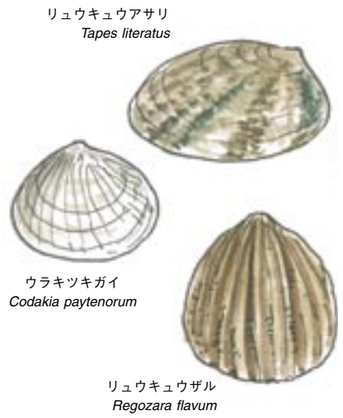
Communities in seagrass beds

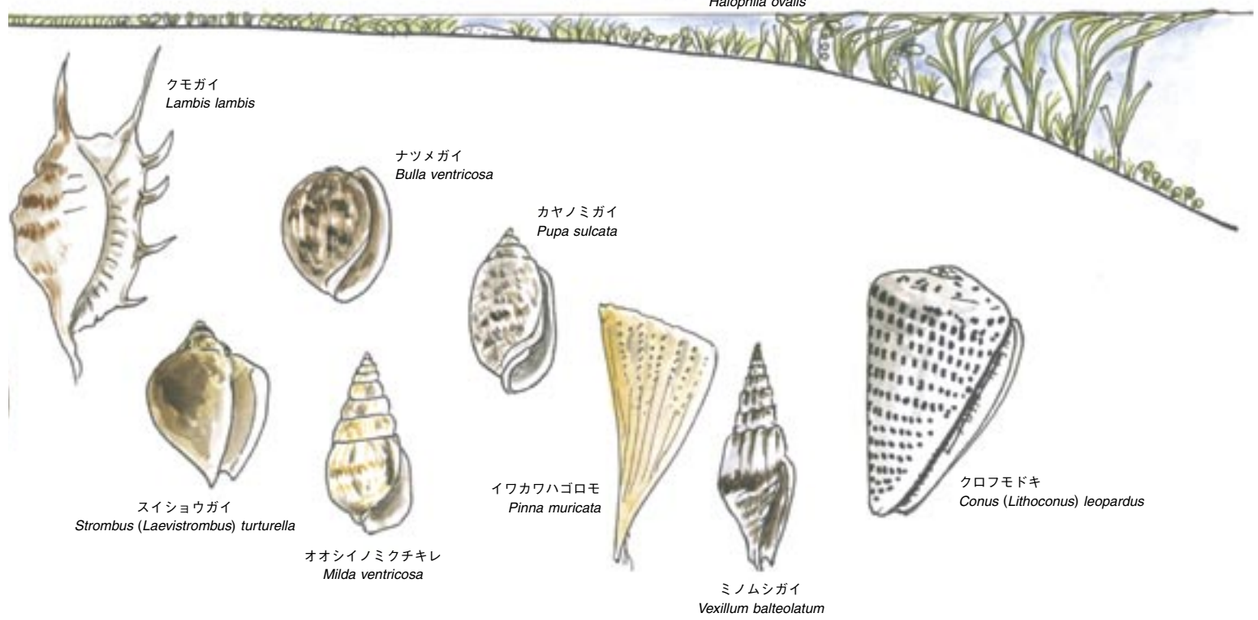
Seagrasses and seaweeds play an important role as primary producers and as sources of organic materials for coral reef organisms. Their role in offering a variety of habitats to small organisms can be likened to that of forests in terrestrial ecosystems. At low tide, fecal pellets produced by sea cucumbers and lug worms, mounds made by ghost shrimps, and siphons of bivalves can be seen; in addition, the sounds made by snapping shrimps can be heard. At high tide, many small fishes swim among the seagrasses, and the extrusion of sandy particles from the burrows of ghost shrimps can be seen.

The conservation of dugong (*Dugong dugon*) is a subject currently receiving much attention in Okinawa. Dugong are distributed throughout the Indo-Pacific, with large populations occurring in Papua New Guinea and Australia. Information about dugong is very scarce, but the conservation of the species is linked to the conservation of seagrass communities, as seagrasses form the major part of the dugong's diet. In recent years, the only place around Okinawa Island that dugong have been seen is in the Ryukyu Archipelago, and their numbers are thought to be extremely limited. This species has been designated a Natural Treasure and has been protected by several Japanese laws, as well as by the Washington Treaty.









Column

Unique genetic properties of acroporids

Masayuki Hatta

Many species of the coral genus *Acropora* participate in 'mass spawning', the synchronous spawning by multiple species. In Okinawa, mass spawning occurs typically once a year, on a night near the full moon in early summer. Huge quantities of eggs and sperm are released simultaneously within an hour by vast numbers of colonies of various species. Synchronized spawning certainly promotes the fertilization of gametes released by sedentary colonies within each species. However at the same time, mass spawning may raise a problem of species identities caused by interspecific crossing, unless eggs and sperm have an effective mechanism of recognition and fertilization only within their own species.

If such species exist that are currently undergoing speciation, the species involved may still be connected reproductively and genetically, although each species has developed its own identity. In reverse, if multiple species are undergoing fusion, the species involved may hybridize to some extent and share a common gene pool through the exchange of genes via hybrids (gene introgression).

These possibilities were tested by systematic crossing experiments and genetic analyses (Hatta *et al.* 1999). Eggs and sperm collected from each individual colony were separated, mixed in various combinations of intra- and interspecies, and the fertilization rate was scored for each individual cross and summed. The fertilization rate within species was always high, and self-fertilization was almost none. Interspecific fertilization was observed among 6 species out of 8 species tested so far. The interspecific fertilization rates varied by individual cross, from 10% to near 100%, and showed non-reciprocal efficiency in combination of eggs and sperm between each pair of species. Strikingly, cross-fertilization was observed even between species that have very different morphologies, such as arborescent and corymbose.

All hybrid embryos developed normally to planula larvae, they were inherited genes from the parents in the Mendelian manner, and metamorphosed to primary polyps. The hybrids may grow to form colonies by asexual reproduction after passing the critical step of development, metamorphosis. The further interests and problems are morphologies and fertility of the hybrids. However, it is very difficult to grow acroporids from primary polyps to mature colonies.

The genetic relationships of the species used for crossing experiments were described using DNA sequences of a marker gene. The 8 species did not form a separate cluster for each species in the phylogenetic tree, instead, they were divided to three genetic groups (Fig. 1). Within each group, individuals of different species are as closely related as within the same species. An important feature is that the cross fertilization was observed within each genetic group. This unusual genetic relationship of the acroporids is conceived as a result of gene introgression driven by hybridization in the near past in nature.

A significant number of hybrids would be produced in nature every year, because eggs are exposed to a high concentration of sperm released from neighboring colonies of different species in the mass spawning events. Since hybrids do not necessarily express intermediate phenotypes, some hybrid acroporids might reveal unexpected morphologies and currently be recognized as independent species. Hybridization might mediate diversification of species and morphologies in mass-spawning acroporids.

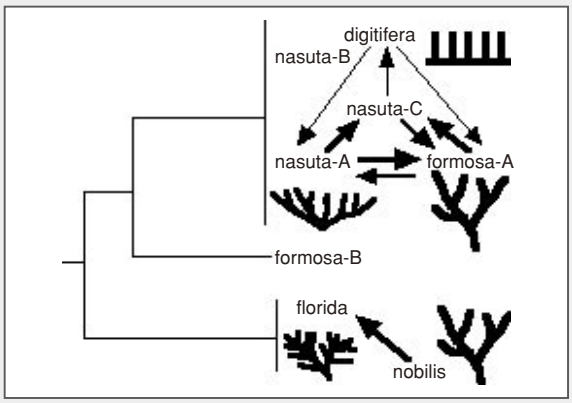


Fig. 1. Schematic diagram of genetic, reproductive and morphological features of acroporids. Cross-fertilization is represented by arrows, and morphological types are indicated by signs on the genetic phylogeny tree.

Chapter 2

Coral reef disturbances

This chapter covers the principal disturbances at various levels occurring or seen as a problem in coral reefs (including non-reefal coral communities) in Japan. The disturbances seen on natural environments are often caused by combination of anthropogenic and natural causes. On coral reefs, dredging by construction works and terrestrial red soil inflows are included in the former cause to a large extent, and world-wide mass bleaching event due to modern human activities can also be included as well with high possibilities. While outbreak of *Acanthaster planci* and widespread of disease-causing sponges on corals are generally considered as the later cause, causal link with human activities still cannot be denied. A new problem has brought about accompanied by the modern economic framework, turning some rural peoples' simple, traditional lives to destructive modern living styles. In addition, a problem of garbage outflow on the sea has become a cross-border debate. We have to take these situations seriously, understand each disturbing factors, and implement concrete countermeasures toward improvement. Furthermore, it is necessary to understand these disparate-looking phenomena as total, interdependent phenomena, including social and economic aspects, and establish a comprehensive philosophy on our behavior. We should strongly be aware that the most 'threatening disturbance' is our 'resignation and disinterest' to the facing problems. It must be our duty, extending to the future, to exert an effort to achieve a good relationship with the blessing nature.

2-1 Global environmental change and coral bleaching

Yoshikatsu Nakano

1 Introduction

Many coral reef researchers around the world recorded the large-scale coral bleaching event that occurred from 1997 to 1998. Wilkinson (1998) used the Internet to monitor bleaching all over the world, and provided a record of the extent of the event. In Japan, information about the coral bleaching was communicated to the public via the website of the Japanese Coral Reef Society*1 (Kayanne 2002).

The rapid communication of this event symbolized the age of the Internet, indicating that our use of technology to disseminate information was advancing in parallel with global environmental change. Unlike local disturbances in coral reefs, this bleaching event occurred on a large scale, within a short period. Research on the bleaching in hermatypic corals was accelerated worldwide. Surveys and research conducted in Japan resulted in many published reports on coral bleaching in that region (Research Institute for Subtropics 1999; Nature Conservation Bureau, Ministry of the Environment 2002).

This section is an overview of the status of coral reef ecosystems, one of the oldest existing ecosystems on Earth (Veron 1995), the hermatypic corals that are the keystone species of these habitats, and the current state of Japanese corals. This information has been collected from recent reports by academic societies, the media, and other sources.

2 Symbiosis between corals and zooxanthellae

Hermatypic coral (hereafter, coral) is the general name applied to those species that belong to several different groups of the phylum Cnidaria, and which contain unicellular algae in their tissues. This includes most species of the order Scleractinia, all the species of the orders Coenothecalia, Stolonifera in the Class Anthozoa, and Milleporina in the Class Hydrozoa (Nishihira and Veron 1995).

The symbiotic algae in corals are called zooxanthellae, and are dinoflagellates (~10 μm in diameter) belonging to the genus *Symbiodinium* (Photo. 1), which lives in the gastrodermal cells of the coral polyp (Kawaguti 1944; Muscatine 1980). To summarize the symbiotic relationship, the zooxanthellae use some of the carbon dioxide generated by coral respiration for photosynthesis, and the coral utilizes glycerol etc. produced by algal photosynthesis as an energy source (Grant *et al.* 1999). The algae also use coral metabolic waste products, such as ammoniums and phosphates, as nutrients for growth. This symbiosis allows corals to flourish in oligotrophic tropical seas. The presence of zooxanthellae in coral tissue also promotes coral calcification (Hidaka 2002); therefore, this symbiosis is important for reef formation by these hermatypic or 'reef-building' corals.

There are millions of zooxanthellae in 1 cm^2 of the tissue surface of a coral colony. Zooxanthellae undergo daily cell divisions in the coral tissue and cells, and are discharged when they cease to function. This cycle is controlled by the interaction of corals and zooxanthellae, and the density of zooxanthellae is adjusted according to external environment parameters (Smith and Muscatine 1999).

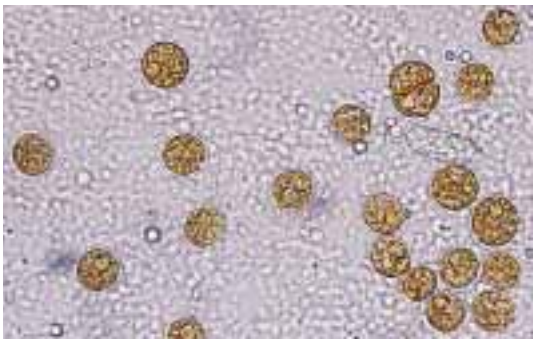


Photo. 1. Zooxanthellae (diameter ~10 μm), with some undergoing cell division.

Photo. 2. A: Healthy *Acropora hyacinthus* colony on the reef flat at 2m depth (April 1998) in front of the Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus. B: Same colony as in 2A, showing bleaching (August 1998). C: Dead colony, the surface of which is covered with algae and silt (October 1998).

3 What is coral bleaching?

Rapid environmental change causes coral stress, making it difficult to maintain the symbiotic relationship. When the symbiotic relationship collapses, zooxanthellae are eliminated from the host coral, causing 'bleaching'. Because zooxanthellae are brown in color and very abundant, a healthy coral appears to have a brown coloration (Photo. 2A). Coral tissues are thin and almost transparent, over a white calcareous skeleton, therefore when zooxanthellae are expelled, the colonies appear white and the corals are referred to as 'bleached' (Photo. 2B). This bleaching is a symptom of stress, but coral tissues can survive under bleached conditions for a limited period of time.

Extremes of environmental factors such as temperature, light, and salinity can induce bleaching (Nakano 2002a). When these factors become higher or lower than the tolerance range of the coral-zooxanthellae association, the resultant stress can lead to bleaching. Patterns of zooxanthellae expulsion vary, according to the fluctuation level of environmental stress: 1) When the change is rapid and large, coral tissues are damaged first and then zooxanthellae will be discharged (Muscatine *et al.* 1992). This is considered acute bleaching, and is a severe threat to coral health. In such cases, most of the discharged zooxanthellae are healthy. 2) When the change is comparatively gradual, there is no remarkable damage to coral tissues, however, zooxanthellae are gradually discharged. Such a discharge is considered to occur due to abnormality of cells (ie., loss of pigment and/or cell contraction) (Kuroki and van Woesik 1999). This condition is known as chronic bleaching and, although corals can survive for short periods in the bleached state, they cannot supply their energy requirements from heterotrophic sources alone; therefore, they will become energy deficient. If this condition lasts for an extended period, corals exhaust stored energy supplies and mortality occurs (Photo. 2C).

There is a boundary between survival and mortality in bleached corals. Jones (1997) has reported that bleached corals are recoverable if the density of zooxanthellae has decreased; they are not recoverable, however, if photosynthetic pigment has been lost in conjunction with the decrease in number. While coral diseases have also been reported as potential bleaching factors, the underlying mechanisms have not yet been clarified (Kushmaro *et al.* 1996; Nakano and Yamashiro 2002).

4 Response of corals to high water temperature

There is a consensus of opinion that an abnormal rise in seawater temperatures around the world was the main cause of the large-scale bleaching of coral reefs in 1997–98 (Wilkinson 1998). Jokiel and Coles (1990) reported that a water temperature rise of as little as 1°C in summer can cause bleaching, eventually leading to coral death. Subsequent bleaching studies have indicated that the main cause of the worldwide coral bleaching in 1997-1998 was a sustained temperature that was 1–2°C higher than the average water temperature in summer.

High water temperature increases the production of toxic substances such as active oxygen within zooxanthellae (Lesser *et al.* 1990). Oxygen free radicals has an unstable charge and is in a high-energy state, which causes damage to cell organelles as well as to Photo System II, thus obstructing photosynthesis (Lesser 1997). Corals may discharge zooxanthellae in self-defense.

High water temperature reduces the amount of photosynthesis and increases the amount of respiration, which increases the carbon dioxide concentration in cells and creates a situation where bleaching readily occurs (Pecheux 1998).

The response of corals to high water temperature differs according to optical conditions, including penetration of ultraviolet rays (Glynn *et al.* 1992; Hough-Guldberg and Smith 1989). Takahashi *et al.* (2001) reported that *Acropora digitifera*, which is a dominant species on many reefs, showed photoinhibition by 250 μmol/m^2/s or more of radiation at a water temperature of 28°C, and by 100 μmol/m^2/s at 32°C. The recovery speed from photoinhibition rapidly decreases at temperatures above 30°C, as compared to lower temperatures. This example also shows that high temperature synergistically affect the physiological function of zooxanthellae.

As biophylactic mechanisms of bleaching, corals synthesize heat shock proteins in response to high water temperature (Sharp *et al.* 1994; Black *et al.* 1995), and through adjustment of calcium ion density in cells (Fang *et al.* 1997). The synthesis of substances to absorb ultraviolet rays in corals (Glynn *et al.* 1992) seems to function as means of alleviating the effects of UV radiation.

Some genetically different clades of zooxanthellae may live together in a single coral colony (Rowan and Knowlton 1995). One of the clades may have a high tolerance to temperature stress; the coral species *Oulastrea crispate*, which contains a high density of this type of zooxanthellae (Chen *et al.* 2003), did not bleach, even during the extreme temperatures of 1998 (Nakano unpublished data). Environmental temperature extremes cause a change in the zooxanthella population composition, which, in turn, leads to different responses to bleaching. In *Goniastrea aspera*, half of the surveyed colonies bleached in 1998, but all recovered, and none of the colonies bleached in 2001 (Nakano 2002b). If different zooxanthella clades are unevenly distributed on the colony, some colonies may bleach in some parts and not others. Differences in coral inheritance types and susceptibility to bleaching at high temperatures are found in *Porites* (Edmunds 1994). Further genetic examination of these phenomena is expected in the future.

5 Impacts of bleaching on corals and coral reefs

After an improvement in environmental conditions, the coral colonies that survived the bleaching showed increased levels of infection by diseases during the recovery process (Williams and Williams 1990). In some corals, the effects of bleaching were manifested in the following reproductive season. In *Pocillopora verrucosa* colonies that recovered after bleaching in 1998, both the number of reproductive colonies and their fertilization rates decreased in 1999. Similarly, colonies of *Montipora digitata* that recovered from bleaching showed decreased numbers of oocytes and smaller testes in the reproductive period of 1999, and embryos from these colonies did not develop normally (Hirose and Hidaka 2000). Glynn and D' Croz (1990) reported that a bleached coral colony required two years for a full recovery and return to normal levels of reproductive output. The death of a parent colony from bleaching directly reduces the number of larvae in the following cohort, but even a surviving colony suffers reproductive abnormalities as a result of bleaching. In sum, bleaching, even if it is only temporary, causes reproductive problems in the coral population and/or community.

The influence of high temperature or bleaching was severe in dominant reef corals such as the fast growing arborescent *Acropora* (Loya *et al.* 2001). Therefore, the mass mortality that occurred in these corals (mainly *Acropora*), following the bleaching in 1998, influenced the entire coral reef ecosystem (Photo. 3).

Photo. 3. Reef flat in front of Cape Busena, where most of the dominant *Acropora* has died out (September 1998). Only a herbivorous fish is visible.

Corals form the basis of the coral reef ecosystem; they create structures, which, in turn, form habitats for other organisms of the coral reef community. Coral reefs that lose a dominant species show decreased coral coverage, reef productivity, and diversity. It has been found that herbivorous fish abundance increases, but that overall fish species diversity decreases (Shibuno *et al.* 1999). It has also been reported that the number of corallivorous fish decreases (Kokita and Nakazono 2001), as does the abundance of invertebrates, such as crustaceans, that are dependent on the corals (Tsuchiya 1999). The abundance of herbivorous sea urchins increased on bare substrate exposed by coral death, and excessive urchin grazing potentially increases bioerosion (Glynn 1990). Increased numbers of grazers may also remove recently settled juvenile corals, thereby impacting the initial stages of recolonization (Suefuji and van Woesik 2001).

6 Coral bleaching in Japan before 1997

Yamazato (1981) observed a comparatively large-scale coral bleaching event in the summer of 1980, on the reef flat in front of the Sesoko Station of the University of the Ryukyus. Sesoko Island is adjacent to the Motobu Peninsula, in the northern part of Okinawa Island. The bleaching was initially observed in August, and the water temperature in the moat was 30–31°C. According to fixed-point observations until next year, 100% of the *Seriatopora hystrix* and 80% of the *Stylophora pistillata* at the survey site died. However, more than 50% of the *Acropora*, *Montipora*, and *Porites* recovered, as well as all of the Faviidae. This seems to be the country's first record of a bleaching event, and the data are presented in Table 1.
Bleaching was not observed at Ishigaki Island in 1980 (Williams and Williams 1990), but coral bleaching was observed in the Yaeyama Islands in the summer of 1983 (Kamezaki and Ui 1984). In the moat and the upper part of the reef slope (<3 m depth), many of the bleached *Acropora* and *Seriatopora* died, but many of the Faviidae and *Fungia* recovered. Bleached *Porites* were not observed at the time. The water temperature exceeded 30°C in July-August at Ishigaki Island, and warm weather maintained the high temperatures. Bleaching was also observed on the reef flat in front of the Sesoko Station in August, from which the author collected a sample of bleached Faviidae (Nakano 1984).

The Okinawa Times (August 11, evening edition) reported a bleaching event at Miyako Island in August 1986. The report stated that the water temperature exceeded the average summer water temperature of Miyako Island by 1°C from June to August. It also showed examples of bleaching observations taken from Cape Zampa on Okinawa Island and from Tokunoshima (Is.) in the Kagoshima Region during the same period. Comparatively extensive bleaching was also observed around Okinawa Island in the summer of 1986 (Tsuchiya *et al.* 1987). *Echinometra mathaei*, an echinoderm that lives in the reef flat in the southern part of Okinawa Island, also suffered high mortality, supposedly because of the high temperature (Tsuchiya *et al.* 1987)

Bleaching was observed at Ishigaki Island in 1990, according to the Nansei Regional Fisheries Research

Table 1. Regions where bleaching was recorded before 1997. ○ shows that bleaching was observed, and × that no bleaching was confirmed.

Year	Location				Reference
	Tokunoshima (Is.)	Okinawa Islands	Miyako Islands	Yaeyama Islands	
1980		○		×	Yamazato (1981); Williams and Williams (1990)
1981					
1982					
1983		○		○	Kamezaki and Ui (1984); Nakano (1984)
1984					
1985					
1986	○	○	○		Okinawa Times (August 11, 1986); Tsuchiya *et al.* (1987)
1987					
1988					
1990				○	Nansei Regional Fisheries Research Laboratory, Fisheries Agency
1991		○			Imai (1992)
1992					
1993			○	○	Department of Planning and Development, Okinawa Prefeccture (1994)
1994		○		○	Fujioka (1994)
1995		○			Nakano (unpublished data)
1996		○			Nakano (unpublished data)
1997					

Laboratory of the Fisheries Agency. In the summer of 1991, bleaching was observed at Okinawa Island and around the neighboring islands of Minna, Kudaka, and Ishigaki (Imai 1992).

In the summer of 1993, a bleaching event was observed in the Miyako and Yaeyama archipelagos (Department of Planning and Development, Okinawa Prefecture 1994), and around Kerama Island (Okinawa Times, August 1, 1993).

In the summer of 1994, coral bleaching and high *Acropora* mortality were observed at Ishigaki Island and on the Motobu Peninsula of Okinawa Island (Fujioka 1994). Bleaching was also observed at Sesoko Island in 1994 and, according to a subsequent survey of *Favites chinensis* and *Platygyra ryukyuensis*, colonies that had recovered from the 1994 event, bleached again in 1995 and 1996 (Nakano unpublished data).

Records of coral bleaching before 1997 focus on Okinawa, which is partly a reflection of local community concern over the coral reefs. The extent of bleaching varied widely between islands and between regions. Bleaching damage (including partial colony damage) was confined to the area from the shallow reef flat to the upper part of the reef slope. These shallow areas were influenced by land-based impacts, as well as by temperature stress, and it is not easy to distinguish which factors were responsible for the bleaching. Environmental change in the field usually occurs as a result of many different factors. The degree of bleaching in shallow waters that are strongly influenced by nearby land (including influx of fresh water and clay sediment) will vary, therefore, between regions.

The response to high temperature and other stresses may be affected by genetic differences, even among corals of the same species (Edmunds 1994), although responses are probably more varied among different species. During local bleaching events prior to 1997-98, bleaching occurred in some colonies but not in all, even within species (Yamazato 1999); therefore, environmental factors were examined for each case individually.

7 Bleaching event after 1998, and the relation with global environmental change

In the summer of 1983, the water temperature off the coast of the Galapagos Islands remained high because of El Niño, and most of the coral species bleached and died. Some endemic species are now thought to be extinct (Glynn *et al*. 1991).

The symbiotic relationship between animals and algae is not restricted to corals and zooxanthellae, but is also seen in many other invertebrates (Yamasu 1988). These associations were also negatively affected in the Galapagos, where a variety of other symbiotic species were bleached. Glynn (1993) suggested that such large-scale bleaching extended beyond the symbiosis between corals and zooxanthellae, and that it should be described, therefore, as a 'coral-reef bleaching event' (Photo. 4).

The large-scale bleaching event that started in the Great Barrier Reef in 1997 spread to the coral reefs of the northern hemisphere by July 1998. The main cause of the bleaching was high water temperatures. The National Oceanic and Atmospheric Administration (NOAA*[2], USA) superimposed images of the progressive coral reef bleaching event on satellite images of seawater temperatures, and clearly showed that the movement of a high-temperature water mass (called a 'hot spot') correlated with the progression of the bleaching (Fig. 1).

This high-temperature water mass reached Japan, causing the bleaching of coral reefs in the Ryukyu Islands and various other places (Table 2). The bleaching situation for the entire country is described in detail in Chapter 6. Large-scale bleaching of coral reefs began in Okinawa around July 1998. Many dominant coral species such as *Acropora* suffered from catastrophic damage on the west coast of Okinawa Island, resulting in decreased coral coverage and a change in community structure (Loya *et al*. 2001).

In the Ryukyu Islands, while corals suffered partial mortality in some regions, many corals recovered from bleaching in other areas. Deviation from the average water temperature, periods of high water temperatures, or the addition of factors such as light, tidal current, and turbid water may have caused these differences. In the Kerama Islands, adjacent to the west coast of Okinawa Island, the bleaching level was low and the corals recovered well. It is possible that the shallow island shelf prevented the warm water mass from reaching the shallow reefs and, therefore, the corals were not exposed to high temperatures for extended periods (Nadaoka *et al*. 2001).

A compilation of global bleaching events (Glynn 1993;

Photo. 4. Coral community in the southwest of Sesoko Island, where the dominant *Acropora* were bleached (August 1998). The large colony in the upper part of the reef is a soft coral.

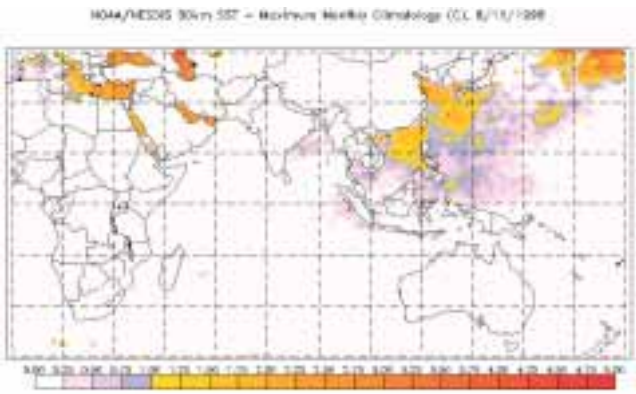


Fig. 1. Hot spot observed by satellite on August 11, 1998 by NOAA. The image shows that sea surface temperatures off the west coast of Japan (including the Ryukyu Islands) were at least 1°C above average (http://orbit-net.nesdis.no-aa.gov/orad/coral_index.html).

Table 2. Locations of bleaching in 1998.

Location	Date of login	Bleached time	Bleached depth bound (m)	Bleached species, groups	Time of died out	Died depth (m)	Died species, groups
Amakusa, Kumamoto Pref.	8.Sep.98		2-5	*Pocillopora*, etc.			
Kinko Bay, Kagoshima Pref.	4.Sep.98		2-5	tabulate *Acropora*			
Kushikino, Kagoshima Pref.	4.Sep.98	middle of Aug		*Acropora*, etc.			
Sakurajima (Is.), Kagoshima Pref.	6.Sep.98		3-5	*Acropora*, etc.			
Nakanoshima (Is.), Kagoshima Pref.	6.Sep.98			*Acropora*, etc.			
West of Tanegashima (Is.)	2.Sep.98	beginning of Aug	2-5	*Acropora*, etc.			
Yakushima (Is.)	8.Sep.98						
Kasari Bay, Amami Oshima (Is.)	9.Sep.98	middle of Aug	2-10	*Acropora*, etc.		2	*Acropora*, etc.
Tatsugou Bay, Amami Oshima (Is.)	4.Sep.98	middle of Aug	2-10	*Acropora*, etc.			
Kikaijima (Is.)	3.Sep.98						
Tokunoshima (Is.)	3.Sep.98						
Okinoerabu Is.	3.Sep.98						
Yoron Is.	3.Sep.98						
Izena Is., Iheya Is.	20.Aug.98						
Henoko, Okinawa Is.	13.Sep.98			*Acropora*, etc.			*Acropora*, etc.
North of Bisezaki, Okinawa Is.	Sep.98	beginning of Aug	2-5	*Acropora*, etc.			*Acropora*, etc.
South of Bisezaki, Okinawa Is.	7.Oct.98	middle of Aug	in moat	*Acropora*, etc.		in moat	*Acropora*, etc.
Cape Busena, Okinawa Is.	15.Sep.98	middle of Aug	≤ 30	*Acropora*, etc.		≤ 5	*Acropora*, etc.
Cape Maeda, Okinawa Is.	20.Sep.98		≤ 30	*Acropora*, etc.			*Acropora*, etc.
Ie Is.	20.Sep.98	middle of July		*Acropora*, etc.			*Acropora*, etc.
Minna Is.	Sep.98	beginning of July	≤ 30	*Acropora*, etc.	late Aug	≤ 5	*Acropora*, etc.
Sesoko Is.	Sep.98	beginning of July	≤ 30	*Acropora*, etc.	late Aug	≤ 5	*Acropora*, etc.
Kumejima (Is.)	9.Sep.98						
Akajima (Is.)	20.Sep.98		≤ 20	*Acropora*, etc.		≤ 5	*Acropora*, etc.
Nittahama, Zamami Is.	25.Sep.98		≤ 20	*Acropora*, etc.		≤ 5	*Acropora*, etc.
North of Zamami Is.	20.Sep.98			*Acropora*, etc.			
Aharen beach, Tokashiki Is.	20.Sep.98		≤ 12	*Acropora*, etc.			*Acropora*, etc.
Miyako Is.	20.Sep.98		shallows	*Acropora*, etc.		shallows	*Acropora*, etc.
Shiraho, Ishigaki Is.	20.Sep.98	middle of Aug		*Acropora*, etc.			
Kabira, Ishigaki Is.	20.Sep.98	middle of Aug	≤ 15	*Acropora*, etc.	biggining of Sep	2-3	*Acropora*, etc.
Osaki, Ishigaki Is.	20.Sep.98	middle of Aug	5-6	*Acropora*, etc.			
Taketomi Is.	20.Sep.98		5-6	*Acropora*, etc.			

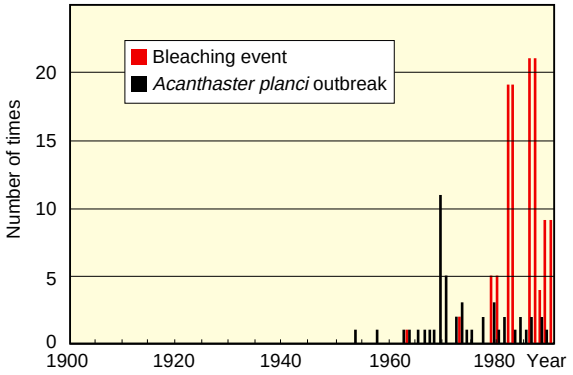


Fig. 2. Frequency of damage to corals by *Acanthaster planci* and by coral bleaching. Bleaching increased rapidly after 1980.

Fig. 2), showed that many coral communities decreased because of predation by the crown of thorns starfish (*Acanthaster planci*) and subsequent bleaching of reefs. Scientific observation of coral reefs developed rapidly with the availability of SCUBA diving technology soon after World War II. Damage from *A. planci* outbreaks started to occur frequently in the 1950s, but as the outbreaks became more significant, reef monitoring became more active. Coral reef bleaching was initially observed in the latter half of the 1970s; it was previously an unknown phenomenon. Glynn was concerned about the correlation between coral bleaching and global warming as a result of human activities. He compared the situation to that of a 'canary in a coal mine', a method that was used in the past to detect low levels of toxic gases in mines. He proposed that coral reefs are sensitive indicators of a deteriorating global environment, and that this issue should therefore be addressed on a global scale.

Bleaching events were localized in 1993, but became global in 1998. Total coral mortality from bleaching seems to have far exceeded the mortality attributed to *A. planci* outbreaks. Computer simulations and statistical analyses have clearly indicated that the rise in seawater temperatures that played a role in the catastrophic crisis in coral reef ecosystems is strongly related to global warming (Barnett *et al*. 2001).

Coral reef bleaching was also recorded at Okinawa Island in the summer of 2001 and 2003 (Nakano 2002b; Nakano unpublished data). Fortunately, these bleaching events were not global, but were caused by the movement of a large mass of warm water around Okinawa and neighboring areas, which was clearly confirmed using satellite observation systems etc (Shimojo *et al*. 2001). Some coral species extended their distribution range further north during periods of anomalously high water temperatures in the Kuroshio Current (Nojima 2001). It is not yet known whether these species will reproduce and establish a regional population or disappear as failed migration. Even if a new population does establish, this might constitute a very rare case. Taking evolutionary time scales into consideration, it is doubtful whether individual species can completely adjust to a new habitat if it is only suitable during short periods of anomalously high temperatures. Environmental tolerance limits may be adjusted to permit range extension, but whether the reef species can adjust quickly enough to exploit the new habitat is unlikely. How big will this crisis turn out to be for coral reef ecosystems? It is vital that we take urgent action and increase our research efforts in this area (appeal in the 1998 Japanese Coral Reef Society convention on coral bleaching).

Cited Website:

*1: http://www.soc.nii.ac.jp/jcrs/english/index.html

*2: http://orbit-net.nesdis.noaa.gov/orad/coral_index.html

2-2 Predation damage to corals

Hiroyuki Yokochi

1 Introduction

There are a broad range of organisms that prey on corals. In this chapter I will discuss crown-of-thorns starfish (*Acanthaster planci*), coral-eating gastropods, and the sponge *Terpios*. These organisms are major coral predators that are capable of causing significant disturbances to coral communities.

2 Crown-of-thorns starfish (*Acanthaster planci*)

This is a large starfish (up to ~80 cm diameter) with approximately 15 arms. It is widely distributed in coral reef areas in the tropics and subtropics throughout the Pacific Ocean, the Indian Ocean, and the Red Sea. Frequent increases in population numbers have caused extensive damage to coral communities at various locations in recent years; in fact, among the organisms that predate on corals, this species has had the biggest influence on coral communities (Birkeland and Lucas 1990; Photo. 1).

While some kinds of starfish reproduce asexually by autotomy, *A. planci* is known to proliferate only via sexual reproduction. One female may produce eggs to the number of several tens of millions during one season. Consequently, a very small increase in the survival rate of larvae can result in a large increase in the adult population; the species can therefore be said to have outbreak potential.

Spawning occurs during July around Okinawa Island and, about a month earlier (early June), around the Yaeyama Islands. The time of spawning is thought to be controlled by water temperature (Yamazato and Kiyan 1973; Yokochi and Ogura 1987); at both locations the water temperature is 27-28°C in June and July. It has been assumed that this water temperature is the most favorable for egg development and larval growth (Lucas 1973).

The life cycle of *A. planci* is described in Fig. 1. Fertilized eggs develop while drifting in plankton and before long hatch as swimming larvae. Larvae remain planktonic for several weeks, progressing through several stages of development, before swimming to the substrate and metamorphosing into a juvenile starfish. At this stage, *A. planci* has five arms (~0.5 mm diameter), like other starfish. Juveniles grow slowly at first, feeding on calcareous coralline algae. Similar to adult starfish, digestion occurs outside the body via a reversed gastric cavity, and

Photo. 1. *Acanthaster planci* (photo taken by K. Nomura).

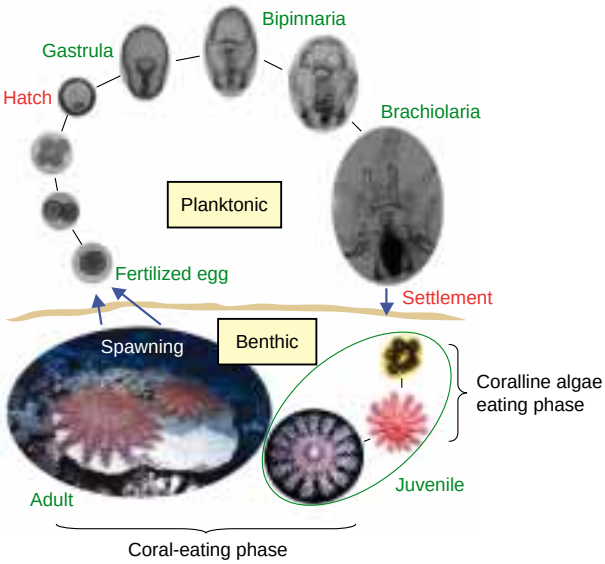


Fig. 1. Life cycle of *Acanthaster planci*.

round white feeding scars are left on the substrate. Around six months after spawning the starfish is ~10 mm in diameter and possesses its full complement of arms. At this stage it begins a gradual transition to feeding on corals, the body colour changes into adult phase, and growth rapidly accelerates. Sexual maturity occurs at ~20 cm diameter, approximately two years after spawning, and most individuals will spawn within the next year (Yamaguchi 1973; 1974; Lucas 1984; Ueno and Yokochi 1990; Yokochi and Ueno 1990). At this stage coral consumption increases massively, and the starfish may be observed in groups on the reef. Although there are no data regarding natural longevity, some individuals are known to have survived about eight years in aquaria (Moran 1997).

1. History and current state of outbreaks

The oldest written record of an outbreak of *A. planci* in Japan is believed to be in an article written by Shirai (1956) about his travels in Amami Oshima. A research report of the Nature Conservation Bureau, Environment Agency (1989) compiled information about historical outbreaks, including the period prior to the 1960s, using anecdotal reports from fishermen and others. Following the publication of this research report, more information was obtained from scientific studies and other sources, such as newspaper articles; these data are included in Fig. 2.

Based on this information, and although there are few written records, it appears that outbreaks of *A. planci* prior to 1960 were sporadic and short-lived. From 1969, however, a series of outbreaks began around Okinawa Island and then occurred simultaneously at various locations over a relatively long time period. Much more information is available about these outbreaks in the form of contemporary reports, research papers, and newspaper articles. The following sections use these materials to describe patterns of outbreaks since 1969 and the current situation in each main sea area.

a) Yaeyama Archipelago

Following a local outbreak around Hatoma Island in 1972, *A. planci* numbers started increasing gradually in the southeast of Sekisei Lagoon. The number of individuals increased explosively in the 1980s, and predation damage extended to the whole of Sekisei Lagoon (Fukuda and Miyawaki 1982). In the early 1980s the outbreak spread to surrounding islands and the sea area from the northern to the southern coasts of Iriomote Island, causing severe damage to these coral communities (Nature Conservation Bureau, Environment Agency 1984; Yokochi *et al.* 1991). Starfish numbers increased explosively around Hateruma Island in 1984, damaging major coral communities in sea areas stretching from the northern to the western coasts (Nomura and Kamezaki 1987). By the middle of the 1980s, all coral communities in the Yaeyama sea area (with some minor exceptions) had been catastrophically damaged by starfish predation. As the number of live corals decreased, the number of starfish dropped sharply, and the outbreak in this area terminated at the end of the 1980s (Fig. 3).

Subsequently, individual *A. planci* were seen sporadically, but their population density remained extremely low. Coral communities started to recover, and developed rapidly in the 1990s (Mori 1995). However, starfish numbers also began to increase, and by 2003 locally high densities were observed in some areas, including southern Sekisei Lagoon and Nagura Bay, Ishigaki Island (Nature Conservation Bureau, Ministry of the Environment 2003). Outbreak densities have not yet been reached in the district of Yaeyama, but the historical data indicate that this might be a possibility in the near future.

b) Okinawa Islands

In 1969 an outbreak was first reported at Onna, on the western coast of Okinawa Island. A survey of the entire island in 1972 found the starfish at high densities off the coast at Onna and through the area around Motobu Peninsula to the western coast of the northern region (Nishihira and Yamazato 1974). Three years later, a dense distribution of the starfish was observed off the southern coast of the island, around to the central eastern coast (Okinawa Prefectural Tourism Development Bureau 1976). By the end of the 1970s, almost all of the corals on all the reefs off Okinawa Island were thought to have been eaten by the starfish. A 1984 survey found *A. planci* widely distributed, but at low densities, and many were seen in areas where coral coverage was high (Sakai *et al.* 1988). Coral coverage in 1984 was, on the whole, lower than in 1972, but in some sea areas it was higher than in 1976. This pattern has been interpreted as a small-scale recovery by coral communities from the 1976 outbreak, with ongoing starfish predation pressure inhibiting larger scale recovery in most areas (Sakai and Nishihira 1988; Fig. 4). This chronic outbreak around Okinawa Island, during which recovered coral communities were affected again and again, may have lasted for more than 20 years.

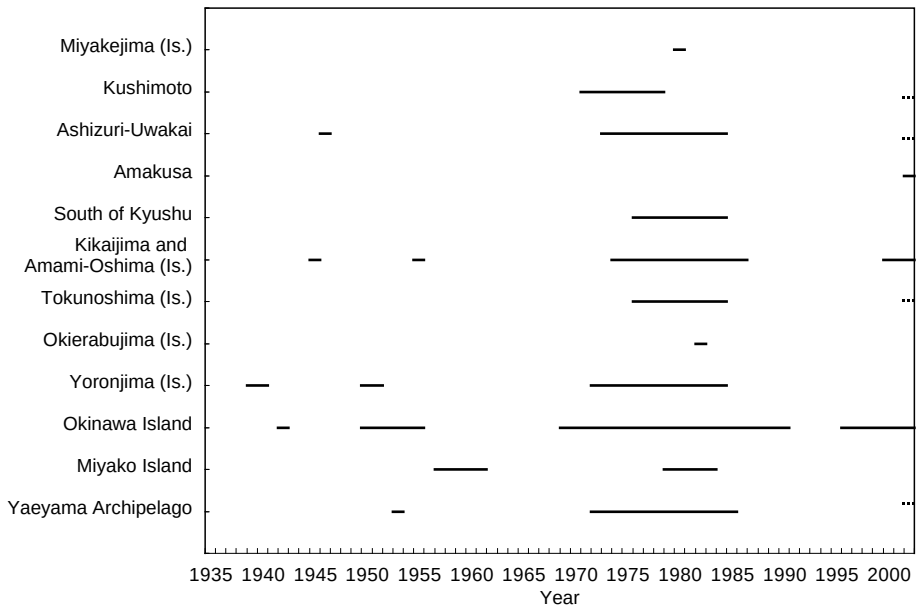


Fig. 2. History of *Acanthaster planci* outbreaks in Japan (modified from Nature Conservation Bureau, Environment Agency 1989).

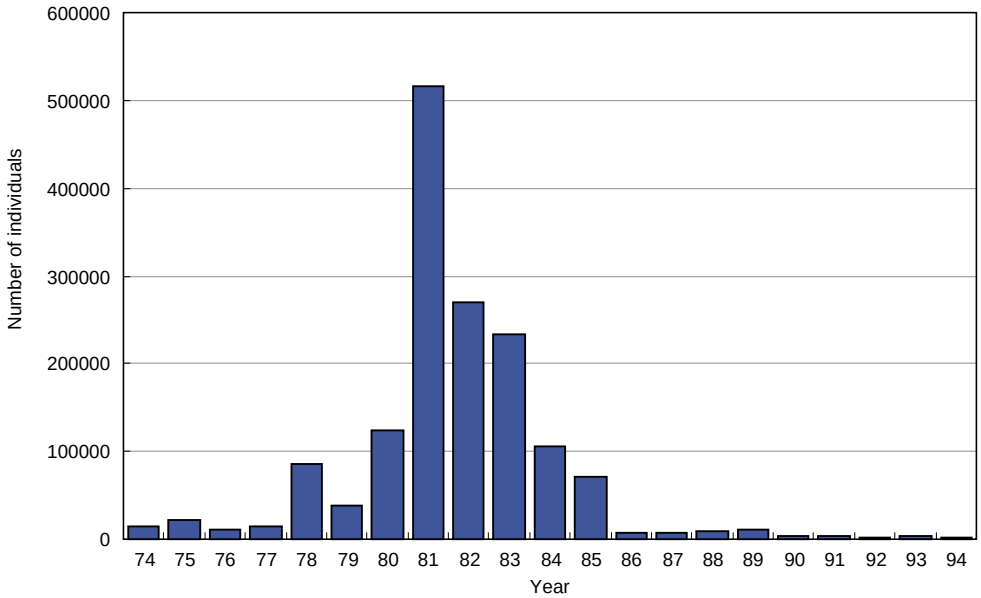


Fig. 3. Numbers of exterminated individuals of *Acanthaster planci* around Sekisei Lagoon (modified from Mori 1995).

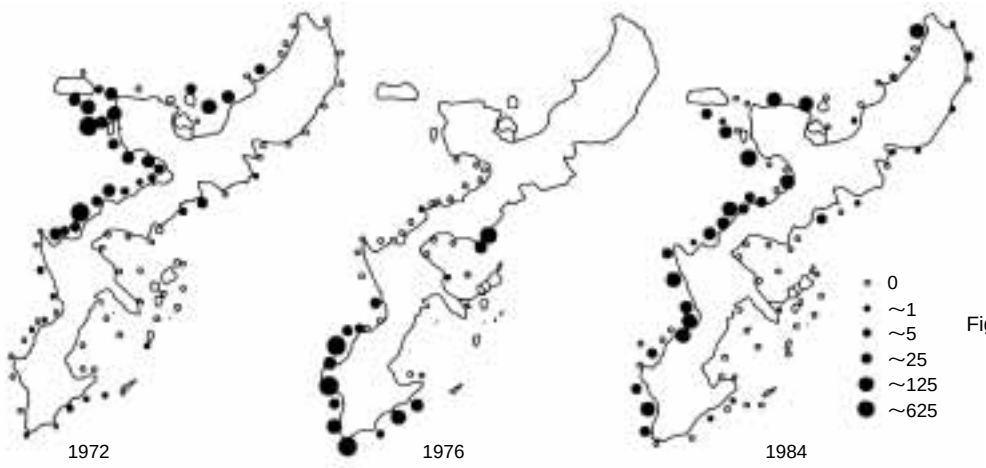


Fig. 4. Changes in observed numbers of *Acanthaster planci* around Okinawa Island, per 10-minute swim period (modified from Kato 1999).

After 1990, *A. planci* numbers remained low for a while. Coral communities showed recovery, and *Acropora* communities in comparatively healthy states were observed off some coasts of Okinawa Island and surrounding islands (Department of Planning and Development, Okinawa Prefecture 1993). However, in 1994 increased starfish numbers were reported off the coast at Onna, where outbreak populations had first been observed in 1969. The presence of a high-density cohort here was confirmed in 1996 (Arakaki and Yamazato 1998). Reefs at Chibishi near Naha City showed signs of damage by starfish in 1997, and this outbreak extended to surrounding islands such as Kerama, where starfish were observed in high density groups from around 2001. The outbreak continued to spread to various sea areas off Okinawa Island, reaching the east coast in 2002. By 2003, high-density groups of the starfish were rarely seen in the waters off Okinawa Island, except in some locations, and coral communities with a high coverage disappeared at the same time. However, outbreak populations were still active around surrounding islands (e.g., Maejima and Nagannujima of the Kerama Islands, and Tonaki Island), with coral coverage decreasing (material from Okinawa Prefecture Nature Conservation Division).

c) Amami Archipelago

Starfish extermination programs started in 1974 at Amami Oshima, and in 1976 at Tokunoshima. Based on the numbers of individuals exterminated, the worst outbreak in this area seems to have occurred at the beginning of the 1980s (Yamaguchi 1986c, 1987). Extermination rates subsequently decreased gradually at Amami Oshima, and remained low during the 1990s. However, rates increased rapidly in 2001, and this area is now considered to have outbreak status (Nature Conservation Bureau Ministry of the Environment 2003).

d) Kyushu, Shikoku, and the Kii Peninsula

Starfish extermination programs have been conducted in southern Kyushu since 1976. Numbers of exterminated starfish peaked at ~600 individuals in 1978 and subsequently decreased (Yamaguchi 1987). *A. planci* has rarely been observed around Amakusa in mid-west Kyushu, but starfish feeding scars were observed recently on local coral communities, and an extermination program was undertaken in 2002-2003 (Nature Conservation Bureau Ministry of the Environment 2003).

In the Ashizuri-Uwakai Sea in Shikoku, extermination programs have been conducted since 1973. The number of exterminated individuals peaked at ~15,000 in 1977 and subsequently decreased; the outbreak ended in the early 1980s. In subsequent years, several hundreds of individuals were exterminated annually in the area of Okinoshima. Although *A. planci* mostly disappeared from the Tatsukushi sea area after ~1990; since 2000, populations have tended to increase once again (Nature Conservation Bureau, Ministry of the Environment 2003), and the possibility of a future outbreak cannot be ignored.

A. planci were first observed around the Kii Peninsula in the 1970s, and 1,385 individuals were exterminated between 1972 and 1980, peaking in the mid-1970s. The starfish disappeared in the early 1980s and were not observed again for some time afterwards. However, numbers have started to increase again recently, and there is concern that this may signal an impending outbreak (Nature Conservation Bureau Ministry of the Environment 2003).

e) Miyakejima Island

The presence of *A. planci* was confirmed for the first time in 1977 at Miyakejima in the Izu Islands. Some 3,500 individuals were exterminated in 1980. Following this extermination program, the population was almost extinct; the few survivors were probably killed by unusually low water temperatures during the following winter (Yamaguchi 1986c).

2. Countermeasures

Despite immense budget funding for *A. planci* extermination programs, the countermeasures generally ended in failure; most coral communities sustained devastating damage from starfish predation during outbreaks. Probable reasons for this failure include the possibility that countermeasures commenced too late (extermination programs were set in motion only after outbreaks became obvious), sea areas targeted for protection were too vast, and the purchasing method tended to disperse extermination effort, thereby preventing thorough extermination (Yamaguchi 1986a). Nonetheless, a partial success was achieved at one location. Vast areas of Sekisei Lagoon have been monitored in annual surveys of corals and *A. planci* by the Yaeyama Laboratory of the Marine Parks Center of Japan since 1983. At the start of this survey program, starfish damage was already such that most of the coral reefs in Sekisei Lagoon had been destroyed. The laboratory recommended, therefore, that the Yaeyama Fishery Cooperative concentrate their extermination efforts on those small areas where live coral cover-

age was still apparent (Kamezaki *et al*. 1987). As a result, the corals in these areas were able to survive the outbreak, just barely escaping starfish damage.

In terms of controlling outbreaking starfish populations, the lessons of these experiences are clear. The protection area must be limited, so that effort can be concentrated. Adequate monitoring is essential to provide warning of an imminent outbreak. Rapid response to warnings is also necessary, and repeated, thorough exterminations must be carried out in the area that is to be protected. These points are now commonly recognized among researchers.

Although countermeasures may have been delayed and inadequate during the current Okinawa outbreak, efforts to learn from past lessons and develop alternatives are being made. A survey conducted by Okinawa Prefecture's Emergency Coral Reef Conservation Project, in 2002, aimed to describe the current status of Okinawa's reefs and to identify priority areas for protection in the event of an outbreak. As a result, concentrated monitoring and extermination programs are being conducted at the five most important conservation areas in the Zamami and Tokashiki island districts of the Kerama Islands. The Ministry of the Environment and the Nature Conservation Bureau of Okinawa Prefecture, in cooperation with fishermen and diving businesses, are collaborating to strengthen monitoring, select protected areas to prioritize, and conduct preventative extermination programs in the Yaeyama Islands, where an imminent outbreak is possible. Similar systems are being organized for Miyako Island. In cooperation with these measures, the Research Institute for Subtropics is attempting to verify whether outbreaks can be predicted by monitoring young starfish feeding on coralline algae (Yokochi 1998).

It has been suggested that the chronic nature of the previous outbreak in Okinawa was fostered by half-hearted extermination programs, which increased the relative food available per starfish, thereby improving conditions for the remaining individuals (Sano 1985; Yamaguchi 1986a). However, extermination programs were conducted in a similar manner in the Miyako and Yaeyama archipelagoes, and the starfish infestation did not become chronic in these locations (*A. planci* almost disappeared at the same time as the corals were devastated); the reason for this difference remains unclear. Anthropogenic eutrophication of the seas around Okinawa Island may have contributed to the chronic outbreak populations of *A. planci*; however, if this was the case, the mechanism is unknown.

In Japan's temperate zones, *A. planci* numbers are affected by the lowest water temperatures in winter following the fluctuation of the path location of the Kuroshio Current, which carries larval starfish from the south (Yamaguchi 1987). As average seawater temperatures have risen in recent years, there have been corresponding reports of northern range extensions for marine organisms along various coasts of southern Japan. Now or in the near future, coral communities in temperate zones may be being damaged by *A. planci,* and appropriate monitoring programs should be developed with this in mind.

3 Coral-eating gastropods

Coral-eating gastropods of the muricid family, particularly *Drupella* spp., sometimes develop into outbreak populations and damage coral communities (Turner 1994). Although damage by the closely related species *Habromorula spinosa* has been reported from Amakusa in Kyushu, in all other areas *Drupella* species have been responsible, in many cases *Drupella fragum* (Photo. 2). Both gastropods are small (40 mm or less in shell length) and widely distributed in live coral areas south of central Honshu (mainland Japan). They use a grater-like feeding organ called a radula to scrape soft coral tissues away from the hard skeleton.

In Japan, outbreak populations of coral-eating gastropods have caused damage to coral communities at Miyakejima (Moyer *et al*. 1982), off the Nichinan coast of Miyazaki

Photo. 2. *Drupella fragum* preying on *Acropora hyacinthus* at Komeotoura, Miyazaki. (photo by H. Yokochi)

Prefecture, the Ashizuri-Uwakai Sea (Nature Conservation Bureau, Environment Agency 1991), and Amakusa (Nature Conservation Bureau, Environment Agency 1994a).

At Miyakejima, the outbreak began simultaneously with that of *A. planci* in 1976, and together these two coral predators caused the destruction of many coral communities. In some places it appeared that the gastropods damaged corals as much as, or more than, *A. planci* (Moyer *et al*. 1982).

Off the Nichinan coast, an outbreak of coral-eating gastropods occurred in 1987, and extermination programs commenced the following year. Despite countermeasures, *Acropora* communities were catastrophically damaged in places such as Komeotoura Bay, around the boundary between the town of Nango and the city of Kushima in Miyazaki Prefecture (Takayama and Shirasaki 1990; Nature Conservation Bureau, Environment Agency 1991).

In 1989 an outbreak was identified at Shirigai, Otsuki, in the Ashizuri-Uwakai Sea. The town of Otsuki immediately put together an emergency budget and began extermination programs (Tominaga 1998). An emergency ecological survey by the Environment Agency in 1991 led to a policy of intensified extermination within a prioritized protected area. Monitoring programs record the health of the coral communities during extermination programs. Administrative agents, citizens, and volunteer organizations cooperate in these operations, and are actively engaged in the extermination effort. As a result, coral communities within the protected area have escaped catastrophic damage and are in a relatively healthy state (Nomura and Tominaga 2001).

Habromorula spinosa caused damage to corals in Amakusa in 1992. Following surveys of the gastropod population and rates of predation damage, two areas were selected: one to be protected through extermination programs, the other to act as an unprotected control site (Nature Conservation Bureau, Environment Agency 1994a). Comparison of results showed that gastropod numbers remained low at the protected site, and that coral damage was minimal; however, at the unprotected control site, coral coverage declined sharply, although the damage was not catastrophic.

Occasional coral damage by high-density populations of gastropods has been reported from various locations in the Ryukyu Islands (e.g., Fujioka and Yamazato 1983; Fujioka 1984; Habe 1989; Shimoike 1995), but there have been no examples of wide-ranging community devastation. Fujioka (1984) reported that outbreak populations of *D. fragum* were causing considerable damage to coral reefs off Chinen, southern Okinawa Island, in 1981-82, but no further details are known.

While damage by high-density populations of gastropods has often been observed on Japanese coral reefs, the impact has generally not been devastating. However, the influence of these gastropods cannot be ignored in places where coral coverage has already decreased because of other causes, like *A. planci.* In these situations the gastropods may cause further devastation and delay recovery.

4 *Terpios*

Terpios hoshinota (Photo. 3) is a sponge that lives symbiotically with a photosynthetic cyanobacterium (Rützler and Muzik 1993). This species is widely distributed in coral reefs of the western Pacific Ocean; the thin ash-black layer of symbiotic tissue sometimes covers and kills corals over a wide range (Bryan 1973; Yamaguchi 1986b; Plucer-Rosario 1987).

The first Japanese outbreak of *Terpios* occurred in Tokunoshima around 1985. Survey teams from the Environment Agency found large patches of *Terpios* (ca. 200×500 m) off the coast of Yonama, Amagi, in the northwestern part of the island (Nature Conservation Bureau, Environment Agency 1986). At Boma, Tokunoshima, off the central area of the eastern coast, a few small patches were found,

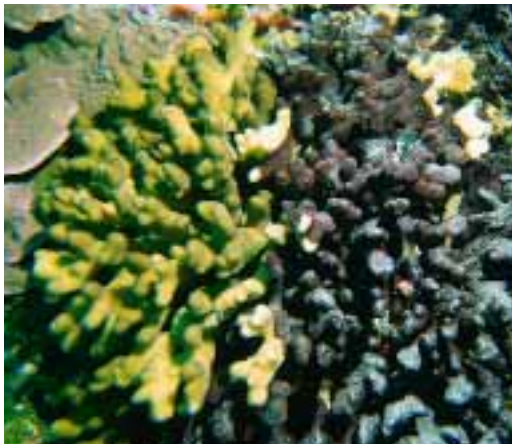


Photo. 3. *Terpios hoshinota* overgrowing *Stylophora pistillata* at Iriomote Island, Okinawa. (photo taken by H. Yokochi)

but the outbreak seemed to have faded. The Tokunoshima outbreak is assumed to have been temporary, and ended without human interference*[1].

Terpios is widely distributed in the Ryukyu Islands (Nature Conservation Bureau, Environment Agency 1986; Rützler and Muzik 1993), but further details are not known. *Terpios* was not mentioned in a coral reef survey report covering almost the entire area of Okinawa Prefecture in 1993-94 (Department of Planning and Development, Okinawa Prefecture 1993, 1994). A 2003 nationwide survey report of *A. planci* distribution in marine park zones did not mention *Terpios* either, although coral-eating gastropods were discussed (Nature Conservation Bureau, Ministry of the Environment 2003). *Terpios* outbreaks may not become a particular problem in these areas.

5 Summary

The causes of outbreaks, with respect to any of the above mentioned species, are not clearly understood. While relationships with the terrestrial outflow of soils and nutrients, etc., have been suggested, verification is difficult and no convincing proof has yet been presented. Clearly, further research is necessary, but the immediate problem of reef destruction requires immediate, effective action. It has been recognized that unthinking, unfocussed control programs have solved none of the problems described above, and may even have prolonged the damage in some cases. Furthermore, it should be kept in mind that extermination of the predator species is not the objective of control programs; their aim is to conserve coral communities.

Even when devastated by disturbances such as those described above, coral communities can recover, as long as the disturbance is temporary. What is of the utmost importance in this respect is the preservation of an environment that facilitates the recovery of damaged coral communities; this can be achieved through conservation (or improvement) programs that monitor and regulate the quality of the sea areas, as well as the adjacent land areas, where coral reefs found.

Cited website:

*1: http://www.cc.u-ryukyu.ac.jp/~coral/Terpios.htm

2-3 Coral diseases

Hideyuki Yamashiro

1 Introduction

Many of the coral communities around the world may disappear within a few decades as a result of influences such as global warming (Hughes *et al*. 2003). In Japan, elevated seawater temperatures during the 1997/1998 El Niño-Southern Oscillation (ENSO) event caused the most severe coral bleaching and mortality ever observed. This phenomenon has continued to occur intermittently during subsequent years. In addition to bleaching, corals have been threatened with predation by the crown-of-thorns starfish (*Acanthaster planci*), smothering by terrigenous sediments, and poisoning by agricultural chemicals in runoff. Since the 1970s, there have been reports of bacterial diseases among hard corals (scleractinians), and the number of such reports increased throughout the 1990s. In some locations, the damage caused by coral disease has been catastrophic. Coral disease is now considered a significant new threat to coral reefs, and this section will further examine the crisis. This paper is a modification of a manuscript that was submitted to the Journal of Fossil Research (Yamashiro 2003), with the addition of new information.

2 Malignant coral diseases

Coral disease transmission processes are poorly understood. They can be caused by infection with pathogenic bacteria, viruses, fungi, or protozoans, as well as by helminthes and arthropods. Coral diseases can also be triggered by abiotic factors such as temperature, soil particles, ultraviolet rays, heavy metals, and agricultural chemicals. However, in reality, both biotic and abiotic factors are likely to be intricately intertwined in many cases, and specifying a single causative factor is not easy.

Many coral diseases have been recognized, but comparatively little is known about the causative agents (Richardson 1998). Research is further complicated by the assignment of more than one descriptive name to a single disease. Thus, there are still many unsolved problems in the study of coral diseases. Some diseases can be fatal to a colony, while others are less harmful and may result in minor skeletal anomalies. The list of coral diseases presented in Table 1 is not exhaustive, and, in addition to the traditional published scientific literature, further information on coral diseases is available on a range of websites*[1]. The large impacts of coral diseases on coral reefs and the diseases for which causes have been identified are included in this section.

Table 1. Coral diseases with known causes (excluding tumors).

Disease name	Causal bacteria	Coral species	Location	Remarks	Reference
White Pox	*Serratia marcescens*	*Acropora palmata*	St. Croix, Belize, Jamaica, Florida, Bahamas	From 1996. Active in summer.	Patterson *et al*. (2002)
Black Band Disease	*Phormidium corallyticum*, etc.	various species	GBR, Fiji, Red Sea, Philippines, Bermuda, etc.	Hypoxia death brought by hydrogen sulfide. Active in summer.	Garrett and Ducklow (1975), etc.
Bacterial Bleaching	*Vibrio* AK-1	*Oculina patagonica*	Mediterranean coast of Israel	Active in high temperature	Kushmaro *et al*. (1996)
Plague type II	*Sphingomonas*	*Diploria*, *Dichocoenia*, etc.	Florida, Bahamas, etc.	From 1996. Necrosis occur at a speed of 2 cm/day	Richardson *et al*. (1997)
Aspergillosis	*Aspergillus sydowii*	*Gorgonia ventalina* (soft coral)	Caribbean Sea	Octocorallia was damaged	Geiser *et al*. (1998)

Coral diseases came under the spotlight in the 1970s, when black band disease (BBD) was discovered in the Caribbean Sea and, subsequently, in the Indian and Pacific oceans. It became apparent that BBD had infected not just Hexacorallia but multiple species of coral, including Octocorallia and Stylasterina. The causal agent of BBD is a consortium of microbes, composed of a filamentous cyanobacterium (*Phormidium* spp.) together with sulfate-reducing bacteria and/or sulfate-oxidizing bacteria that create a microbial mat structure. When these bacteria are introduced and propagate inside coral tissues, a black mat is formed, which makes the diseased coral easily distinguishable from healthy, live coral. Tissue necrosis, caused by oxygen depletion and the release of hydrogen sulfide from the bacteria, occurs at a rate of several millimeters per day (Richardson *et al.* 1997). The dying coral tissue becomes a source of nutrients for the bacteria.

White pox is a widespread disease that has killed about 90% of the branching *Acropora palmata* in Caribbean coral reefs, resulting in this species being classified as an endangered species. It has been reported that corals are being killed at the rate of 10 cm^2 per day. The causal bacterium is *Serratia marcescens* (Patterson *et al.* 2002). *Serratia* bacteria are better known as enteric bacteria; these bacteria are implicated in human infection and have become a problem in hospitals. A vibrio virus (*Vibrio* AK-1) has also been found that rapidly kills the tissue of *Oculina patagonica* at the rate of several centimeters per day (Kushmaro *et al.* 1996). In addition, the cause of a mass die-off of Octocorallia (*Gorgonia ventalina*) in the Caribbean was attributed to the universal soil fungus *Aspergillus sydowii* (Geiser *et al.* 1998).

Recently, a new disease called *Porites* ulcerative white spot disease (PUWS) has been identified on *Porites* species in the Indian and Pacific oceans (Raymundo *et al.* 2003). From an initial colony 3–5 mm in diameter, the disease can spread and lead to the death of an entire colony. Although the cause is still uncertain, precautions should be taken.

The mass die-offs of coral caused by pathogenic bacteria have been reported only relatively recently, indicating that most of these diseases have developed since the 1990s. This implicates the deterioration of the marine environment and an accompanying decrease in the strength of corals' immune systems in the development and spread of the coral diseases that are caused by pathogenic bacteria.

3 Coral diseases associated with tumors

Some researchers do not consider overgrowth (i.e., hyperplasia, a state in which the polyps become huge) and tumors (e.g., neoplasm, mutation) as symptomatic of disease in corals. For example, Loya *et al.* (1984) suggested that overgrown polyps of massive corals, such as *Platygyra* on the Great Barrier Reef, are normal. Thus, an abnormal external morphology may not directly signify a diseased state in corals. Tumors have been observed growing on a variety of coral species worldwide (e.g., Cheney 1975; Bak 1983; Loya *et al.* 1984; Peters *et al.* 1986; Coles and Seapy 1998; Yamashiro *et al.* 2000; Gateno *et al.* 2003), but the causes have not been clarified.

Tumors on corals generally appear as hemispheric lumps with a lower zooxanthellae density than that of the surrounding colony. The tumor growth includes the skeletal structure of the coral and does not kill the colony; therefore, it is usually thought of as a so-called benign structure. However, at the site of the tumor, there is a decrease in polyp number and in fecundity, indicating that it is more appropriate to consider the tumor to be a diseased condition. Corals with tumors are easily recognized in the field by their lower polyp number and the whitish appearance that results from a reduced number of zooxanthellae.

Coral colonies display a multiplicity of morphologies,

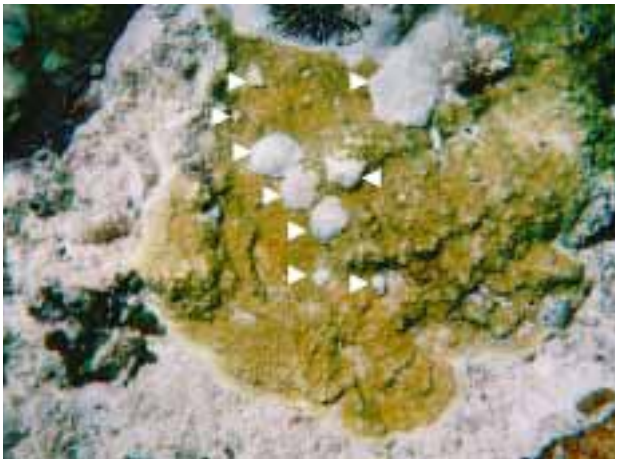


Photo. 1. Tumor on encrusting *Montipora informis* on Sesoko Island, Okinawa. Usually, the hemispheric portion swallows the neighboring tissues, zooxanthellae density and polyp density decrease, and the tentacles disappear. In the end, the characteristic morphology of this species is lost at tumor sites.

which are determined by species, growth stage, and habitat; for example, corals can be branching, tabulate, massive, or encrusting. On the other hand, the primary characteristic of tumors is a lack of individualized forms. In other words, the characteristic skeletal construction of each coral species will disappear as the tumor becomes a hemispheric lump that is surprisingly similar regardless of the species or the original colony shape. For instance, the characteristic denticles of *Montipora informis* are completely absent at a tumor site (Photo. 2).

In addition to an abnormality of the skeletal frame (osteoporosis), metabolic disorders, such as changes in lipid metabolism, can be caused by tumors (Peters *et al.* 1986; Yamashiro *et al.* 2001). It is often thought that tumors are merely lumps that do not affect coral health, but this may not be the case. We noted the occurrence of abundant tumors on encrusting *Montipora informis* found on Sesoko Island, and we consequently began measuring and analyzing these corals in spring 1998. The data on growth rates could not be collected, however, owing to a mass bleaching event in the summer of 1998, when the 20 colonies that had been marked for measurement all died. It was apparent that the high temperature stresses caused tumors to die earlier than healthy coral (Yamashiro *et al.* 2000). Therefore, it appears that tumors are more sensitive to adverse environmental changes. Although, polyp density decreases on tumors, the polyp itself does not exhibit any apparent external changes. However, stereo and optical microscopic observations have revealed that polyps at the tumor site do not undergo oogenesis. Thus, tumor growth reduces the overall reproductive capacity of a coral colony.

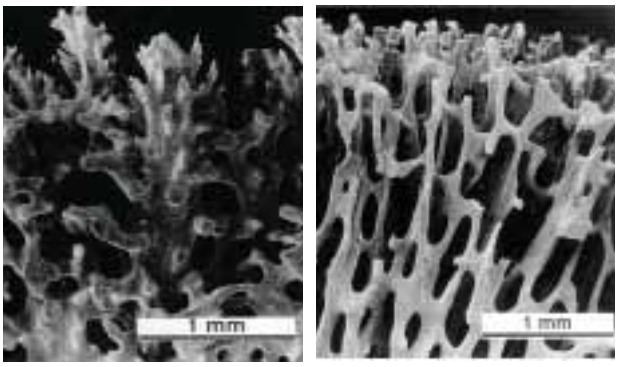


Photo. 2. Scanning electron micrographs of normal (left) and tumored skeleton (right) in *Montipora informis*.

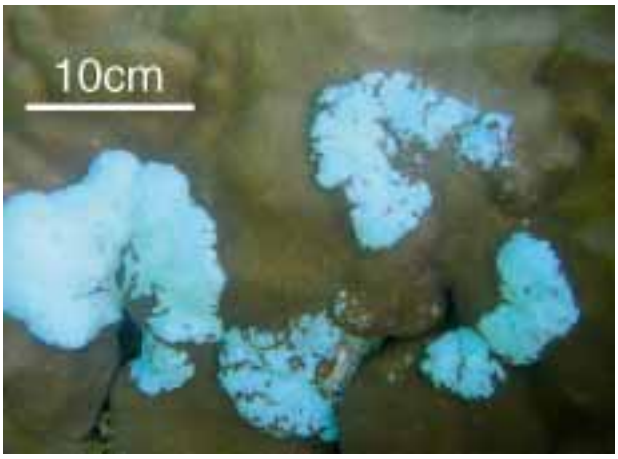


Photo. 3. Whitish and pale brown tumor seen on a massive *Porites lutea* colony on Okinawa Island. The boundary is indistinct, and emboli of the normal tissue can be seen on the whitish tumor.

Living things generally store food energy in the form of fats and sugars, but corals store their metabolic energy as lipids (Yamashiro *et al.* 1999). Studies by Yamashiro *et al.* (2001) revealed that the lipid content (i.e., the weight of extracted lipids per dry-weight of tissue expressed as a percentage) was 32.2% in normal tissue and 10.6% in tumor tissue. Additionally, wax and triacylglycerol amounts were markedly lower in tumor tissue. A decrease of lipid content supports the observation of suppressed oogenesis, as oogenesis requires a large amount of lipid. The increased susceptibility of some tumors to high water temperatures might be closely related to the lower capability for lipid storage in tumor tissue. Similarly, the lipid content in normal but bleached coral colonies of several species also decreased (Yamashiro *et al.* in preparation), signifying the importance of lipids in coral metabolism. Whether a coral will survive the 'war of attrition' will likely depend on its ability to effectively mobilize stored lipid as an energy source during periods of stress.

At present, the mechanisms underlying tumor development are uncertain. However, it seems more than coincidental that tumors, as well as other diseases, are becoming more common in corals at the same time as global environmental deterioration continues to degrade marine conditions.

A new type of tumor was identified on *Porites lutea* colonies in the moat off Okinawa Island in September 2002 (Nakano *et al.* unpublished data); subsequently, it was also found in several areas in Okinawa Prefecture. This tumor is distinctive, in that it usually swells, making it quite noticeable, and the number of zooxanthellae is extremely reduced (Photo. 3). The growth rate of this tumor seems to be very slow. Moreover, unlike other

tumors discovered previously, this tumor has an indistinct boundary, with emboli present on the surrounding tissue (Photo. 3).

Investigations of how tumor tissue is maintained are in progress. At present, two possibilities are being considered: the tumor tissue obtains food from outside the colony, or nutrients are supplied to the tumor from neighboring tissue inside the colony (Yasuda *et al*. unpublished data).

4 Coral diseases caused by helminthes

A helminth that clings to *Porites* colonies has been identified as the cause of another emerging coral disease called Porites pink block disease (PPBD), which is easily recognized because the surface of the colony turns pink. According to research conducted in Hawaii, the Trematoda *Podocotyloides* parasitizes coral polyps. The first host for this helminth is a bivalve; the second is the coral; and the last is a fish, such as a butterfly fish (*Chaetodon*) (Aeby 2003). Although quantitative data have not been collected, this disease is expanding rapidly around the Ryukyu Archipelago. Although the portion of a *Porites* colony affected appears to be small, having a diameter of only a few millimeters, this disease has been reported to cause a 50% decrease in the growth rate of the colony (Aeby 1992). A decrease in zooxanthellae density also occurs in the infected portions. However, because *Porites* is not a favored prey of the crown-of-thorns starfish and is comparatively more resistant to high water temperatures than many other species, the impact of the disease may be tolerable.

5 Conclusion

In 2003, a large number and variety of tumors were reported in the coral reefs off the southern part of Yonaguni Island (broadcast from NHK Okinawa on 19 February 2003). The investigation showed that the tumors had developed primarily on *Montipora informis*. Similar outbreaks might also be occurring elsewhere but be as yet undocumented. In addition, a large coral community with tumors was found around the Kerama Islands in an area with healthy, mature communities and high water transparency, in April 2003 (Irikawa and Yamashiro unpublished data) (Photo. 4). Two causal

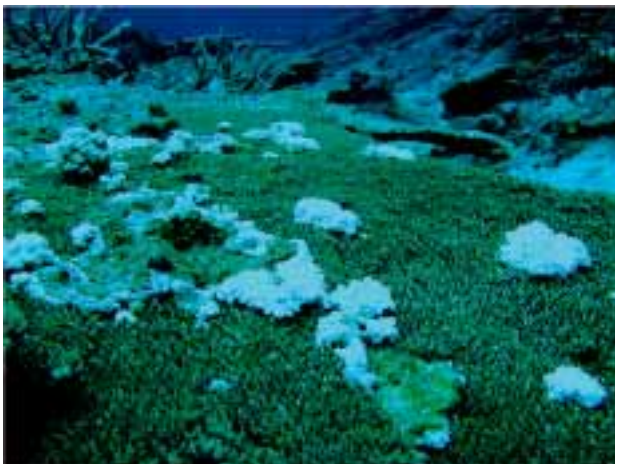


Photo. 4. Tumors on tabulate *Acropora* sp. on Kerama Island, Okinawa. (photo by A. Irikawa)

mechanisms may explain this phenomenon: a genetic abnormality associated with the age of the colony may have occurred, or a bacterial infection might have taken advantage of the suppressed immune system of coral exposed to adverse environmental conditions. We cannot be complacent about the impact of tumors on coral structure and function, particularly fecundity. If coral diseases are closely associated with the deterioration of their environment then we must be aware of the increasing risk and take precautions to prevent diseases that are capable of causing catastrophic damage to corals from spreading widely in the future.

Recently, coral cultivation and/or transplantation techniques aimed at coral reef restoration have been studied in many institutions. When transplanting corals to other regions, we need to carefully consider not only the possibility of so-called genetic disturbance but also the threat of disease expansion.

Acknowledgments
We would like to thank Y. Nakano (Tropical Biosphere Research Center, University of the Ryukyus), A. Irikawa (EAC Co., Ltd.), and N. Yasuda (Tokyo University of Marine Science and Technology).

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*1: WWW pages related to diseases of hermatypic corals:
http://www.sbg.ac.at/ipk/avstudio/pierofun/aqaba/disease1.htm
http://www.nmfs.noaa.gov/prot_res/PR/coraldiseases.html
http://www.wcmc.org.uk/marine/coraldis/home.htm

2-4 Direct impacts of coastal development

Yoshikatsu Nakano

1 Introduction

The major sources of disturbance modifying and/or destroying coral reefs are civil engineering works, which include dredging and reclamation. These are clearly premeditated, direct, artificial disturbances. Contractors should be made aware of their moral responsibility with respect to the possible future effects of such development on the site concerned and on neighboring regions. Details of discussions carried out by concerned parties during the planning process, and notes of the consensuses reached, should be kept; the points made in these instances should be found to have been adhered to when the project is subsequently evaluated. However, there have been very few cases in which those who carried out the work have also carried out the post-construction evaluations. Recently, increasing public awareness of the natural environment has led to terms like 'coexistence with nature' and 'sustainable development' becoming widely used. In order to achieve the goals indicated by these terms, it is necessary to develop a feedback mechanism that evaluates the success of development projects in adhering to preset guidelines, not only with respect to environmental impacts, but also in relation to economic, societal and cultural effects. When these factors come together, greater flexibility in the setting of planning guidelines in response to the changing needs of the environment will be facilitated, as will the implementation of more sustainable development.

2 Coastal landforms and development works on coral reefs

The most developed coral reefs in Japan are found in the Ryukyu Islands; most of the reefs south of Yakushima Island are fringing reefs. On these fringing reefs, especially in the lagoons where people walk at low tide, various resources have been used for many years, not only in fisheries but also with respect to the local residents' livelihoods. Therefore, these areas have been more finely partitioned by local residents than their geological zonation would suggest (Toguchi and Yoshikawa 1990).

Modern development takes place, in the main, on the reef flats of fringing reefs, in surrounding shallow-water areas, and on coastal land sites that are closely connected to coral reefs. The civil engineering projects undertaken in shallow lagoons generally involve basic engineering works and are, therefore, implemented and used intensively on islands with weaker economic bases. Therefore, the modification of coral reef coastlines takes place relatively easily. The mangrove forests that occur in river mouths and the tidal flats where seagrasses grow are also often integrated into development plans; these biotopes, therefore, can be treated as an integrated system, both ecologically, and with regard to the threat posed to them by development.

3 Development projects and activities in the vicinity of lagoons

The issues relating to coral reef conservation have been addressed only relatively recently in Japan. In the 1980s, the Japanese version of the White Paper on the Environment included statistics detailing the disappearance of tidal flats, but coral reef degradation and destruction were not addressed. Fujiwara (1994) detailed the decline of the coral reef south of Amami Oshima in the period between the 2nd Natural Environmental Preservation Base Investigation by the Nature Conservation Bureau, the Ministry of the Environment in 1978 and the most recent 4th investigation (Table 1). By 1992, the total area of lagoonal coral reef that had disappeared (2,308.9 ha) corresponded to 2.4 % of the total estimated area of coral reefs south of Amami-Oshima (96,023.3 ha). The largest areas of reef lost were around Okinawa Island (1,672.2 ha), where 6 % of the total estimated area of coral reefs near the island (27,770.7 ha) were destroyed. The main cause of this disappearance was thought to be reclamation, with dredging for the shipping lane and harbor constructions (Table 2) being a secondary cause. The main

Table 1. The area of coral reef destroyed south of Amami Oshima in Japan (unit: ha).
* represents an area that was newly identified as being destroyed during the latest survey (after 2nd survey), and therefore does not indicate total coverage destroyed before 1978 (modified from Fujiwara 1994).

Prefecture	Location	Disappeared time					Date unknown	Sum of 1979-1992	Sum total
		-1978*	1979-1980	1981-1983	1984-1989	1990-1992			
Kagoshima	Tokara Archipelago	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.6
	Amami Archipelago	0.0	0.0	0.0	100.5	8.4	0.0	311.5	420.4
Okinawa	Okinawa Island	290.3	36.2	595.3	85.1	498.7	8.7	157.9	1672.2
	Miyako Island	31.0	0.0	0.6	3.6	16.3	49.2	2.5	103.2
	Yaeyama Archipelago	6.4	0.0	0.0	0.0	5.4	98.7	0.0	110.5
Sum		327.7	36.2	595.9	189.2	528.8	156.6	474.5	2308.9

Table 2. The areas of coral reef destroyed by different factors (unit: ha; modified from Fujiwara 1994).

Prefecture	Location	Reclamation	Reclamation by drainage	Dredging	Others or unknown	Sum
Kagoshima	Tokara Archipelago	1.6	0.0	1.0	0.0	2.6
	Amami Archipelago	371.0	0.0	49.1	0.3	420.4
Okinawa	Okinawa Island	1592.3	0.0	73.8	6.1	1672.2
	Miyako Island	94.4	0.0	0.0	8.8	103.2
	Yaeyama Archipelago	106.5	0.0	0.0	4.1	110.5
Sum		2165.8	0.0	123.9	19.3	2308.9

Table 3. Case studies of coral reef destruction by construction works.
Years indicate completion dates of construction works. *indicates under construction.

Prefecture	Location Sea area	Local authority	Objective of construction	Area cover (ha)	Year
Kagoshima	Amami Archipelago	Kasari Town	New Amami Airport	100.0	1985
Okinawa	Okinawa Island	Itoman City	Urban development	532	1982
		Okinawa City, Gushikawa City	Port & harbor	242	1988*
	Miyako Island	Hirara City	Port & harbor	41	1991*
	Yaeyama Archipelago	Ishigaki City	Ishigaki Port	97	1991*

types of development leading to the destruction of tidal lands and lagoons were urban site, airport, and port developments (Table 3).

In the Ogasawara Islands, 3 ha of the reef were destroyed by reclamation and dredging between 1982 and 1991, and an additional 2 ha were destroyed by the resulting influx of terrestrial earth and sand.

The most recent, major coastal land reclamation project in Okinawa Prefecture is now being undertaken in Nakagusuku Bay (Reclamation in Nakagusuku Bay Port (Awase District) Public Water Area). A coastal area of 7.2 ha has been designated for prefecture business and 177.4 ha for state affairs. This was licensed and certified in 2000 and reclamation is now underway. This project will reclaim an area offshore from Awase, in Okinawa City, for the purpose of constructing a harbor, marina facilities, meeting and exhibition facilities, and residential accommodations. It is expected that the project will take about six years to complete. During the course of this reclamation, the 266 ha area of the Awase tidalflat, the largest are of tidalflats in the Nansei Islands, will be destroyed. There is, however, opposition to this reclamation project; this opposition is fuelled by concerns about the disappearance of rare species of algae, the disturbance of a stopover point for migratory birds, and the destruction of the northern limit of the dugong's habitat, due to the removal of seagrasses.

Another major reclamation project is planned at the U.S. military base at Henoko, in the city of Nago, in northern Okinawa. The project will construct 2,200 meters of airstrip and extend the area of the base by 184 ha; it will also involve the reclamation of an area that includes a coral reef. The selected site of Camp Schwab has been designated as a Strictly Protected and Conserved District of Natural Environment (evaluation rank I) by the Guiding Principle of Maintenance of the Natural Environment*[1], formulated by Okinawa Prefecture in 1998. In pushing forward with the project, it is requested to commit the Guiding Principle. In connection with this, data are lacking on the necessity for the conservation of seagrass beds, which are used as dugong habitat. The ecological survey of this area is currently being conducted by groups of the NPO.

Table 4. The administrative division of coastal management in Okinawa (from the Okinawa prefectural government homepage).
The governor specifies the maintenance area under the Coastal Law, and the administrator is defined in each division, as below.

Division of coastal maintenance area	Administrator	Competent minister
General locations	Prefectural governor, city and town mayor, or mudir of villages	Minister of the Ministry of Land, Infrastructure and Transport
Locations overlapped with harbor area or harbor adjacent area	Director of the harbor's administrator	Minister of the Ministry of Land, Infrastructure and Transport
Locations overlapped with public notification water area	Prefectural governor	Minister of the Ministry of Land, Infrastructure and Transport
Locations overlapped with fishery harbor	Director of the fihery harbor's administrator	Minister of the Ministry of Agriculture, Forestry and Fishery (Fisheries Agency)
Locations where coastal maintenance facilities exists which is managed under Land Improvement Law, or where land improvement plans have already been defined	Prefectural governor, city and town mayor, or mudir of villages	Minister of the Ministry of Agriculture, Forestry and Fishery (Fisheries Agency)
Locations where there is a coastal maintenance facilities for maintaining agricultural land, and where it is managed irrespectiely of Land Improvement Law	Prefectural governor, city and town mayor, or mudir of villages	Minister of the Ministry of Agriculture, Forestry and Fishery (Fisheries Agency)

4 Conservation and the administrative division of the coast

The coastal policy in Japan is based on the Coastal Law, established in 1954, and is aimed at the 'protection' of land areas from coastal disasters such as tsunamis. However, in recent years new problems, such as water pollution and coastal resource management, have arisen. The Coastal Law was revised for the first time in 1999 with the addition of sections on 'environment' and 'usage' to the former section on 'protection'; the aim was to integrate these factors into existing coastal administration*2. Under the new planning system, formulated in April 2000 from the revised Coastal Law and enforced by the Ministries of Agriculture, Forestry and Fisheries, Transport, and Construction, it was stated that coastal conservation, including the protection of the environment and resource use, should be promoted. The action program for the implementation of the revised Coastal Law has been designated by the national government as Coastal Conservation Basic Policy*3; prefectural governments will create and enforce the Coastal Conservation Basic Plan by following this policy. The department in charge of implementation is generally the civil engineering department and/or the River Section. In Okinawa Prefecture, the Harbor Section of the Civil Engineering and Construction Division formulated the Coastal Conservation Basic Plan for the Ryukyu Islands in 2003*4. Individual projects have been enforced by several provinces separately (Table 4). In Okinawa, the Agriculture, Forestry and Fishery Division, and the Civil Engineering and Construction Division are the main administrative units involved in the implementation of the Act, since the project is presided over by both the Ministry of Agriculture, Forestry and Fisheries, and the Ministry of Land, Infrastructure and Transport.

National parks, quasi-national parks, marine park zones, national environmental preservation areas, and protected water areas are designated by the National Parks Law and authorized by the Ministry of the Environment, and by the Law for the Conservation of Aquatic Resources, authorized by the Ministry of Agriculture, Forestry and Fisheries. The modification and exploitation of these coastal areas are restricted to various levels, and these restrictions are also included in the Coastal Conservation Basic Plan.

Okinawa Prefecture is composed of 160 islands, including 40 that are inhabited. The total length of the coastline is 1,748 km, most of which consists of coral reef coasts. According to the maintenance plan of coastal areas of the Ryukyu Islands (Okinawa Prefecture 2003), coastal maintenance operations in Okinawa Prefecture have progressed as follows:

Coastal maintenance was not kept up-to-date under U.S. military rule, but was made a priority at the time of the handover to Japan in 1972. Until 1985, operations for coastal security were undertaken according to the guidelines of the Coastal Law. Coastal maintenance was performed through the application of 'linear protection' methods, which included the construction of simple structures such as upright bank protection and breakwaters. In the 1980s, methods that were more 'water friendly' began to gain recognition. Coastal maintenance methods have now shifted from those aimed at protection to those aimed at improving the 'environment' and 'usage', through the application of such measures as sloping

shore protections. Recently, improvements to operations relating to seashore use and landscaping have advanced, and coastal maintenance programs have begun to adopt more 'spatially protective' measures, such as artificial reefs and the designation of sections of coast for recreational use. The stretch of coastline for which disaster prevention is particularly vital is about 379 km in length, in total, i.e., about 22 % of the total coastline; the prefectural government is maintaining these areas, based on the Coastal Law. In other regions, management practices have been the same as those used in relation to government-owned land but now, due to the revision of the Coastal Law, appropriate management changes are thought necessary with respect to the general public coast. In many parts of the arterial road along the coast the landscape is deteriorating; road use is being restricted, and the natural coast is being lost because so many upright bank protections were constructed to defend the road from wave erosion. A number of projects, including the reconstruction of lost beaches, enhancement of access, and landscape improvements are anticipated for the protection of existing roads. Future road and bank protection methods must consider the natural environment, its use, and landscape.

According to the 5th National Survey on the Natural Environment, conducted in 1998, the greatest increase in artificial coastline (coast where artificial structures exist in the intertidal zone) after 1993 (Nature Conservation Bureau, Environment Agency 1994b, 1998), when the 4th investigation was carried out, occurred in Okinawa Prefecture, where the length of artificial coastline was extended to 102.95 km, an increase rate of 47.99 %. The decrease in the length of natural coast (where no artificial structures occur) was 39.37 km in Okinawa Prefecture, behind Hokkaido's decrease of 96.58 km and Aomori Prefecture's decrease of 47.53 km.

5 Future development planning

According to the survey results of the Aerial Coverage of Local Authorities Across the Nation, taken in the fiscal year 2003, and published by the Geographical Survey Institute in February, 2004, the total land area of Japan (including northern territories and the Senkaku Archipelago) was 377,899.20 km^2. This represents an increase of 11.95 km^2 from October 1, 2002. Within prefectures, Okinawa Prefecture had an increase of 128 ha, second only to Aichi Prefecture (431 ha). Both of these increases were due to coastal reclamation.

A vast fallow land can be seen on the shore at Nishizaki, near the city of Itoman, in Okinawa Prefecture. This is the largest scale coral reef reclamation project in Japan (Table 3; 532 ha of coral reefs disappeared in 1982). In contrast, commercial activities have been developed on the reclaimed land at Kuwae, near the town of Chatan (49 ha of coral reefs disappeared in 1986; Fujiwara 1994). By looking at these two contrasting examples, it is clear that good planning and thorough analyses of forecasted economic effects are essential for the creation of successful development plans.

Plans to develop a new airport by reclaiming the Shiraho reef in Ishigaki were abandoned after a protest campaign was staged by local residents and domestic and foreign nature conservation groups. A new, on-land location for the airport was agreed upon in 2000.

Okinawa Prefecture has adopted the Guideline for Natural and Environment Conservation for the preservation of these natural environments. However, in some extent, there are inadequacies in applying the Guideline to development plans. In addition, although Ryukyu Islands was selected as one of the candidates to be nominated as World Narural Heritage site by the domestic commission, yet to be nominated because its conservation is not guaranteed. As you can see those facts, some important natural environment which should be protected is not fully guaranteed.

In order to conserve the precious natural environment in Okinawa, it is required to take the point of view of nature conservation into fully consideration in making various development plans.

Cited websites:

*1: http://www.pref.okinawa.jp/okinawa_kankyo/shizen_hogo/hozen_chiiki/shishin/index.html

*2: http://law.e-gov.go.jp/htmldata/S31/S31HO101.html

*3: http://www.jfa.maff.go.jp/gyokogyojo/subx8.htm

*4: http://www3.pref.okinawa.jp/site/view/contview.jsp?cateid=220&id=1375&page=1

2-5 Terrestrial inflow of soils and nutrients

Tatsuo Omija

1 Introduction

The deterioration of the coral reef environment as a result of human activities has been reported from all over the world. Eutrophication and pollution from increasing sedimentation are among the threats to coral reefs that originate on land (Wilkinson 2002). Owing to the intensive soil erosion that accompanies land development projects, coral reefs along the coasts have been repeatedly covered by silt throughout the modern history of the Ryukyu Islands, causing decay (Omija 1992). Moreover, in the Ogasawara Islands south of Tokyo, introduced ibex have run wild, consuming the vegetation and resulting in topsoil run-off that negatively affects the coastal environment (Kawakubo 1988; Inaba and Suzuki 2000). This section introduces the soil inflow of Okinawa Prefecture of the Ryukyu Islands as a case study and also describes research of the nutrient content of the surrounding sea water.

2 What is red soil pollution?

When heavy rain falls on the islands of Okinawa, coral reefs near the river mouths often develop a 'cloudy red' appearance where there was once clear water (Photo. 1). Such inflow disturbs coastal coral reef ecosystems and negatively affects the fishery and marine-related tourism industries. These remarkable soils are made up of not only *Kunigami maaji* soil, generally called a red soil, but also the gray soil *Jaagaru* and the country rock mudstone, *Kucha*. In this section, these soils are collectively referred to as 'red soil' and their adverse effects on coastal waters as 'red soil pollution'.

3 Why does red soil pollution occur?

Red soil pollution tends to occur when human impacts, such as land development, are affected by natural factors. These natural factors include the following in Okinawa: soils that easily disperse due to a lack of organic matter, geographical features in which mountains are steep and rivers are short, and rainfall that is three times as erosive as the national average (Fig. 1). Of course, such natural factors alone do not always cause red soil pollution. Red soil pollution occurs most often after human factors are added, such as development projects that turn the mountain greenery into bare land. Farming, land development, and activities within the U.S. military training area cause enormous amounts of run-off and are considered the three major outflow sources in Okinawa. Most of the red soil carried to the sea by rivers is deposited on semi-

Photo 1. Coral reef exposed to the turbidity of terrestrial soil (e.g., red soil) run-off.

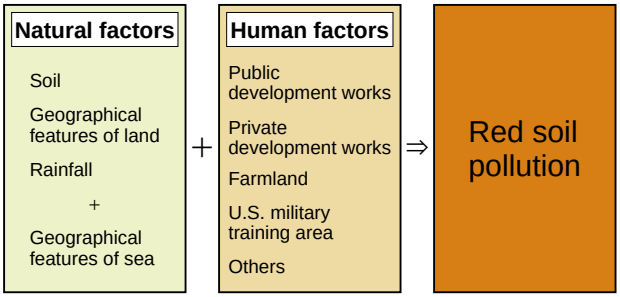

Fig. 1. Mechanisms of red soil pollution.
Larger amounts of soil begin to run off when human impacts are added to preexisting natural factors. On reef moats, discharged soils often remain owing to limited circulation of seawater and thus damage coral communities continually despite only periodic run-off.

enclosed reef moats adjacent to the coast, and often the red soil is repetitively stirred up by turbulence induced by typhoons and monsoons. The water becomes cloudy again, and the soil is redistributed over the reefs. In other words, red soil pollution is not a temporary phenomenon that occurs only during heavy rains; it can continue causing damage to coral reefs indefinitely.

4 Red soil pollution monitoring

Some of the evaluation techniques for measuring red soil pollution in Okinawa are as follows: processing sediment with hydrochloric acid, as used in the fisheries environmental survey by Okinawa Prefectural Fisheries Experiment Station (1978); categorizing the grading of sediment, as used by Ujiie (1986) in granulometry research of silts at the sea floor; a five-stage visual observation method of bottom state used in coral reef research by the Department of Planning and Development, Okinawa Prefecture (1993, 1994), and the sediment traps used for coral reef ecological surveys by Fujioka (1997).

In addition, the Content of Suspensible Particles in Sea Sediment method (referred to as SPSS) was developed by the Okinawa Prefectural Institute of Health and the Environment to monitor soil pollution in 1985 (Omija 1987; Omija in press). The use of this method requires little time input, convenient tools and materials, simple operational skills, and no specific laboratory to provide scientific data (Fig. 2). As a result, the method is used extensively in the research efforts of various administrative bodies, universities, NGOs, school environmental education programs, and fisheries' management agencies. A database of collective results began to be assembled in 1983, and the total number of data points had reached approximately 4,000 as of September 2003. The value measured by SPSS corresponds well to the actual benthic appearance of a reef (Table. 1); thus, it is useful in explaining the current condition of a specific coral reef area. This method has been elected as the standard procedure for monitoring red soil pollution in the marine environment of Okinawa Prefecture.

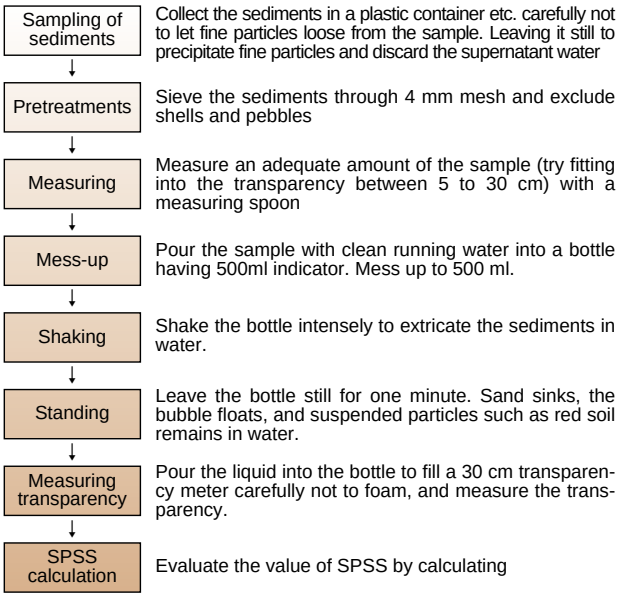

Fig. 2. Procedure of SPSS (content of Suspensible Particles in Sea Sediment) estimation.
Most of the sediment on coral reefs is made up of sands derived from organisms such as corals. These sands have a different particle size from that of terrestrial soils. Using this distinction, SPSS evaluates how many kilograms of suspended particles (e.g., red soil) are inside 1 m^3 of suspended matter.

Table 1. Relationship between SPSS (content of Suspensible Particles in Sea Sediment) values and benthic properties.

SPSS (kg/m^3)			Status of bottom sediment and other properties
Rank	Lower bound	Upper bound	
1	—	< 0.4	Below determination limit. Fine particles are not suspended even when bottom sediment is stirred. White sand extends the area and organisms are rarely observed.
2	0.4 ≦	< 1	Fine particles are not easily suspended even when bottom sediment is stirred. White sand extends the area and organisms are rarely observed.
3	1 ≦	< 5	Fine particles can be suspended by stirring the bottom sediment. A lively coral reef ecosystem can be observed. Water transparency is high.
4	5 ≦	< 10	Water becomes little turbid when bottom sediment was stirred, although it will not occur in calm conditions. A lively coral reef ecosystem can be observed.
5a	10 ≦	< 30	Fine particles can be observed on the surface of bottom sediment by careful observation. This rank corresponds to the SPSS upper bound where lively coral reef ecosystem can be observed.
5b	30 ≦	< 50	Dust-like fine particles cover the sediment surface. The transparency declines and adverse effect on coral coverage starts to occur.
6	50 ≦	< 200	Sediments such as red soil can be seen at a glance. If the bottom sediment is stirred, suspension is apparent in dark color. Above this rank, it is judged that obvious pollution by the man-caused outflow of red soil occurs.
7	200≦	< 400	Shoe sole's patterns are left clearly on the surface. Sedimentation of red soil is remarkable, but sands can still be seen. Large colonies of branching *Acropora* will are not seen, and massive corals increases.
8	400 ≦	—	Feet get bogged in mud. Sands can rarely be observed. A massive type corals which have strong sediment-resistance distributes.

5 Influence of red soil pollution on coral reefs

A rich coral reef ecosystem centering on coral communities can be seen in the coastal areas of Okinawa. Coral reefs are said to hold the largest number of species per unit area on earth, along with tropical rain forest ecosystems. Branching and tabulate coral colonies have a maze of internal, three-dimensional spaces that offer shelter to small reef animals. As larger animals tend to predate on these smaller animals, a multi-leveled community structure evolves. *Acropora* species are the main corals of such reef structures. When corals die out and three-dimensional space decreases, eventually the numbers of fish and other organisms also decrease.

In moats adjacent to the open sea, where strong winds tend to cause high waves, the suspended sediment is easily stirred up. In such areas, seasonal variation in SPSS levels sometimes occurs (Omija *et al*. 1993). In that case, the highest SPSS values correspond well with the upper bound of the coral coverage area (Omija *et al*. 2000a). The relational expression between coral coverage and SPSS derived from a dataset of 97 points on Okinawan reefs is shown below.

$$Y^{(1/2)} \leq -5.43\log X + 15.6$$

X: SPSS (kg/m^3)

Y: Coral coverage (%)

In the Kerama Islands, where red soil pollution is rare, coral coverage is generally high and *Acropora* dominates the area (Photo. 2). When red soil pollution progresses and SPSS levels begin to exceed 30 kg/m^3, coverage of *Acropora* decreases. As red soil pollution further progresses, large colonies of *Acropora* disappear and coral coverage also decreases. In contrast, the percentage of massive corals that have few interior hiding places (e.g., *Porites spp*. and Faviidae) increases. When the highest value of SPSS exceeds 400 kg/m^3, the appearance of the reef becomes desert-like and only massive corals are scattered in the turbid water. *Acropora* species can recruit under such conditions,but they cannot grow large and most die within 1 to 2 years (Omija *et al*. 2003). Coral reefs that have reached this stage lose almost all value as a resource for fisheries or tourism.

A certain relationship between the highest value of SPSS and the composition of coral species can be recognized.

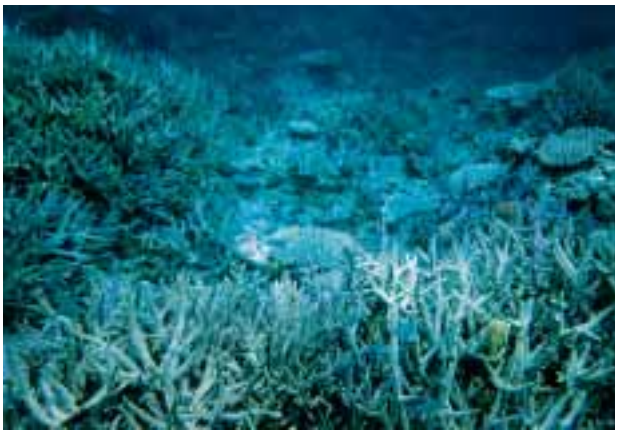

Photo. 2. Coral reef communities in the Kerama Islands, where red soil pollution is scarcely seen. In such areas, *Acropora* species are dominant.

The massive *Porites* species have a relatively high emergence ratio in any sedimentation level and tend to have strong bleaching tolerance as well (Omija *et al*. 2000b). Owing to this, they can be considered one of the corals that are best able to tolerate variations in environmental conditions. Also, *Oulastrea crispata* appears characteristically in high SPSS areas and may be valid as an index species for turbidity (Omija *et al*. 1999).

6 History of red soil pollution

Notable red soil pollution problems are said to have emerged when the U.S. military brought in heavy equipment such as bulldozers to make pineapple fields in mountainous areas of northern Okinawa Island and the Yaeyama Islands after World War II. After Okinawa was handed over to Japan in 1972, large-scale public construction projects were completed, one after another, to develop social infrastructure on Okinawa. The aim was to achieve a level of development equal to that of mainland Japan. At that time, prevention measures for soil run-off were practically nonexistent and, if practiced at all, were implemented at the level of halving the amount of outflow. Large-scale development projects thus caused some reefs to become covered with red soil, resulting in complaints of damage to fisheries.

Mass media in the prefecture led a campaign to stop the red soil pollution in the late 1980s, and public opinion in Okinawa changed, with a switch in priority from development projects to the prevention of soil run-off. Six groups related to the fishing industry collected signatures from 55,000 people in 1992 and requested that the prefecture

promptly enact an ordinance to prevent soil run-off. As a result, Okinawa Prefecture established The Okinawa Prefecture Red Soil Erosion Prevention Ordinance (referred to simply as the Red Soil Ordinance) in 1994, and it was enforced by October 1995.

According to the Red Soil Ordinance, the leaders of a development project of 1,000 m^2 or greater are required to submit a written report in advance. Moreover, the effluent standard from the development site is set at 200 mg/l or less of the suspended solid (SS) as an indicator of water impurity. For example, when a reclamation project is conducted with no countermeasures, SS reaches up to 10,000 mg/l in red soil areas and 80,000 mg/l in mudstone areas. In other words, developers are required to take measures to cut 98-99% of the soil run-off.

7 Future prospects on red soil pollution

The database of SPSS was analyzed to assess the changes in red soil pollution on Okinawan coasts, comparing results from before and after the red soil ordinance was enforced in 1995. The results showed that nearly 40% of the coast was still exposed to red soil pollution, although soil run-off from the development sites was restricted and extreme sedimentation decreased. The main run-off source was considered to be farmlands (Omija *et al.* 2002) (Photo. 3).

While the administrative body has proposed some effective measures against soil run-off from farmlands and their effectiveness has been shown, the use of these measures by farmers has been slow to spread, owing mostly to the required cost and labor. In the future, therefore, it is necessary to introduce and establish a system in which farmers can easily take measures. For that to occur, a discussion on the necessary reduction level of soil run-off for coral reef conservation is inevitable. Comprehensive research will be necessary to connect land and coral reefs in the future. This research should include the establishment of environmental guideline values, the establishment of forecasting models of outflow and diffusion, the accumulation of demonstrative data on the effects of various farmland measures, and the evaluation of the cost of farmland measures versus the economic value of coral reefs.

Photo. 3. Decayed farmland. Major terrestrial soil (e.g., red soil) run-off is from this kind of farmlands in Okinawa.

Moreover, through training courses organized by the Japan International Cooperation Agency (JICA), the SPSS monitoring procedures, techniques, and information regarding soil run-off prevention in Okinawa are being transferred to trainees from developing countries that have coral reefs. The experience with and results from the soil run-off prevention measures on Okinawa are expected to contribute to these countries in the near future.

8 Nutritional research

Field studies analyzing the effects on coral reefs of nutrients originating from the Okinawan land are extremely scarce compared with studies of soil run-off. Nakano (2002a) reviewed laboratory tests on the impacts of the nutrients on corals. Below are the results of some field studies concerning nutrient outflow onto reefs around Okinawa.

In Okinawa Prefecture, total nitrogen (TN) and total phosphorus (TP) are measured two to six times a year at 53 fixed points in ten locations as part of water quality monitoring. The results are reported annually. The Ministry of the Environment determines the environmental quality standards for TN and TP according to the intended use of marine areas. This set of standards applies only to designated marine areas where phytoplankton might proliferate remarkably, while oligotrophic coral reef regions are not considered. Consequently, this set of standards does not apply to Okinawa. The most severe environmental quality standards in Japan define the annual means (arithmetic mean) as 0.2 mg/l for TN and 0.02 mg/l for TP. Assuming that these standards were applied to Okinawa, the public marine areas would

exceed these standards by 16 points (30%) for TN and 5 points (9%) for TP, according to measurements by Okinawa Prefecture in fiscal year 2001 (Department of Culture and Environment, Okinawa Prefecture 2003).

Excess nutrients in waters surrounding coral reefs are supplied from the land by means of surface water and/or underground water. Umezawa *et al.* (2001) focused on the fact that the ratio of nitrogen (^{15}N) was significantly higher in river water and in underground water as compared to the ratio in the outer sea of the coral reefs off Ishigaki Island. There are ^{14}N and ^{15}N isotopes of nitrogen, possessing mass numbers of 14 and 15, respectively. Umezawa *et al.* inferred nutrient outflow from the land based on the fact that measured ^{15}N ratios in seaweeds decreased with increasing distance from the shore. In addition, dilution by river and/or underground water outflows into the sea causes salinity levels to decline. This led Omija *et al.* (2003) to consider the excessive nutrients on Okinawan reefs to be of land origin because the areas that had high nutrient concentrations tended to have lower salinity.

There seems to have been no long-term observation of fixed points around Okinawa in terms of the relationship between nutrients and corals. In a short-term case study, Shimoda *et al.* (1998) monitored the condition of corals and the nutrient concentration at 25 points and found that corals did not grow well with a TN level of 0.1 mg/l or more or a TP level of 0.01 mg/l or more.

Omija *et al.* (2003) added nutrient and salinity analyses to ongoing long-term research on SPSS and coral growth in 2 × 2-m quadrats at 24 fixed points over the prefecture. In the quadrats where relatively high levels of TN and TP were observed, recruits of *Acropora* were seldom seen. As *Acropora* recruits were observed even in areas with equivalent or higher rates of SPSS, it was determined that nutrients have a negative impact on *Acropora*.

The Department of Health and Environment, Okinawa Prefecture (1989) conducted a research study on red soil sedimentation and coral growth in Kin Bay in 1988. Coral assessment was conducted at 27 points, and there was no point at which *Acropora* was predominant. In fact, *Acropora* was observed at only one point. Around Kin Bay, the geographical features are semi-enclosed, the population is high along the coast, and there is a complex of hog farming. This leads to a high nutrient concentration in the bay. The reason for the observation of less *Acropora* could be the influence of the high nutrient concentration.

9 Environmental guidelines for coral reef conservation

One of the threats to coral reefs from the land is an excessive outflow of soils and/or nutrients. Under current circumstances, environmental quality standards for permissible amounts of soil sedimentation and nutrients should be strengthened; it is also necessary to control land activities to achieve these standards. Unfortunately, this is not considered by existing policies for environmental quality standards in Japan. The results of our long-term observation of fixed points around Okinawa, in combination with other research of various points, show SPSS values of 30 kg/m^3 or less at locations where corals that are vulnerable to soil sedimentation, such as *Acropora* species, appear to grow well. Therefore, it was proposed that to conserve coral reefs on Okinawa, the environmental guideline for soil sedimentation should set an annual maximum SPSS of 30 kg/m^3 or less (Omija *et al.* 2003). In addition, it would be beneficial to immediately set a guideline for the allowable nutrient concentration.

2-6 Inappropriate activities around coral reefs

Coral reef degradation and sustainable use in the Yaeyama Archipelago, Okinawa:
A Study of Lift-Net Fishery and Fishermen's Perspectives and Opinions

Tomoya Akimichi

1 Introduction

In recent decades, degradation of coral reefs has been widely reported from many tropical and sub-tropical regions around the world. In Southeast Asia, coral reefs are under serious threat (Wilkinson and Rahman 1994). Declines in biodiversity and biomass on coral reefs have been highlighted recently by a severe bleaching event, which led to extensive coral mortality in a number of locations, including Okinawa (Kayanne 2002). Coral reef degradation is caused by natural and anthropogenic factors, and occurs on a variety of scales, ranging from the small-scale destruction of individual colonies by anchor damage to large-scale bleaching of entire reef systems, caused by the prolonged elevation of sea temperatures. The activities of humans have led, unintentionally or otherwise, to more serious impacts on coral reefs than those caused by natural phenomena such as typhoons, heavy wave action, predation by crown-of-thorns starfish (*Acanthaster planci*), and global warming. For example, coastal reef systems are vulnerable to sedimentation and increased riparian runoff caused by remote, inland logging and mining (Cesar *et al.* 1997). Coastal land reclamation for purposes of industrial and agricultural development has had a more direct impact on coral reefs, through the conversion of former reef-sites into man-made coastal flat land. Given the complexity of coral reef ecosystems, which are not yet fully understood, targeted socio-economic research is urgently needed to identify anthropogenic pressures on coral reefs in order to prevent or minimize future degradation (Ruddle 1993).

For the purpose of proposing an appropriate framework for the sustainable use and management of coral reefs, four topics will be discussed here:

a. Holistic approach:
The causes of coral reef degradation are varied and complex, even within a limited geographical area, and research is vital to the identification and assessment of the mosaic of factors involved. The land-sea interface, in particular, should be integrated into management planning for coral reefs in the region.

b. Indigenous knowledge and practices:
When considering relevant ecological and socio-economic factors, indigenous perception, knowledge and experience of coral reefs and their ecology are important. This knowledge is often retained by local fishermen through their daily fishing activities, and helps us to understand the nature and causes of coral reef degradation. Field experience, especially in Southeast Asia and the Pacific, has demonstrated that local fishermen are generally knowledgeable about marine ecology, as they have the opportunity to observe the changes occurring in the coral reef environment on a daily basis (Ruddle and Akimichi 1984; Ruddle and Johannes 1985; Akimichi 1995).

c. Temporal and transitional processes:
Coral reef disturbance should be seen as a process and as an accumulation through time, rather than as a one-off episode or occurrence caused by direct natural and anthropogenic factors. For instance, agricultural land reform and road construction do not always have direct impacts on marine environments. However, these land-based activities show indirect or gradual impacts over the course of time. These impacts may be delayed until the onset of the rainy season, or even for several years. Typhoons often cause direct damage to coral reefs, but these impacts can also only be assessed after the end of seasonal and annual cycles. Both short-term and long-term natural and anthropogenic impacts on coral reefs should be regarded as transitional processes.

d. Illegal fishing on coral reefs:
Fishing activities on coral reefs are not always undertaken on a sustainable basis. Destructive and illegal techniques such as blasting and cyanide fishing are prevalent in developing countries (APEC-MRCWG 1998). Poverty is generally considered the primary cause of destructive fishing. However, regulatory measures executed by the Japanese Fisheries Cooperative Association (FCA) and *sasi* practices in eastern Indonesia have demonstrated that community-based enforcement is one of the most effective ways to prevent illegal

Photo. 1. Small-scale fixed net for reef fish in the Yonara Waterway. (photo taken in 2003)

fishing (Bailey and Zerner 1992; Akimichi 1995). Regional economic markets for fish in the central Philippines also suggest that rapid development in the domestic economy, rather than poverty, is the primary cause of illegal fishing (Akamine 1999). In this regard, illegal fishing should be seen as a universal phenomenon rather than as poverty-driven.

Based on the four areas of interest outlined above, this study focuses on changes in coral reefs, as recorded from small-scale observations by fishermen over several decades in the Yaeyama Archipelago, southwestern Japan. The author has also studied coral reefs in the Yaeyama Archipelago; therefore, a comparison of scientific findings with the observations and opinions of local fishermen may facilitate future discussions of coral reef degradation and issues pertaining to sustainability. This study concludes by emphasizing the significance of the four areas of interest outlined above, and by offering them as the basis for effective approaches to understanding transformations in small-scale coral reef fisheries in tropical and sub-tropical regions.

2 Study area and coral reef fisheries in the Yaeyama Archipelago

The Yaeyama Archipelago is located at the southwestern extremity of Japan. The environment and climate is subtropical, although the sea is considered tropical, as the annual mean surface temperature off Ishigaki is 24.7°C (Shokita 1988). The Yaeyama Islands consist of eight major islands: Ishigaki, Iriomote, Taketomi, Kuroshima, Kohama, Aragusuku (Uechi and Shimochi) and Hatoma (Fig. 1). Most of these islands are fringed by coral reefs, and they have at their centre the Sekisei Lagoon. This lagoon is characterized by extensive coral reefs (ca. 13,000 ha), the outer margin of which is barrier reef. It is rich in diverse coral habitats and supports major fishing grounds for local small-scale fisheries.

Coral reefs are characterized by their high diversity of habitats and organisms. Fishing activities on coral reefs tend to be small-scale, and are often divided into nocturnal and diurnal fisheries; in addition, fishing strategies also show a dichotomy, in that they are divided into strategies for individuals and for aggregations. In this region, a variety of small-scale fisheries are in operation. Some of the fishing methods currently employed in the coastal zones of the Yaeyama Archipelago include, fish driving for fusiliers and reef fish, gill netting, small-scale fixed nets for reef fish (Photo. 1), lift nets for live bait, cage trapping for groupers and lethrinids, spear-fishing, line-fishing and shell collecting. Some of these fisheries are seasonal, while others continue year-round. Most of the catch consists of surface, demersal, and benthic reef-dwelling species. At the outer reefs and in off-shore zones, troll-lining for tuna, wahoo and skipjack, bottom-lining for snapper and large squid, pole-lining for skipjack, and long-lining for tunnids are the major fishing techniques (Kuchikura 1977, Ruddle and Akimichi 1989). Recently, *payao* (fish aggregating devices) for large surface swimmers such as tuna, wahoo and marlin have been commonly deployed in deep water (Kakuma 2002). As well as these capture fisheries, coastal mariculture operations for seaweed, pearl shells, giant clams, and groupers have been launched.

This study aims to examine how fishing sites, and their value to the live bait fishery in the Yaeyama Archipelago, have changed in the last few decades. The objectives of this study were, first, to identify changes in the use of fishing sites; second, to examine the causes of these changes in relation to economic development; and third, to propose possible measures for future conservation initiatives.

Research focused on changes in the perceptions and practices of coral reef fishermen over the last few decades was conducted at Ishigaki Island and in the adjacent coastal waters in the Yaeyama Islands. Using field data collected during 1971-2002, and through direct observations, on-board interviews, and GPS techniques, research was conducted in January and March, 2003. The research was undertaken as part of an annual survey carried out by the Japan Wildlife Research Center; field research was

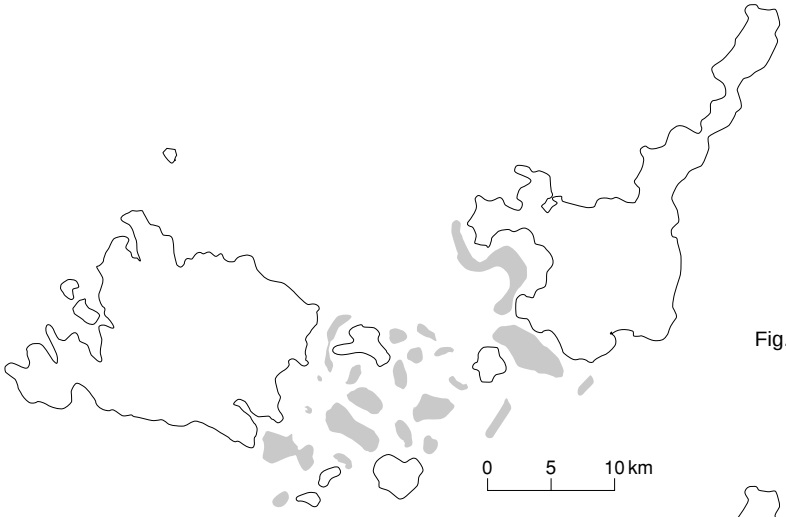

Fig. 1. Distribution of *yana* sites (coral rocks and patch reefs) in the lift-net fishery surveyed in 2003.

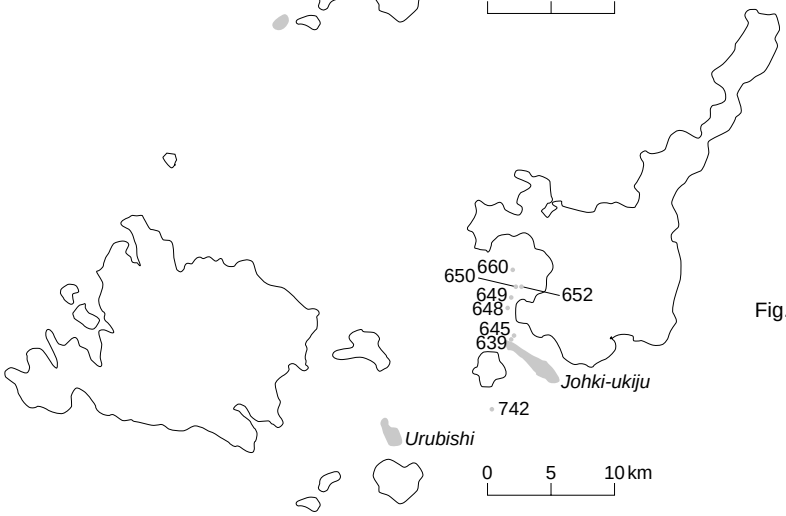

Fig. 2. Location of degraded *yana* sites (coral rocks and patch reefs) in Sekisei Lagoon.
The numbers indicate specific survey points and *Johki-ukiju* (lit., steamships floating) and *Urubishi* (lit., reefs made of *Acropora* corals) are given local names on *yana* sites.

conducted with the assistance of local staff at the International Coral Reef Research and Monitoring Center on Ishigaki Island. Six expert lift-net fishermen participated in the identification and evaluation of fishing sites from on board the boat, over five days.

3 Perception and use of corals in lift-net fishery

In the Yaeyama Archipelago and elsewhere in Japan, lift-net fishery is employed to obtain live bait for skipjack pole-line fishery. Live bait is scattered throughout schools of the voracious skipjack fish (*Katsuwonus pelamis*) and is used to entice them to take artificial bait. Target fish for live bait are small aggregating species such as fusiliers (*Caesio* spp.), cardinalfish (*Apogon* spp.), and damselfish (*Abdefuduf* spp.). These fish aggregate in holes and crevices in coral rocks in the daytime, leaving their shelter to feed nocturnally. Large numbers of aggregating fish are usually hauled in lift nets at dawn when the fish return to their shelter (Kuchikura 1977).

According to fishermen in Yaeyama, dwelling sites for any kind of fish are generally called *yana* (lit., house), but in the case of lift-net fishery, the term *yana* refers specifically to the coral rock habitat of small live bait fish. According to previous research conducted from 1972 to 2002, a total of approximately 800 named *yana* are known to lift-net fishermen. A *yana* may be a small coral rock about one to two meters long, but which often indicates extensive coral reefs several hundreds of meters in length. These *yana* are scattered extensively throughout the Sekisei Lagoon, Nagura Bay and adjacent waters (Fig. 1). Expert fishermen, given only the name of the *yana*, can recount site details such as the location, shape and nature of each *yana*, the seasonality of the locale, and the species of fish that shelter there.

Local names for *yana* sites are a combination of the geographical name of the area, features of the coral, names of fish, depth, direction etcetera. For example, the name *Kannunduu shichuu nu yaa* designates 'a house of sweetlips (*Kyphosus* spp.) of the Kannondo Chinese Temple' (point 645 of Fig. 2), and *Takidon agari nu shiraumii nu yaa* means 'a house of fusilier (*Paracaesio* spp.) at the

east of Taketomi Island' (point 742 of Fig. 2). At the former site, sweetlips are said to feed on small fish among the coral rock, while the latter site is reputed to be abundant in fusiliers.

As well as lift-net fishery, coral reefs in the Yaeyama Archipelago are utilized for numerous other types of fishery, in which fishing grounds are not specifically named. This is because lift-net fishery demand more accurate site allocation than the other fisheries operating in the Yaeyama Archipelago. For example, *Urubishi* reefs (lit., reefs made of *Acropora* corals) extend for about 4 km along the NW to SE axis north of Kuroshima (Fig. 2). These reefs are frequently used for fish-driving, gill-netting, nocturnal spear-fishing, and other types of reef fishing. In these fisheries, there is no need to pinpoint the fishing site. Instead, it is more important to have the temporal knowledge required to productively cast nets in response to daily and tidal rhythms that govern fish movement. In night diving, searching extensive coral reef areas does not require on-board site allocation.

Lift-net fishing is a group activity, which involves four to six divers operating a lift net. When a school of live bait fish is hauled, it is immediately stored in a floating bamboo container measuring ca. 1.0 × 2.0 × 1.5 m. Skipjack boats collect these live bait fish from the container and use them to attract skipjacks. Two bamboo containers are used by each group. Each lift net group has an annual contract to provide bait fish to a skipjack mother boat during the fishing season.

Only two skipjack boats were operating in 2002, in contrast to the twenty-seven boats employed at the peak of the fishery in Yaeyama waters in the early 1970s. During this peak period, competition occurred for prime fishing sites in the live bait fishery. It is not clear exactly when the lottery practice commenced, but by 1971 there was an established agreement among lift-netters to limit access to *yana* sites.

In order to select the most productive fishing sites and to avoid conflicts, an annual meeting is organized by the Yaeyama FCA at the beginning of the fishing season (early April) to decide on the assignation of exclusive fishing rights to ten sites. Leading lift-netters conduct a lottery at the meeting, in which the first winner in the lottery has top priority in choosing one *yana* site, the second claims another site, and so forth. After the first round of drawing, the order of the process is reversed, with the last group having the opportunity to be the first to choose their second site. This method for ordering site selection is repeated until each group has chosen ten different sites. The fishing sites that are claimed by the lift-netters are generally called *kuji-ana* (a hole by lottery), and exclusive fishing rights are guaranteed to each group for the duration of the fishing season. All of the other sites, which were not claimed, are referred to as *uki-ana* (empty hole), and open access to these sites by any group is allowed. Thus, if twelve groups enter the fishery in a given season, 120 distinct *kuji-ana* will be chosen (Akimichi 1985). During the operation of the fishery, no conflicts among the groups or poaching have been observed; floats and markers are generally deployed to designate the exclusive ownership of *kuji-ana* sites.

4 Factors affecting coral reef degradation

More than thirty years have passed since my initial research in the Yaeyama Archipelago. The testimonials of fishermen who have witnessed changes to the coral reef environment are now crucial to our understanding of the degradation process, as theirs are the only continuous long-term site observations. Although scientists and administrative officers have also visited these sites, their trips are more sporadic and are of relatively short duration. During the winter and spring of 2003, lift-netting sites were visited with expert fishermen, both retired and still working, in order to identify the locations of *yana* sites using GPS, and to investigate whether each site is presently in use. The reasons why certain sites had been abandoned or avoided were investigated. This study is still underway, and the present findings represent the results of visits to 230 sites and areas, about one-third of the 800 previously investigated sites.

The research revealed marked changes in coral communities. Most corals located in the shipping lane and anchorages for large vessels between Ishigaki Port and Taketomi Island have been destroyed. This area has been generally called *Johki-ukiju* (lit., steamships floating) (Fig. 2, Photo. 2) which suggests that in former times steamships frequented. Since Okinawa's return to Japan in 1972, large-scale investment in port construction has been promoted. As a result, large container vessels now anchor in front of Ishigaki Port, and it is evident that the coral in the shipping lane has been completely destroyed by this anchoring. Discussion with lift-net fishermen

Photo. 2. A large container vessel on the shipping lane. This area has been generally called *Johki-ukiju* (lit., steamships floating). Corals in such areas have been destroyed by anchoring.

revealed that, of 42 *yana* between Ishigaki Island and Taketomi Island, more than 70% were abandoned because of the physical damage caused by anchoring.

In areas other than the shipping lane, the reasons for disuse differ from site to site, and site-specific or generalized explanations were provided by the fishermen. For example, ***hireekuu*** corals (flat-shaped corals of the *Acropora* genus) in the lagoon were destroyed by a typhoon that hit the area in 2000, and coral trout (*Plectropomus* spp.) subsequently disappeared. Since the piscivorous coral trout is known to feed on small fusiliers and damselfish in coral, it is possible that the typhoon damaged the habitats of both prey and predator. At the *Naga-guu* site (lit., a long coral rock), a large coral patch reef in Nagura Bay (site 660 of Fig. 2), bleaching has frequently occurred and fishermen have reported that there are a number of *A. planci* on the corals.

Other causes of coral reef deterioration identified by the fishermen were red-soil sedimentation caused by land reclamation, the construction of roads and factories, and coastal pollution caused by an influx of waste water, pesticides, and soap. Such ideas are clearly not founded on speculation based on newspapers and television programs; these ideas are based on the fishermen's personal observations. The fishermen's concern, with respect to coral reef deterioration, has been focused on both sea and land-based impacts.

In short, the degradation and disturbance of coral reefs in the Yaeyama Archipelago has been shown to have been caused by a combination of natural factors such as typhoons and predation by *A. planci*, and anthropogenic factors such as anchor damage, red-soil runoff, pesticides, livestock waste and waste water. Why coral-bleaching has been prevalent at some sites rather than others is as yet, unknown, although high water temperatures are undoubtedly one factor in the phenomenon. Even expert fishermen may have difficulty in identifying specific causes of bleaching at particular coral reef sites.

Thus, much information on the changes occurring in coral reefs can be gained from the underwater observations of individual fisherman. Explanations for the possible causes of reef degradation are also based on their observations. However, up-to-date information on coral reefs from such sources may not be easily available. This is because there are, at present, only two groups engaged in lift-netting; thus, the current situation offers no comparison to that which existed when as many as twenty-seven groups competed for the best fishing grounds. However, the location of *yana* for lift-netting is also an important concern for those who conduct other types of fishing, since *yana* are generally regarded as good fishing grounds for catching large, carnivorous fish that feed on the smaller fish. Data on *yana* that were presented to representatives of the Yaeyama FCA elicited extraordinary interest.

It must be added here that destructive practices such as blast and cyanide fishing, which are prevalent in Southeast Asia, seem to be minor causes of coral reef degradation in the Yaeyama Archipelago. On the other hand, socio-economic change and development have had significant negative effects on marine environments. The question of whether reefs are suffering simply because of rapid economic development needs to be clarified. In the following section, past trends in fishing technology and fish sales systems are examined in order to assess changes in the use of coral reefs.

5 Transformations in coral reef fishing technology

1. Small-scale fishing economy up to the early 1970s

In the past, blast and cyanide fishing occurred illicitly in the Yaeyama Archipelago. When I conducted research in Ishigaki in 1971, destructive fishing seemed to be common. Clearly, these fishing methods damage the coral reef environment, yet the question of why such destruc-

tive practices continue is not easy to answer. In developing countries where illegal fishing is prevalent, poverty is regarded as the main factor leading to destructive fishing. In Okinawa, however, this does not seem to be the sole reason. During the period of US administration (1945-1972), inspection of the fishery sector and enforcement of fishery laws were not appropriately implemented. Also, in the past, the Yaeyama FCA did not fulfill its role as the coordinating agency for conflict avoidance among fishermen, or for the control of illegal fishing. Instead, informal agreements in the small-scale fisheries, such as those at Itoman, southern Okinawa, were important for avoiding conflict and managing resources (Akimichi 1984).

In addition to these characteristics of the fishery sector, we must also note that the economic side of fish selling and the fish processing industries was commonly dealt with through small-scale economic transactions in Okinawa. Fishermen's wives and mothers frequently worked as fish retailers, or ran small-scale sashimi (raw-fish) shops or kamaboko (fried fish-cake) factories (Imamura 1990; Akimichi 2002). In other words, the fish catch brought back by the fishermen was dealt with through family-based networks, rather than through the fish marketing channels of the Yaeyama FCA. In 1971, there were more than 100 fish shops in Ishigaki city, and only a few middlemen ran businesses to contract with individual fisherman to obtain exclusive rights to purchase fresh fish. This reduced the ability of the Yaeyama FCA to influence fisheries' management and the fish marketing system. This family-based economy allowed individuals to ignore social conflicts and penalties, even with regard to illegal fishing.

2. Innovation of underwater diving equipment after the 1970s

Institutional reorganization and modernization processes have drastically transformed the management system and the economic channels of fisheries as a whole. After the re-establishment of the Yaeyama FCA, under the control and management of the central government, fishermen were urged to sell fish through FCA's market, rather than through family-based, small-scale enterprises. Development of the cold-chain and modern marketing systems have also led to an increase in the long-distance transport of fresh and frozen fish, which is air-freighted directly to Naha, and even to Tokyo and Osaka.

Innovations in fishing equipment and techniques have also greatly modified diving activity. In the early 1970s,

Photo. 3. Crown-of-thorns starfish (*Acanthaster planci*) collected in the extermination program (January-October, 2003).

Photo. 4. Preliminary work on the boat for the coral fragments' transplantation.

immigrant fishermen from Miyako Island introduced a new method of nocturnal spear-fishing, using a waterproof flashlight. Diurnal fish species were the major targets in this fishery (Kuchikura 1977). In the 1980s, a powerful battery pack, carried on the back, replaced hand-held flashlights. This improved the efficiency of nocturnal fishing, and the technique became widespread among a number of small-scale fishermen.

Since the 1980s, scuba diving technology has been applied to fish-drive fisheries. This has inevitably caused more intensive fishing, and large hauls of fish have been landed (Takekawa 1998, 2001). Unfortunately, some divers have suffered from decompression sickness, as a result of prolonged periods underwater. Since the 1990s, oxygen supply equipment has come into use. This apparatus greatly improves bottom-time and fishermen now work through the night. This has led to over-fishing (Takekawa 2003).

3. Live bait and groupers

The major fishing sites for nocturnal divers largely over-

lap with those used by the lift-net fishery. Major target species for nighttime spearing are daytime feeders such as groupers, coral trout, and parrotfish. These piscivores and coral-eating fishes feed in the daytime and take shelter at night. For divers it is easier to spear resting fish than swimming ones and, therefore, for the night-divers, the location of the coral heads and reefs to which these fishes tend to retreat is very important. For this reason, the *yana* locations used in the lift-net fishery have also attracted the attention of divers.

Parrotfish used to be one of the less expensive reef fish. However the sale price has risen, perhaps due to overfishing. On the other hand, coral trout and grouper are highly-prized, and the prices for these species have long been the highest among reef fish. Recent declining trends in grouper catches have increased awareness among local fishermen, and among fisheries scientists affiliated to the prefecture, of the need for conservation. This is clearly shown by the discussion concerning the closure of lethrinid fish aggregation sites during the spawning season (Akimichi 2001).

6 Conservation and sustainable use of coral reefs in the Yaeyama Archipelago

As seen above, many complex factors are associated with the environmental disturbance of coral reefs in Yaeyama. It is of primary importance to determine the relative status of these factors, in addition to seeking practical measures to eliminate both direct and indirect negative impacts, when attempting to integrate the conservation and management of coral reefs. However, the conservation of coral reefs should not depend solely on mere responses to external impacts and to legal enforcement. Positive action programs such as mariculture (Shokita 1988), coral transplantation, beach cleaning, and the promotion of eco-tourism must be implemented. A few examples of projects that have been undertaken during the last decade or so in Yaeyama will be described below. These developments have implications for future holistic management schemes. The cases of *A. planci* extermination and coral transplantation are described in '2-2' (Photo. 3) and '5-1' (Photo. 4), respectively.

1. Consensus making on the closing of fishing grounds

Apart from *A. planci* extermination, the legal regulation of fishing practices is another effective means of conserving coral reefs from degradation. As we have clearly seen above, environmental laws and conservation acts are insufficient for the elimination of illegal fishing. The local FCA's hegemony represents influential political power, which most affiliated fishermen follow. However, once stakeholders operate outside the FCA's regime, consensus becomes increasingly difficult. A recent discussion on the closure of four sites during spawning aggregations offers a good example of this problem (Akimichi 2001). In other words, a long process of discussion must take place before any action on the closure of fishing grounds or fishing seasons is implemented.

2. Eco-tourism: accepted or rejected?

In a number of tropical and subtropical regions of the world, marine eco-tourism has attracted much attention from policy-makers, tourists, the hotel industry, and anthropologists. Eco-tourism promotes the sustainable use of valuable marine resources, and subscribes to the positive values of environmental education, psychological relief, aesthetic satisfaction, and the conservation of biodiversity. Local economic benefits are gained through increased employment, small-scale tourism industries, and other facilities. A recent report by the WWF also suggests that coral reefs have tremendous economic potential (Spergel and Moye 2004), and that eco-tourism in coral reef environments shows great promise. However the blue-print of eco-tourism is not always fully accepted by local communities.

In the Yaeyama Archipelago, beautiful coral reef environments have attracted tourists who wish to experience the diving and tropical atmosphere first-hand. In the 1990s, a scuba diving boom began, and thousands of people of all ages have visited the Yaeyama Archipelago. Many new dive shops have opened in Isihgaki, offering diving tour packages; in addition, weeklong diving schools have been established for incoming tourists.

Local fishermen, particularly those who engage in diving activities, have formed a negative opinion of tourist divers. The reason for this antagonism is simple: it is feared that tourist divers' careless underwater activities will frighten fish, and may eventually cause fish to disperse, leading to a serious negative impact on the fishermen's livelihood (Akimichi 2002). The fishermen's frustration is apparently directed primarily towards tourist divers and dive operators who guide tourists to the prime dive sites. As there is no law excluding tourist divers

from coral reefs, local fishermen feel powerless to prevent this disturbance. Although there seems to be no explicit dispute between fishermen and tourists in the Yaeyama Islands, the possibility remains that conflicts may emerge in the near future. It is hoped that serious incidents, such as the physical confrontations and decade-long conflicts seen in the Miyako Archipelago, can be avoided (Ueda 1992; Takekawa 2003).

Conflicts between fishermen and tourists may not be easily resolved, as demonstrated by the recent dialogue case-study into reef fish resource management in Ishigaki (Akimichi 2001). The coordination of round-table discussions among stakeholders is also problematic. As the management of common property resources is at issue here (Ruddle and Akimichi 1989; Feeny *et al*. 1992), it is expected that further theoretical considerations may produce guidelines for a future maritime regime.

7 Fishermen's perspectives and opinions on the coral islands

Finally, I offer an example of the way in which local fishermen perceive the importance of interactions between land and sea. After the completion of the research conducted for this study, the author visited the village of Shiraho in the company of a lift-net fisherman. On the beach at Shiraho, the fisherman pointed out that waste waters from the residential area discharge directly into the sea. I learned that in the past, environmentalists and some community members in Shiraho had opposed a new airstrip development that was likely to pose a threat to the blue coral (*Heliopora coerulea*) located in front of the community. At present, the infrastructure of the community remains underdeveloped. We observed some construction work that was underway within the village, and we were told that a new waste water pipe was being created that would discharge into the sea. It is clear that before protests are organized on a national and international scale, there are many issues that have to be addressed at a local level. Fishermen in the Yaeyama Islands know this, and that is why their points of view and opinions must be acknowledged and taken into account.

Acknowledgments
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Chapter 3

Coral reef monitoring

Coral reefs in the world have suffered devastating damage by 1998 mass bleaching event. This trend of high seawater temperature and resulting stresses, appeared as coral bleaching, has frequently occurred in succeeding years as well, exposing corals to chronic stresses. In addition, outbreak of *Acanthaster planci* has also occurred in various regions from 1980s in Japan. Classic anthropogenic disturbances such as terrestrial soil inflows and physical breakage of corals by anchorage are still far from resolution. These occurrences have emphasized the importance of monitoring survey that can lead to understand the latest state of the reefs, find the abnormality, and to take measures as soon as possible. This chapter introduces such monitoring surveys, mainly on coral communities and other biological parameters, conducted in Japan. Additionally, research examples using remote sensing techniques that have been advancing rapidly in recent years will be discussed. This technique can cover broader areas and is expected to process monitoring much efficiently.

3-1 Coral monitoring in Japan

Tadashi Kimura

1 Introduction

An understanding of the current status of coral reefs is indispensable for their conservation. Changes in this status over time can only be quantified through repeated and continuous monitoring surveys, which also enable forecasting of future problems and planning of countermeasures. Under normal circumstances, the requirement for monitoring sometimes goes unrecognized, but in the event of an abnormality, adequate past monitoring data are essential.

Coral reefs in Japan have been subjected to many large-scale disturbances, including crown-of-thorns starfish (*Acanthaster planci*) outbreaks in the 1970–1980s; terrestrial red soil runoff, owing to developmental works on Okinawa Island, through the 1980s; a mass bleaching event caused by abnormally high water temperatures in 1998; and, currently, another outbreak of *A. planci* in the Amami Archipelago and Kerama Islands in 2000s. During these disturbances, the need for regular monitoring surveys, as a way of providing accurate comparative data and evaluation of the extent of the disturbance, as well as offering a basis for forecasting and for planning countermeasures, became apparent (Nature Conservation Bureau, Environment Agency 2000a; Nature Conservation Bureau, Ministry of the Environment 2003a). As global increases in seawater temperature affect the balance between coral and macroalgal communities in the temperate marine environments of Japan, monitoring will also track the anticipated changes in the composition and ecology of coral communities.

With this basic understanding, coral reef monitoring surveys have been undertaken by various institutions, researchers, administrative bodies, and volunteers. However, most individually obtained data from the past have not been comparable, nor shared, and their capability to portray the status of synchronized phenomena over vast areas is limited (Nakaya 2001). Therefore, the Ministry of the Environment and Okinawa Prefecture, where most of the coral reefs are distributed, have begun construction of an integrative monitoring framework.

This chapter discusses past and present instances of *in situ* monitoring surveys in Japan, and also presents some future issues and directions for research. Monitoring by remote sensing will be presented in the next chapter.

2 Definition of monitoring

According to Nishihira (2001), monitoring involves recording the current status by observation, comparison of results with previous records, evaluation of the current status, forecasting of future status and, when problems are found, the planning and execution of countermeasures. For coral reefs, monitoring is generally conducted with a view to conservation, and focuses on comprehension and evaluation of status, determination of the effectiveness of conservation measures, and validation of anthropogenic impacts on coral reefs (GBRMPA 1998).

3 Background of coral reef monitoring in Japan

Japanese coral reef research originated in the Palao (Palau) Tropical Biological Station in the 1930s, as well as at Tohoku University. The opening of the University of the Ryukyus in 1950, and the establishment of the Sesoko Marine Science Laboratory (presently called the Tropical Biosphere Research Center) in 1971, prepared the ground for substantial development of coral reef biology and geology research, focused on Okinawan reefs. However, since the 1970s, Okinawa's coral reefs have been heavily disturbed by repeated outbreaks of *A. planci,* land-derived red soil runoff, and mass bleaching events. These problems have turned the attention of scientists and administrative officials toward the conservation of coral reefs. *A. planci* outbreaks, in particular, have triggered systematic monitoring of coral reef environments.

Disturbances to coral reefs (mostly anthropogenic) have also occurred in many other parts of the world (AIMS 1998). Coral reef conservation was placed on the international agenda in 1995, when the International Coral Reef Initiative (ICRI) was launched by the U.S., the United Kingdom, Australia, and Japan. One of the central aims of the ICRI is global-scale coral reef monitoring, through international cooperation and consultation (ICRI 1995). The 1998 worldwide coral bleaching event reinforced the idea that coral reef conservation is an international task, and emphasized the need for a worldwide monitoring framework. Japanese authorities consider the construction of a domestic monitoring framework central to international cooperation efforts for coral reef conservation.

4 Monitoring methods

Coral reef monitoring methods that have been used in Japan include: 1) manta tow, 2) spot check, 3) line intercept transect, 4) quadrat, 5) belt transect, and 6) line point methods. Each method has its own advantages and disadvantages, and should be used according to the objectives of the monitoring program.

1. Manta tow method

Manta tows involve an observer recording changing bottom features while being towed at or near the surface behind a boat. This constitutes a good overview method, because large areas can be covered in a relatively short time; it is particularly useful for assessing coral coverage or population densities of *A. planci* over vast areas. However, the data are generated by visual estimations of the observer and therefore contain some subjectivity.

2. Spot check method

To conduct spot checks, an observer swims around the reef with snorkeling equipment while recording observed bottom features (such as coral coverage and *A. planci* population densities). This method is effective on inner reef environments or around complex patch reefs, where restrictions on boat access make manta tows impractical. The method is cost-effective and vast areas can be covered within a relatively short time period but, as with manta tows, data tend to be subjective. This method was originally developed in Japan and is widely used in Japanese fieldwork (Appendix 3).

3. Line intercept transect (LIT) method

This method requires a long line upon which distance intervals are marked. This transect line is placed on the reef, and benthic characteristics (such as coral cover, colony morphology and benthic features) occurring below the line will be recorded. Coral cover can be estimated using the total length of the line intercepted by corals. The data are objective and can be used for various applications, but the method cannot provide information about spatial changes (e.g., rates of coral spat recruitment and coral growth rates).

4. Quadrat method

Observers place a quadrat on the reef and record data from inside the quadrat (e.g., coral cover and benthic features). Detailed spatial data are available using this method, and thus information on spatial changes can be obtained. However, the method is relatively time-intensive and is therefore not appropriate for assessment of extensive target areas.

5. Belt transect method

As with the LIT method, a transect line is placed on the reef, but in this case features occurring within a belt (e.g., 1 m on each side of the line) are observed and recorded. This method is also time-intensive but yields detailed spatial information.

6. Line point method

As with the LIT method, a transect line is placed on the reef, with observation points marked on it at certain intervals. At each measuring point, benthic features within concentric circles (Marine Parks Center of Japan 1999a) or quadrats of a certain size are recorded. If the equipment is available, assessment can be much more easily accomplished using a digital video camera to film benthic features along the transect line. Monitoring points can later be randomly selected and quantified by computer (AIMS 1997). Objective data are produced and relatively large areas can be covered, as compared to what can be achieved using LIT or quadrat methods.

5 Case examples of monitoring in Japan

Many monitoring surveys have been conducted on Japanese coral reefs, by various bodies (e.g., government, local administration, university, research institute and voluntary non-governmental organizations). Data may be produced through 1) a general monitoring program, to assess the overall condition of reefs, or 2) an areal monitor-

ing program, which targets specific areas (e.g., marine park zones), or 3) theme monitoring, which focuses on particular subjects (e.g., *A. planci* and bleaching; Nakaya 2001).

1. General monitoring

General monitoring programs aim to rapidly collect the basic information about coral distribution, coral coverage, and health that is necessary to assess the status of the reef. Some of the major projects in this category are described below.

1) General monitoring by administrative bodies

a) National Survey on the Natural Environment

The 'National Survey on the Natural Environment' is the largest-scale general monitoring program in Japan, and is being conducted nationwide by the Ministry of the Environment. Basic information about natural environments (including both land and sea environments nationwide) has been assembled to fulfill the requirements for conservation under the Natural Environment Conservation Law. Coral community surveys were undertaken in 1978 (the 2nd), 1989 (the 4th), and 2000 (the 5th). Aerial photographs were analyzed based on field data collected using manta tows and spot checks. The 2nd survey (conducted in 1978–1979) estimated the total coverage of coral reefs (i.e., coral communities) for each prefecture (Nature Conservation Bureau, Environment Agency 1979), and the 4th survey used these estimated coverage results to produce a coral reef distribution map, covering the Amami Archipelago to the Okinawa Archipelago (Nature Conservation Bureau, Environment Agency 1994a, 1994b) (see index maps of Chapter 6). According to this monitoring program, the total reef (flat) area was ~83,000 ha in 1979 and ~ 96,000 ha in 1989, but the apparent increase was simply due to an increase in the survey area. In 1989 the total coral community area (including areas with coverage of 5 % with an areal extent of more than 0.1 ha) in non-coral reef areas was estimated to be 1,409.3 ha, a reduction of 14.7 ha from 1979. The reduction is thought to have been caused by predation (by *A. planci* and *Drupella*) and by environmental deterioration, due to construction and reclamation projects. The result of latest 5th survery revealed the total estimated area to be 33,531 ha and 1,864.2 ha in coral reef areas and non-coral reef areas, respectively (Nature Conservation Bureau, Environment Agency 1998c).

b) Actual Condition Survey of Coral Reefs

The Okinawa Development Agency (presently the Cabinet Office, Okinawa Development and Promotion Bureau) conducted an 'Actual Condition Survey of Coral Reefs' and coral communities, throughout the Okinawa Prefecture, from 1999 to 2002. The objectives were the collection of basic data for future continuous surveys, in order to understand the change of the reefs status and to examine appropriate monitoring methods. The 1999 survey involved 44 sites throughout the prefecture (from around Okinawa Island to the Yaeyama area); this number was reduced in subsequent years. Conventional quadrat and LIT methods were used, by which colonies were identified to genus level, coverage areas were estimated, and the numbers of *Acropora* spats were recorded. For some sites in Okinawa Island a decline in coral coverage was apparent from 1999 to 2000. Coral coverage in one of the richest coral communities in the area, the Kerama Islands, averaged 20.8 % in 2001, and decreased markedly in 2002 due to *A. planci* predation (Cabinet office, Government of Japan 2001, 2002, 2003).

c) Actual Condition Survey of Coastal Areas

The Okinawa Prefecture Department of Planning and Development conducted an 'Actual Condition Survey of Coastal Areas' in 1993 and 1994, in order to understand the status of Okinawan coral reefs that had been damaged by land development and *A. planci* predation. Surveys focused on Okinawa Island in 1993, and the Miyako and Yaeyama regions in 1994. Visual estimations of coral cover, coral species, and the presence of other benthic organisms were made within quadrats measuring 5×5-m. Other features, such as numbers of individuals and feeding traces of *A. planci* (counted during a 10-min swim), the accumulation of red soil (five-level estimation), and the rate of coral spat recruitment (number of recruits per 1 m^2) were also recorded (Department of Planning and Derelopment, Okinawa Prefecture 1993, 1994). After 1994, this survey was continued by the Okinawa Environmental Technology Association (2003). These surveys revealed the local and overall status of coral reefs at Okinawa. During the 1998 survey, coral bleaching was observed in many areas.

2) General monitoring by non-governmental organizations and volunteers

Public awareness of issues related to coral reef conservation has gradually increased, and non-governmental organizations and volunteers have started to conduct monitoring surveys. The government sometimes funds these activities but they occur basically, through the voluntary will of organizations and individuals.

a) 'Reef Check' was launched worldwide in 1997 as an international, voluntary, community-based coral reef monitoring protocol. Data collected all over the world are analyzed at the head office[*1] and world trends are calculated. Four 20-m lines are established on the reef, and for each 0.5 m the benthic organisms occurring under the line are recorded and percent cover of corals is estimated. Numbers of individuals of index fish species occurring in the belt transect (within 2 m of the line on each side) are also recorded. Various groups and individuals participate in the Reef Check framework, which, in Japan, is mainly coordinated by The Coral Network (an NGO). As well as being sent to the head office, the data are presented on their website[*2]. Although variation in data quality occurs, due to variation in the experience levels of the volunteers, Reef Check still plays an important role in reef conservation because it enhances the importance of conservation to leisure divers. Despite being collected by volunteers, data from various locations in Japan clearly confirm the recent trend toward coral community degradation. This information is important for understanding domestic trends, as well as for incorporation into the international database.

2. Areal monitoring

Areal monitoring occurs in marine park zones and nature preservation areas, both within national parks and inside the quasi-national parks that have been designated by prefectural governments. Areal monitoring is similar to general monitoring, except that specific areas within protected areas are targeted. Aside from administration-led areal monitoring programs, various institutions and researchers conduct many areal monitoring surveys.

1) Areal monitoring by administrative bodies

1-1) Government-led monitoring

a) Sekisei Lagoon

The Yaeyama Marine Park Laboratory (Marine Parks Center of Japan) instituted a monitoring survey of the distribution of corals and *A. planci* in the Sekisei Lagoon in 1983. This survey continued until 1997 through the support of Taketomi Town, Nature Conservation Section (Environmental Health Department, Okinawa Prefecture), and the Iriomote National Park Administration Office (Environment Agency) (the names of some administrative bodies have since changed). From 1998 to 2001, this monitoring was jointly conducted by the Okinawa National Park and Wildlife Office Environment Agency and the Yaeyama Marine Park Laboratory as a cooperative research project, and from 2002 until the present, monitoring programs have been run by the Ministry of the Environment. The monitoring involves spot checks (a method developed by the Yaeyama Marine Park Laboratory) on 102 fixed points in Sekisei Lagoon and neighboring areas. The results show that reefs in the area of Sekisei Lagoon suffered catastrophic damage during the 1980s *A. planci* outbreak, and for the next ten years little or no recovery was observed. A rapid recovery occurred from around 1991, with almost full recovery by 1995. However, after the 1998 bleaching event, reefs in the area suffered repeated disturbances (e.g., high water temperatures in 2001 and 2003, low water temperatures in the winter of 1999, an *A. planci* outbreak in 2001, and infestations of disease in 2003) (Taketomi Town 1983–1986, 1987–1997; Nature Conservation Bureau, Environment Agency 1998b, 1999b, 2000c; Nature Conservation Bureau, Ministry of the Environment 2001a, 2002a, 2003b).

b) Ishigaki Island

The Environment Agency (now the Ministry of the Environment) expanded the target area of the Sekisei Lagoon monitoring project to include 75 sites around Ishigaki Island. The coral communities suffered severe damage during the bleaching event in 1998 but appeared to be in a process of recovery after 1999. However, prospects for continued recovery have been clouded by subsequent major disturbances such as predation by *A. planci* and coral eating gastropods, and sedimentation due to red soil runoff (Nature Conservation Bureau, Environment Agency 1998a, 1999c, 2000b; Natune Conserration Bureau, Ministry of the Environment 2001b, 2002a).

c) Iriomote National Park

With the intent of preserving communities within the marine park zones of Iriomote National Park, The Environment Agency has conducted monitoring surveys in the area since 1998. In addition to spot checks, an LIT method was used in which five points were set on a 100-m line at 25-m intervals. At each point, coral coverage and other benthos were recorded within a circle of radius 3 m, and fish fauna within a belt 5 m on each side of the line were identified. Results showed that four marine park zones, originally designated because they contained excellent *Acropora* communities, were severely damaged during the 1980s *A. planci* outbreak. However, rapid recovery occurred from 1990, and full recovery was observed by the mid 1990s. The effects of the 1998 bleaching event appeared to be relatively

limited (Nature Conservation Bureau, Environment Agency 1999a).

d) Sakiyama Bay
Sakiyama Bay is on the western coast of Iriomote Island and was designated as a nature conservation area in 1983 (Nature Conservation Bureau, Environment Agency 1983). Monitoring surveys were conducted by the Environment Agency in 1983–1984 with the specific objective of preventing or documenting invasion by *A. planci*. Analyses of aerial photographs, manta tows, and spot checks were used, as well as a belt transect (1 m on each side of a 10 m line)/manta tow combination method (Nature Conservation Bureau, Environment Agency 1984). Post-monitoring was conducted in 1989 to document subsequent status, using 2×2-m and 1×1-m quadrats to identify coral species and colony size (Nature Conservation Bureau, Environment Agency 1990). In addition, the Environment Agency executed a follow-up survey in 1998 using the same methods as in 1989. As happened to other reefs of the Yaeyama region, the area was catastrophically damaged by *A. planci* predation; the area appeared to stagnate through the 1980s, with some recovery of coral cover observed in the survey of 1997 (Nature Conservation Bureau, Environment Agency 1999d).

1-2) Prefectural and local authority-led monitoring

a) Amami Oshima
Surveys of coral reefs around Amami Oshima have been conducted by Naze City in Amami Oshima, Kagoshima Prefecture. Fixed belt transects (30 m × 0.5 m) were established at each site and coral cover (with species identified to genus level) was recorded. The results revealed that 10–30 % of corals died during the 1998 bleaching event. No damage was seen during subsequent high water temperatures in the summer of 2001, and corals in the area appear to be recovering (Oki 2002; Amami Marine Museum [*3]).

b) Quasi-national parks in Okinawa Prefecture
The Nature Conservation Division, Okinawa Prefecture, conducted coral reef monitoring surveys in quasi-national parks in Okinawa in 2000. The LIT method was used to record coral cover (including morphotypes), benthic features, visual estimation of red soil sedimentation, and the presence of coral predators at 12 sites around Okinawa Island, and at 8 sites around the Kerama Islands (Nature Conservation Division, Okinawa Prefecture 2001). The results showed that the average coral coverage around Okinawa Island was only 8.9 %. Many *A. planci* were observed around the Kerama Islands, where the average coral coverage was 39 %.

c) Yaebishi
The Yaebishi (Yabiji) reefs in the Miyako Archipelago are important fishing grounds and are also famous for the landing tour (see also Chapter 4–5). In a 1999 survey designed to assess the influence of the landing tour on the reefs, the Fishery Division of Hirara City set up permanent quadrats of 4 m^2, in which coral cover to species level was recorded twice a year. Coverage was found to be 5–20 % in reef edge areas, and 20–70 % on the reef slope. Cold winter water temperature apeard to cause coral death, the amount of which would be equivalent to that of coral growth. (Nature Conservation Bureau, Ministry of the Environment 2002b).

2) Areal monitoring by researchers

Researchers and research institutes also conduct coral reef monitoring in specific areas. Methods vary, according to the aims of the study and the researchers themselves.

a) Uchiura Bay
The 4th National Survey on the Natural Environment in 1991 discovered a large-scale (5,000 m^2) *Acropora tumida* dominated community in Uchiura Bay, Numazu City. The Institute of Oceanic Research and Development, Tokai University, started monitoring this community in 1995. In 1996, it was found that low water temperatures had caused a decrease in coral cover to less than half the levels that had previously been the norm; this further decreased to 5 % in 2001, due to *Diadema setosum* grazing (Funakoshi and Ueno 2002). Countermeasures aimed at protecting the remaining *A. tumida* community against *D. setosum* grazing have been conducted by Numazu City and appear to have been effective (see also Chapter 6–2–1b).

b) Kushimoto Marine Park Zones
Kushimoto Marine Park has been monitoring coral communities in areas around Kushimoto, Wakayama Prefecture, since 2000, with the intent of describing the status and conservation of important communities. Three fixed sites have been established, at which coral coverage and species composition have been monitored annually, using LIT methods. Results have been published in the 'Marine Pavilion' and other journals. Reef Check and specific monitoring of *Drupella fragum* populations also occur in the area. Past surveys have

revealed high coral coverage (up to 80 %) in some areas around Kushimoto, and remarkable levels of *D. fragum* predation have also been recorded (Nature Conservation Bureau, Ministry of the Environment 2002b).

c) Otsuki
Manta tows have been conducted by the Kuroshio Biological Research Foundation since 2002 off the southern coast of Otsuki and around the Tatsukushi area in Tosashimizu, Kochi Prefecture (Kuroshio Biological Research Foundation 2003). High coral cover tended to occur at wave exposed areas while coverage tended to be low in areas subject to terrestrial soil inflows.

d) Unzen-Amakusa Marine Park Zone
Since 1999, the Amakusa Marine Biological Laboratory (Amakusa, Kumamoto Prefecture) has monitored coral communities in neighboring sea areas (including two marine park zones around Amakusa and Ushibuka City and Tomioka Town), twice a year, because of concerns about the impact of increasing seawater temperatures. In recent years, increasing seawater temperatures seem to have caused coral communities to displace macroalgal communities in the area. Sizes of marked colonies inside fixed sites are monitored, and coral recruitment rates are estimated using settlement plates. Densities of coral spat and sea urchins (algal grazers) are also monitored. The results show high coral coverages around Amakusa, with macroalgal communities being replaced by coral communities (Nature Conservation Bureau, Ministry of the Environment 2002b).

e) Sesoko Island
The status of the dynamic coral populations and communities in front of the Tropical Biosphere Research Center of University of Ryukyus at Sesoko Island, Okinawa Prefecture, has been monitored since 1991. Coverage of colonies (identified to species level) has been recorded within permanent quadrats. Recent results show that most coral communities have decreased to 10 % or less in coverage (except for some areas of 80 % *Porites cylindrica* coverage) following repeated bleaching events in 1998 and 2001, and disturbance by typhoon waves (Nature Conservation Bureau, Ministry of the Environment 2002b).

f) Akajima
Coral reefs around Akajima in the Kerama Islands have been monitored at four sites, since 1998, by the Akajima Marine Science Laboratory, with the objective of recording ecological transition states following a mass bleaching event. At each site, 0.5×30-m areas were selected, and coverage and species have been recorded by video sampling, once or twice a year, and in addition, when epidemic events occur (Taniguchi 1999). Remarkable bleaching events have not occurred since 1998 in Akajima, and these coral communities can be considered to be in a recovery stage from the 1988 bleading (Nature Conservation Bureau, Ministry of the Environment 2002a).

g) Ishigaki Island (I)
From 1995 to 2001, Fujioka and Ohba monitored community composition and environmental conditions with regard to hermatypic corals and algae at 16 sites around Ishigaki Island. They used three survey methods: 50×4-m belt transects for overall coral distribution, 1-m belt transects for profile surveys (from shore to reef edge), and fixed point monitoring using 1 m^2 quadrats. Many massive *Porites* and branching *Montipora* colonies were observed during these surveys, along with many newly recruited small colonies that were unevenly distributed around the island's northern shores (Fujioka and Ohba 2003).

h) Ishigaki Island (II)
The University of Tokyo has been monitoring Shiraho Reef at Ishigaki Island since 1998, and reefs in Kabira Bay since 1995. At Shiraho, coral coverage and dominant genus (sometimes species) have been recorded along belt transects (1 m width) running from the shore to the reef edge. In Kabira an LIT method (20 m) has been used simultaneously with the belt transects. The 1998 bleaching event occurred immediately after the establishment of sites in Shiraho, and the consequent ~50 % decline in coral coverage was recorded in detail. Branching colonies (*Montipora, Acropora*, and *Porites*) had the highest death rates and were most susceptible to bleaching, while *Heliopora coerulea* and massive *Porites* appeared more resistant to bleaching (Kayanne *et al*. 1999, 2002).

i) Urasoko Bay
The Ishigaki Tropical Station (Seikai National Fisheries Research Institute, Fisheries Agency) has been monitoring fixed points within Urasoko Bay, Ishigaki Island, twice each year (and additional observation during epidemic events) since 1995. The aim of this project is to understand relationships between coral reef environments and other biological communities, including

fishes. They use LIT (100 m fixed line) to assess coral coverage, and belt transects (using the same line, but 2 m width each side) to quantify fish fauna. Results show that *Acropora* communities in Urasoko Bay were selectively damaged by a typhoon in 1997 and by the bleaching event in 1998. It was also observed that if they survived the initial disturbance, rapidly-growing *Acropora* could quickly replace the previous community, but that if there were no local survivors, recovery took much longer (Hashimoto 1999; Shibuno 1999).

j) Shiraho
Kokushikan University and WWF Japan have been monitoring Shiraho reef off Ishigaki Island since 1995. Quadrat, LIT, and video transect methods have been used to monitor fixed transects and points. They have been conducting on both the similar monitoring and 30-min SCUBA observations at other sites in Ishigaki Island. It was concluded from the results of these surveys that coral communities at Ishigaki Island had suffered severe damage during the 1998 mass bleaching event; this could be because they had been pre-damaged by red soil runoff during the preceding rainy season (Mezaki 1991; WWFJ and Ishigaki City 1998; Hasegawa 1999).

k) Kuroshima
Harashima and Kunugi (2003) examined coral growth monitoring methods at Kuroshima, in the Yaeyama Archipelago, from 1994 to 2001. Permanent quadrats (1 m^2) were monitored using stereographic images. In addition, they assessed the effectiveness, for monitoring purposes, of a video camera attached to the hull of a boat (Harashima 1997). In communities that had been annihilated during the 1980s, but which had experienced high frequencies of water exchange, growth of new recruits and colony portions were observed from around 1994, and pre-1980s coverage had been achieved by 1998.

3) Areal monitoring by NGOs and volunteers

Monitoring on coral reefs has also been conducted by local NGOs and volunteers, especially at Shiraho and in the Sekisei Lagoon. These monitoring projects have sometimes been included in government programs.

a) Miyake Island
In 2000, a large-scale volcanic eruption occurred on Miyake Island (in the Izu Islands), forcing all residents to leave. Accumulated volcanic ash on the sea bottom partially buried coral communities around the Island. The Reef Fish Conservation Network of Japan, a volunteer group, ran a monitoring project in Togahama, a major habitat of hermatypic corals, starting in 1999. Coral cover was visually estimated using 1-m^2 quadrats and in 5×5 m area along a 100-m line transect. Monitoring stopped in August 2000 because of the eruption. The 1999–2000 survey results indicated an increase in coral coverage by several percent, but the impact of the eruption has yet to be quantified fully (WWF Japan 1999[*4], 2000[*5]).

b) Yakushima
As part of the conservation of marine park zones project, led by the Ministry of the Environment, a local society called the Yakushima Marine Organism Research Workshop monitored coral communities and fish fauna around Yakushima (Kagoshima Prefecture) in 2003. Coral communities were assessed using LIT (30 m line) and visual censuses along the same transects used to quantify fish fauna. The coral cover (20.3–49.0 %) showed little change, as compared to previous results in 1999 (a monitoring survey conducted by the Ministry of the Environment), and *A. planci* was not observed (Nature Conservation Bureau, Ministry of the Environment 2003a).

c) Ishigaki Island
Plans for the construction of an airport on Shiraho Reef (Ishigaki Island), put forward in 1979 by Okinawa Prefectural Government, were withdrawn following a strong protest campaign by local residents, WWF Japan constructed the Coral Reef Conservation & Research Center at Shiraho Village, in 2000, to further conservation activities. Annual monitoring on Shiraho Reef involves the assessment of coverage of benthic organisms by using LITs (350 m) and by taking photos of 1-m^2 permanent quadrats. A larger-scale, longer-interval monitoring program (scheduled to occur once every five years) began in 1989; it covers reefs all around Ishigaki Island, recording coral cover, number of coral genera, *A. planci* populations, and species and numbers of individuals of *Chaetodon* and anemonefish along 50-m LITs. The decline of coral reef environments has been apparent over the past ten years of this monitoring program, and recovery following the 1998 bleaching event is not complete, even in areas where communities were previously in good condition (WWF Japan [*6]).

d) Sekisei Lagoon
The Yaeyama Coral Reef Conservation Council was

established by the Yaeyama Marine Park Research Station, the Environment Agency, and local diving services. The former two organizations have been conducting coral reef monitoring to aid the management of marine park zones in Sekisei Lagoon since 1983. The Council uses the 'My Point' system to enable voluntary individual monitoring by members. The method requires selection of a favorite site by each member, which the member then monitors at regular intervals using the spot check method. Data are collected from all members, compiled, and circulated as a news sheet to participants. In addition to collecting and publicizing the latest data, this method is expected to educate members about the conservation of coral reefs. The International Coral Reef Research and Monitoring Center has now taken on the role of secretariat for this monitoring program [*7].

3. Theme monitoring

When large scale, catastorophic disturbances (such as *A. planci* outbreaks and bleaching events) occur, immidiate surveys should be conducted to gauge their impact on coral reef ecosystems. In many cases, such surveys should be continued afterwards, using the same method, or incorporated into a continuous monitoring program, in order to prepare for future re-occurrences and for comparison with past events. Here, I present some thematic surveys that have covered events that are thought to have a high likelihood of future local re-occurrences.

1) Monitoring crown-of-thorns starfish outbreaks

a) 1970s outbreak, Okinawa (I)

Following the *A. planci* outbreaks throughout Okinawa in the 1970s, various administrative bodies conducted urgent monitoring programs (using the swim count method, in which traces of individuals and numbers of individuals were recorded during a 10-min swim). These bodies included the Nature Conservation Bureau, Environment Agency (1973: 80 points around Okinawa Island in 1971 and 20 points around Kume Island in 1972), the Okinawa Prefectural Tourism Development Bureau (1976: 40 points; 37 sites replicating the above mentioned 80 points and an additional 3 sites around Okinawa Island), the Department of Planning and Development, Okinawa Prefecture for 1992-1993 (Department of Planning and Dvelopment, Okinawa Prefecture 1993, 1994), and the Okinawa Convention and Visitors Bureau (2000: 85 points around the islands of Okinawa, Miyako, Ishigaki and Iriomote). More than 600 individuals, on average, occurred within a 10-min swim northwest of Okinawa Island in 1972, and south of Okinawa Island in 1976. However, in 1999 the average number had decreased to less than 10 at many sites (excluding some local distributions), at which point the outbreak was considered to be over.

b) 1970s outbreak, Okinawa (II)

Also using the 10-min swim count method (Nishihira and Yamazato 1974), Sakai *et al.* (1988) evaluated damage at 84 points around Okinawa Island in 1987. In 1984 these authors recorded a low-level outbreak and disturbance around the island (3.9 starfish per 10-min swim, and 46.2 % coral cover), relative to levels observed in 1972 (11.8 starfish per 10-min swim, 7.2 % coral cover).

c) Outbreaks in 2000 and 2003, Okinawa

Outbreak populations of *A. planci* occurred again around Okinawa and the Kerama Islands in 2000. The Nature Conservation Section, Department of Culture and Environment, Okinawa Prefecture, inaugurated a special council meeting to develop an *A. planci* monitoring method. They adopted a 15-min swim count method, incorporating spot checks. Some locations around Okinawa and the Kerama Islands were experiencing significant outbreaks of more than 20 individuals (per 15 minutes) during the 2003 survey (Nature Conservation Division, Okinawa Prefecture 2003).

2) Monitoring of bleaching events

a) 1998 bleaching event, Sekisei Lagoon.

Following the 1998 mass bleaching event, the Environment Agency (presently the Ministry of the Environment) conducted an urgent survey to quantify bleaching damage to coral communities in Sekisei Lagoon. Eight sites were selected, based on geographical features and the apparent extent of damage, and coral community status was assessed using LIT (50 m) methods. In April and November to December 1999, the species and abundance of fish fauna were recorded along a 10-m total width belt transect along the same line. The impact of bleaching, in terms of the coral/zooxanthellae relationship, was investigated in a separate project involving collection of *Pocillopora damicornis* in April 1999 (Nomura 2000). Spot check methods were used to quantify subseguent recovery of communities at 17 sites classified as "highly damaged" (Yoshida and Hongu 2000). The results showed that where water exchange was limited, high rates of bleaching and colony death occurred (~90 % reduction in coverage at some sites). Offshore patch reefs sustained

less damage. This trend was also observed on reefs around Ishigaki Island (Nature Conservation Bureau Environment Agency 2000a).

b) Bleaching event of 1998, Urasoko Bay
Following the 1998 mass bleaching event, the Ishigaki Tropical Station conducted a series of urgent surveys in Urasoko Bay, Ishigaki Island. The number of colonies and coral coverage (live, bleached, or dead) were recorded to species level within 10×10-m fixed quadrats, at each of three established monitoring sites, in September 1998 and in January and March 1999 (Fujioka and Shibuno 1999). Fixed LITs were added as part of the extraordinary monitoring program to help evaluate the extent of the damage in July and October 1998, and in January and March 1999 (Hashimoto *et al.* 1999). Additionally, a newly established 1×9-m belt transect was photographically monitored in August 1998 and February 1999 (Hashimoto *et al.* 1999). Changes in benthic organisms, and in the content of chlorophyll *a* in algae growing on dead coral colonies, were monitored in lagoon and reef slope sites in November 1998, and in January and March 1999 (Takada *et al.* 1999). Changes in coral metabolic rates before and after the bleaching event were investigated in two colonies of *Porites lutea* by measuring organic and inorganic carbon production and the balance of nutrients in the field (Hayashibara *et al.* 1999). Species richness, number of colonies, and coverage decreased at all sites in Urasoko Bay after the bleaching event. The impact on *Acropora* was particularly noticeable, with live colonies decreasing to 5.2 % in total coverage, and to almost 0 % in the reef flat habitats (Seikai National Fisheries Research Institute, Fisheries Agency 1999).

c) Bleaching events around Ishigaki Island
The Ishigaki Tropical Station also conducted surveys around other parts of Ishigaki Island. Fish faunas were censused at 14 sites around the island from November 1997 to March 1999 (2–8 times), by video sampling (Mito *et al.* 1999). Coral community surveys were conducted in March 1999 at 10 sites around the island. During these surveys, coral species, coverage, extent of bleaching, and species and number of encountered fish and large benthic organisms were recorded at 100 ×4-m sites in reef flat and slope environments. Most of the reefs around Ishigaki Island suffered severe bleaching impacts, with the exception of the Yoshihara moat, the reef flat at Shiraho, and the reef flat at Kabira. Reduction of fish fauna was also apparent where coral communities were highly damaged (Arai *et al.* 1999).

3) Monitoring red soil runoff and water quality

Red soil runoff and subsequent sedimentation on coral reefs became a big problem in Okinawa after the area came under Japanese control in 1972. Red soil runoff is caused by terrestrial development works. The observed problems have given rise to many research projects and assessments of the effects of red soil runoff on coral reefs. Below, we discuss red soil issues and water quality monitoring surveys conducted in the area by various organizations.

a) Ministry of the Environment
The Ministry of the Environment monitored sedimentation on corals at six sites in Sekisei Lagoon. A 5-cm diameter sediment trap was used to measure sedimentation rates in 2000–2001; in addition, from 2000 to 2003, 1-m^2 quadrats, placed both sides of a fixed 15-m transect line, were used to record coral cover to species level. In general, sedimentation occurred at higher rates around the river mouth, indicating that terrestrially-derived sediments were the major cause. However, high rates of sedimentation were also found to occur at reef edges in Sakiyama Bay, which indicated that some sediments had originated from organisms, and had been transported by wave motion (Nature Conservation Bureau, Ministry of the Environment 2001c, 2002b, 2003a).

b) Ishigaki Tropical Station
From 1994 to 1996, the Ishigaki Tropical Station monitored the influence of sedimentation and high water temperatures on coral distribution in Urasoko Bay, Ishigaki Island. This survey used small and large quadrats (three 1-m^2 quadrats at each of ten sites; one or two 10×10-m or 20×20-m quadrats at each of ten sites) to quantify coral distribution. Sedimentation rates were investigated using two methods: by using a pump to extract all sediments from a 25×25-m quadrat, and by establishing groups of three identical sediment traps (2.5 cm diameter) at each site. Remarkable increases in sedimentation levels were observed with the approach of a typhoon, indicating that sedimentation occurs not only because of terrestrial soil runoff following heavy rains, but also because strong waves function as a diffusion medium, resuspending accumulated sediments (Fujioka 1997).

c) Department of Health and Environment, Okinawa Prefecture
From 1994 to 1997, the Department of Health and

Environment (Okinawa Prefecture) developed a monitoring method to evaluate the influence of red soil runoff on coral reefs at the mouth of the Todoroki River, Ishigaki Island. Monitoring sites and methods were tested in 1994–1995, and test monitoring was conducted at five sites in 1996–1997. Quadrats (2×2-m in 1994 and 1 m^2 in 1995) were used to assess coral distribution, and the mapping of coral colonies was enabled by the use of permanent 5×5-m quadrats. Sedimentation rates were measured using the Suspended Particles in Sea Sediment (SPSS) Convenient Measuring Method (see also Chapter 2–5; Department of Health and Environment, Okinwa Prefecture. 1994, 1995, 1996, 1997).

d) Okinawa Prefectural Institute of Health and Environment
The Red Soil Laboratory of Okinawa Prefectural Institute of Health and Environment developed SPSS, an easy method to estimate rates of sedimentation. The laboratory has been using this method in annual monitoring of red soil pollution at 14 sites in Okinawa Prefecture since 1995, along with visual censuses of quadrats (2 × 2-m permanent quadrats) to estimate coral cover. Their results show that at the Akase coast near Onna, where heavy dredging had occurred during agricultural land development in the 1980s, SPSS rates dramatically decreased during the period of the survey and, at the same time, coral cover increased from less than 1 % around 1990 to more than 50 % in 1998. Measurements in the estuary of the Kamu River, near Kin, from 1996 to 1998 also showed trends toward a reduction in SPSS and an increase in coral cover (from 3 to 15 %). A decrease in coral cover and increases in SPSS levels were observed on the Odo coast, owing to the erosion of agricultural land (Nakasone *et al.* 2000).

e) University of Ryukyus
These authors sought to understand the relationship between water quality (nutrient and sedimentation), coral distribution, and coral spat recruitment at three different locations (Sesoko Island, Amitori Bay of Iriomote Island, and Kuroshima), in 1996. They randomly established four permanent quadrats for measuring coral distribution (coral cover to genus level), settlement plates (two 10×10-cm slate plates fixed 2 cm apart, bolted to the reef) for spat recruitment, and sediment traps (10 cm height ×9 cm in diameter), from which they quantified sedimentation by dry weight, ignition loss, and particle composition. Water quality parameters included temperature, salinity, SS, T-N, NH_4-N, NO_2-N, NO_3-N, and T-P. Differences were apparent in terms of sedimentation and water quality between sites, but not between areas (Yui and Sakai 1997).

f) Ishigaki Island Red Clay Watch Network
The Ishigaki Island Red Clay Watch Network is a voluntary network established in 1999 by the Yaeyama Fisheries Cooperative, the Yaeyama Diving Association, and the Red Clay Runoff Awareness Association. The network used the SPSS method to monitor sedimentation at moats surrounding the island, once a year, from 2000 to 2002, and the results are shown on their website [*8]. Strong trends toward increasing sedimentation rates are apparent in the data. The percentage of 'rank 6' sites (considered to result from obvious anthropogenic effects; see also Chapter 2–5) increased from 21 % in 2000 to 67 % in 2002, and eight sites scored the maximum sedimentation level of 'rank 8' in 2002, as compared to none in 2000.

g) WWF Japan [*4]
Since August 2000, the Japanese WWF Coral Reef Conservation and Research Center has used volunteers to measure sedimentation by the SPSS method, monitoring at 32 fixed points on Shiraho Reef (Ishigaki Island), four times a year. The mean SPSS rate of all locations on Shiraho Reef over three years (2000–2002) was 14.8 kg/m^3, which corresponds to 'rank 5a' (see also Chapter 2–5); this is considered to constitute the upper boundary of SPSS values at which a live coral reef ecosystem can exist. Areas scoring 'rank 6' or higher were observed but were limited to sites proximal to the northern part of the Todoroki river mouth. Seasonal variations in SPSS rates were not detectable when data were averaged across all locations, but when locations were compared, obvious peaks in SPSS rates occurred at sites proximal to the northern part of the river mouth during heavy rain in summer to fall.

4. Other monitoring

Other kinds of monitoring of coral reefs involve environmental assessment and impact monitoring (conducted before and after development works), as well as post-monitoring, to evaluate the effectiveness of coral transplantation projects for example. An example of assessment monitoring is discussed below.

The Department of Ports and Harbors, of the Tokyo Metropolitan Government, conducted environmental assessment monitoring to investigate the impact that the

construction of Ogasawara Airport would have on local coral communities in 1999 and 2000. Prior to construction, the status of the coral communities near the Tatsuminaka and Kominato coasts of Chichijima were assessed to obtain initial comparative data. Permanent quadrats of 1 m^2 were established at six sites, at each of 12 locations, and coral species and their coverage, as well as species of other benthic organisms and their coverage, were recorded. The monitoring was executed biannually for two years (Tokyo Metropolitan Government 2000, 2001).

6 Problems with past monitoring programs

Although there are plentiful examples of Japanese coral reef monitoring projects, most programs have targeted specific themes or locations. These data did not enable anticipation or rapid recognition of high-impact events that were wide-ranging in scope (e.g., mass bleaching or *A. planci* outbreaks). There have been only a few instances of long-term monitoring, and many programs have been conducted independently, by separate organizations, using methods that were not comparable. Moreover, the monitoring reports are usually distributed only to the institutions concerned, not openly disclosed to the public (e.g., via websites); therefore, much time and effort must go into locating existing data for later use in conservation projects.

7 A new monitoring framework

Recently attempts have been made to establish a new monitoring framework, designed to address the major problems mentioned above.

The Ministry of the Environment opened a forum for information exchange on this issue, targeting researchers from various locations in Japan. A unified method for coral reef monitoring (which should also be effective for non-reefal communities) has evolved from long-term monitoring methods already in use in national parks. This expert forum is now considering a unified approach and framework for implementing information exchange, as well as for providing information to the GCRMN. Some of this information will appear in the next 'Status of Coral Reefs of the World' report.

The Japanese Coral Reef Society established a 'Conservation Committee' (membership of which is open to all interested parties) as a forum for general discussion of coral reef conservational issues. A Monitoring Subcommittee has also been established to discuss the collection, evaluation, and utilization of monitoring information in Japan.

8 Future prospects

Development of the unified monitoring framework noted above is underway, although progress towards its establishment is slow. Current discussions are focusing on details of the overall monitoring design, i.e., what kind of data must be collected, at which sites, and how best to use the collected data. Other issues related to the submission, organization, and utilization of locally generated data at the national level still need to be addressed. An administrative center responsible for database management and data compilation will be required, and there will be further problems to overcome with respect to data ownership and utilization.

A fully functional, national monitoring framework will be of use to other countries worldwide. The pressing nature of the domestic issues noted above notwithstanding, the top priority is to forge a connection between monitoring programs and coral reef conservation outcomes. This will require the construction of appropriate networks and relationships between various stakeholders; in addition, the promotion of mutual understanding will be important. Further involvement of existing networks, including universities, research institutions, and non-governmental organizations may be advantageous in this endeavor. Through active implementation of a nationally effective monitoring framework, with reflected outcomes in actual conservation, cohesive efforts within Japan should emerge as a matter of course; these achievements will contribute, in turn, to global initiatives aimed at further development of coral reef conservation worldwide.

Cited websites

1 http://www.reefcheck.org/
2 http://hs.st41.arena.ne.jp/ reefcheckjapan/
3 http://www.synapse.ne.jp/kaiyo/news/0204.html
4 http://www.wwf.or.jp/enetwork/josei/1999/no9913.htm
5 http://www.wwf.or.jp/enetwork/josei/2000/no9913.htm
6 http://www.wwf.or.jp/shiraho35vil/
7 http://www.coremoc.go.jp/
8 http://coral.h2o.co.jp/akatuti.html

3-2 Remote sensing of coral reefs in Japan

Kazuo Nadaoka, Enrico C. Paringit, Hiroya Yamano

1 Introduction to remote sensing of coral reefs

Accurate, up-to-date and accessible information on the state of coral reef ecosystems is indispensable for informed and effective management of these important marine resources. Remote sensing holds a vital role in the science and management of natural resources since they provide a rich source of spatial information at synoptic scales and at different periods. For coral reefs, remotely-sensed images can be interpreted or analyzed to produce maps of various themes (presence/absence distribution, species composition, abundance) with degree, extent and detail at a rate that cannot be matched by field methods alone.

This chapter chronicles the contributions made by the Japan in the field of remote sensing applications to the science and management of coral reefs. To set the context, the topics contained herein include a brief background on coral reef remote sensing observation. The specific applications to benthic cover or habitat mapping, detection of coral health and bleaching, coral morphology estimation, bathymetry mapping, assessment of sedimentation, seagrass mapping, sea surface temperature monitoring are then presented with some other emerging applications. Each section in this chapter will first outline the recent efforts that were poured into the development of remote sensing technique and then will expound the specific methods and applications in Japan.

In Japan, most corals are located in the Ryukyu region, situated southwest of mainland Japan. Naturally, most of the study areas for coral reef studies are located in this region. The same is true for research topics that apply remote sensing techniques. In the entire Ryukyu Islands, the southeastern island of Ishigaki had received the most attention, particularly the east portion called Shiraho reef area not only because of its high degree of diversity which attract scientists but also for its accessibility and convenience for researchers. Shiraho reef is especially well-studied that much of the field data gathered by biologists and reef scientists are further utilized in performing validation of processed satellite image data. Although benthic cover mapping results are a popular fare among published reports, analysis of reef sedimentation and coral bleaching are increasingly becoming preferred topics of recent studies.

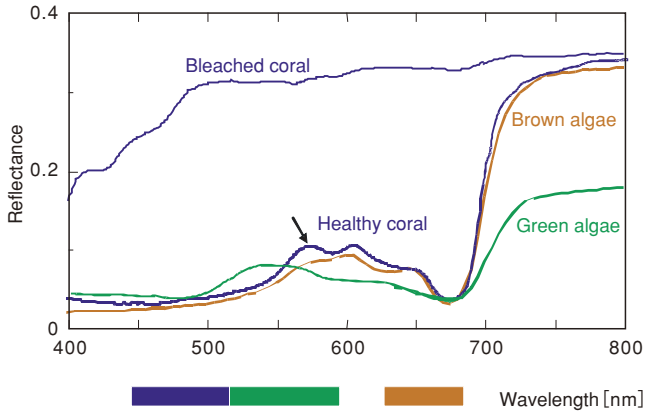


Fig. 1. Reflectance spectral of coral reef benthic organisms (coral and algae) and observation bands for Landsat TM. Spectral feature of coral is indicated by an arrow.

Remote sensing analysis attempts to develop methods by which imagery acquired from distant sensors can be related with that of existing physical conditions found on the earth's surface at the time of data acquisition. Images are grid array of signal data of varying intensity detected at different wavelength ranges. A key principle in remote sensing exploits the fact that objects exhibit spectral responses that vary with wavelength, known as spectral signatures (Fig. 1). The ability of optical sensors to "see" through the water column is an advantage for examining submerged objects like corals or seagrasses and the like. However, optical sensors are severely vulnerable to harsh weather conditions. Presence of clouds, haze and various forms of water vapor impede acquisition of clear scenes. Signal-to-noise ratio is likewise a key issue since water absorbs a large portion of the incoming energy rendering low contrast

among submerged objects especially when the radiometric resolution of the sensor is low.

The techniques applied to interpret coral reef areas are rooted on traditional methods of visual interpretation commonly applied to aerial photography. Deduction of natural features is accomplished by examining image tone or color, scale, texture or pattern. Delineation of objects or detection of a certain phenomenon is usually carried out manually on printed images or digitized onscreen either by trained, experienced or knowledgeable interpreter.

Remote sensing of coral reefs is faced with three major difficulties. First, water column on coral reefs strongly absorbs wavelengths longer than 650 nm (approx), thus the use of light is limited to visible regions (400–650 nm). This aspect marks a significant difference from terrestrial vegetation remote sensing that makes extensive use of the near infrared sensors. Second, because of their symbiosis with zooxanthellae, corals show reflectance characteristics similar to that of algae (Fig. 1). This means that multispectral sensors with wavelength resolution of several tens of nanometers, such as Landsat TM, will find difficulty in distinguishing between corals and algae with precision. Third, because coral reefs are highly heterogeneous, the spatial resolution of currently available, widely used satellite imagery is considered to be too coarse to map reefs in detail due to spectral mixing in one pixel.

Nonetheless, current advances in remote sensing technology may circumvent or alleviate these limitations. The availability of digital imagery such as those obtained by sensors onboard satellite platforms enables implementation of numerical algorithms on computers to infer reef characteristics. The advent of sensors with multiple bandwidth detection capabilities made it possible to acquire multispectral (10 bandwidths or less) and hyperspectral data (more than 10 bands, e.g., airborne CASI and satellite-borne Hyperion). This development have vis-à-vis rendered analysis of images more complicated due to introduction of physics-based approaches, specifically radiative transfer models, but also presents greater potential for full extraction of object optical properties. At longer time scales, analysis of archived aerial photographs and satellites has been proven to be very effective in monitoring decadal changes in coral reefs at large spatial scale.

Japan enjoys a strong support and a solid infrastructure for conducting remote sensing research. This is primarily due to the presence of a national agency for space technology research and applications, the Japan Aerospace Exploration Agency (JAXA) (formerly called the National Space Development Agency - NASDA). Since 1978, Japan has launched about 5 (MOS-1, MOS-1b, Japan Earth Resource Satellite or JERS-1, ADEOS, and ADEOS II) earth observation satellites excluding the course-resolution Geostationary Meteorological Satellite (GMS) system, which is intended primarily for weather forecasting, and the Tropical Rainfall Measuring Mission (TRMM). Most satellite image datasets, including those produced by foreign missions are available from the Remote Sensing Technology Center (RESTEC), the distribution data distribution and technology promotion of NASDA.

Another organization in Japan that is involved in remote sensing activities is the Earth Remote Sensing and Data Analysis Center (ERSDAC), a non-profit foundation and now belongs, legally, to the private sector. The prime objective of ERSDAC is to accelerate the research and development of remote sensing technology to be applied to exploration for non-renewable resources as well as environmental monitoring on a global scale. ERSDAC currently acts as the data distribution center for ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), a sensor developed by Japan onboard the satellite Terra launched by the United States.

Often, the satellite images used in the analysis of coral reefs included ASTER, Landsat 7 ETM+, Landsat 3, 4 and 5 TM, ASTER, Ikonos and to a lesser extent, SPOT. An airborne hyperspectral sensor is also available from NASDA and has been used to acquire images over Kuroshima (Is.), Ishigaki Island and parts of the Okinawa and Kerama Islands.

2 Benthic cover classification of coral reefs

Remote sensing techniques allows for the investigation of wide area, including often inaccessible remote sites routinely, and thus is very effective for monitoring earth surface features including coral reefs. In reef areas, the most elementary biotic classes are coral, algae, and sand. Dead corals due to bleaching or infestation by crown-of-thorns starfish or COTS (*Acanthaster planci*) will be covered by algae, thus distinguishing corals and algae can be useful not only for mapping coral-reef elementary benthic organisms but also for monitoring coral reef health.

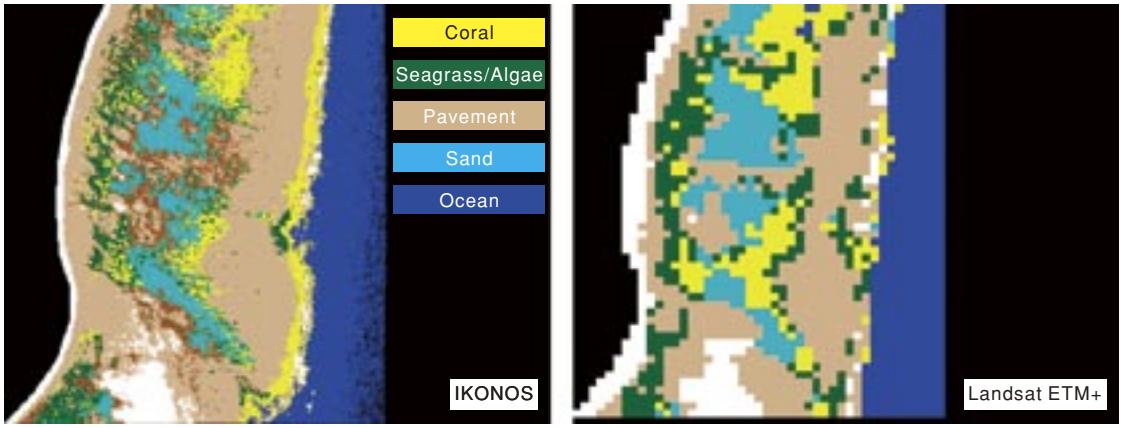


Fig. 2. Comparison of classification results by Ikonos and Landsat ETM+ (Shiraho Reef, Ishigaki Island).

In the Ryukyu Islands, classification of coral reefs using aerial photographs began in the late 1970's (Ohba and Aruga 1978). While most of these studies are rely on visual interpretation of the images, digital image classification was conducted by Nakamori and Sugai (1990) and Fujiwara *et al.* (1997). Kite photography was also used to detect bleached coral colonies (Hasegawa *et al.* 1999).

For classifying images, Landsat TM/ETM+ and SPOT HRV have been mainly used (Kato *et al.* 1992; Hasegawa 1993; Miyazaki *et al.* 1995, Nadaoka *et al.* 1997, 1998). Recently, high spatial resolution satellite sensor Ikonos, was used for classification, and an overall accuracy of 81% was achieved in Shiraho Reef, while the 64-% overall accuracy was obtained by Landsat ETM+ (Andréfouët *et al.* 2003) (Fig. 2). Furthermore, the use of this first hyperspectral satellite-borne sensor, EO-1 Hyperion, for classification of coral reef benthic habitats situated at the eastern coast of Ishigaki Island is in progress (Matsunaga *et al.* 2003). They acquired and examined Hyperion data for diagnosing spectral features from shallow coral reef area and benthic classification (Matsunaga *et al.* 2001a). Furthermore, by simulating the top-of the atmosphere radiance as to be detected by Hyperion, Matsunaga *et al.* (2001b) showed that signal-to-noise ratio (SNR) and sensor spectral response may affect classification performance. It was also shown that spectral derivative analysis may pose potential for classifying sea bottom coverage.

As mentioned, although reflectance signatures of corals may be similar to other reef benthic habitats, their location within the reef may dictate their actual classification (Mumby *et al.* 1998). Paringit and Nadaoka (2004) used a contextual classification approach by morphology to constrain possible location of benthic classes. They have also introduced spectral unmixing approach for estimating the fractional coverage of benthic habitats. Instead of classification maps, the scheme produces fraction maps for every benthic habitat. If a classification map is desired, it can be derived by simple setting a threshold coverage for every benthic cover and combining the results.

Reflectance measurement by *in-situ* spectrometer has been conducted since 1990's (Hasegawa 1993; Matsunaga and Kayanne 1994; Miyazaki *et al.* 1995). Recently, the spectra obtained by hyperspectral sensors provide continuous data, and the analysis of reflectance spectra has successfully discriminated coral reef features (Holden and LeDrew 1999; Mumby *et al.* 2001; Hochberg *et al.* 2003). With radiative transfer simulation, the effectiveness of airborne hyperspectral remote sensing is believed to contribute to a much better classification results (Yamano *et al.* 2002). In the Ryukyu Islands, airborne hyperspectral sensor, CASI, was used to classify coral reef benthic features in Kuroshima and Akajima (Miyazaki *et al.* 1997, 1998; Yamano *et al.* 2003a).

The reflectance spectra as would be measured at the top of the atmosphere are substantially different from the *in-situ* spectra, due to differential attenuation by the water column and, most importantly, by atmospheric Rayleigh scattering. The result is that many of the spectral features that can be used to distinguish coral species from their surroundings or from one another, which have been used successfully with surface or aircraft data, would be obscured in spectral measurements from a spacecraft (Paringit and Nadaoka 2002a). However, above the atmosphere, the radiance contrasts between most coral species and mostly brighter non-coral objects remain noticeable for water column depths up to 20 m. Over many spectral intervals, the reflectance from dark coral under shallow water is smaller than that of deep water. The maximum top-of-atmosphere radiances, and maximum

contrasts between scene types, occur between 400 nm and 600 nm. This supports the conclusions of recent satellite reef mapping exercises, which suggest that coral reef identification should be feasible using satellite remote sensing, but that detailed reef mapping (e.g., species identification) may be more difficult (Mumby *et al.* 1997). The measured and modeled hyperspectral reflectance spectra were examined separately to compare the degree to which different substrate types can be discriminated once the water column is "added" to the spectra. The classification accuracy assessment indicated that the ability to discriminate benthic habitat based on hyperspectral characteristics is limited when the effects of the water column are included as the kappa statistic drops from 0.70 to 0.49.

3 Evaluating coral health and detecting bleaching events

Remote sensing can be used for detecting stressed/bleached corals, as demonstrated by recent papers by Yamano and Tamura (2004) for bleached corals in Japan (see Section 7) and by Elvidge *et al.* (2004) for those in Great Barrier Reef of Australia.

Stressed corals show decreased physiological function, such as decreased photosynthetic activity and pigmentation, and changes in fluorescence spectra were detected prior to visible bleaching (Hardy *et al.* 1992). Yamano *et al.* (2003b) observed the reflectance spectra of naturally bleached corals and experimentally stressed corals by exposing them to high temperature and strong solar radiation, and analyzed changes in reflectance spectra, photosynthetic capacity, and zooxanthellae status. In response to stress, the corals became dominated by degraded, shrunken zooxanthellae, and their photosynthetic capacity decreased. In both experimentally stressed and naturally bleached corals, the red edge (maximum of the first derivative of a reflectance spectrum based on hyperspectral reflectance measurement) in the reflectance spectra shifted to a shorter wavelength (Fig. 3), suggesting the use of reflectance spectra as a potential tool for detecting stressed corals.

Bleached corals provide a strong optical signal that suggests that remote sensing investigations of major bleaching events are feasible using airborne or satellite sensors. However, patchy coral cover, varying intensities of bleaching, and water depths are likely to limit the application of remote sensing techniques in monitoring and mapping coral

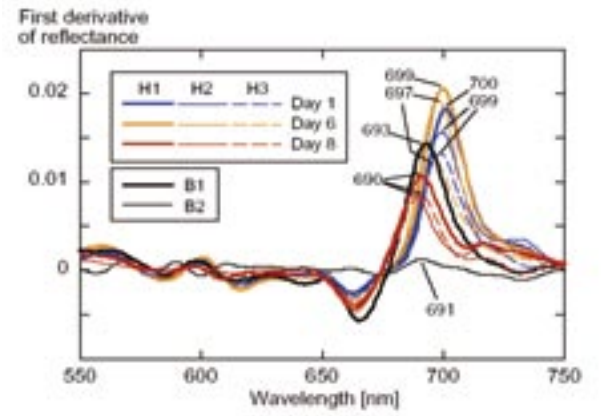


Fig. 3. First derivatives of reflectance spectra for *Montipora digitata* samples (H1 to H3) during the stress experiment and for naturally bleached *M. digitata* samples (B1 and B2). The location of the red edge is indicated.

bleaching. Analysis of scanned aerial photographs acquired during the 1998 bleaching event over the Great Barrier Reef (Australia) at various spatial resolutions, from 10 cm to 5 m showed that accuracy of mapping bleaching is highly sensitive to spatial resolution. Highest accuracy was obtained at 10 cm resolution for detection of totally bleached colonies. At 1 m resolution, as much as 50% of the 10-cm resolution signal is lost, though the spatial patterns remain correctly described (Andréfouët *et al.* 2002). Partially bleached (pale) corals are difficult to detect even in aerial surveys, leading to an underestimation of overall bleaching levels (total and partial bleaching) in aerial photos compared to *in-situ* surveys. If data volume and processing time are limiting factors, local variance analysis suggests that the optimal resolution necessary to capture spatial patterns of bleaching is in the range 40-80 cm.

4 Detection of coral morphological features

It is widely known that key remote sensing factors such as direction of the sun, reflection, refraction, scattering and shading control the angular distribution of light in coral. The quality of the optical spectrum that reaches the bottom of shallow waters is influenced by the sequential layers of enveloping atmosphere, the water column starting from the water surface state and along depth (Fig. 4). These influences repeatedly alter light as it exits upward from the bottom and subsequently detected by the sensor. Various forms of the radiative transfer model are used to quantitatively describe the effects of the optically-active constituents

present on these layers to the sun radiance as it enters the environment and its eventual capture by remote sensors. As explained in the previous section, spectral mixture models provide a way to quantify proportion of different benthic cover within a pixel.

The remaining gap thus lies in the morphological aspect of coral reflectance modeling. Previous mapping attempts for example, do not consider them as volume-occupying and bulk-filled entities as they are in reality. Therefore, the actual quantitative aspects governing the spectral response changes at different observation angles and various coral structural attributes must be clarified since morphologic variations within coral assemblage further results in unequal distribution of light within the canopy. The dependence of light intercepted by coral with viewing geometry and morphology forms the basis for defining the bidirectional reflectance distribution function (BRDF) for corals. While previous studies have identified various factors contributory to bidirectionally-reflecting nature of corals (Joyce and Phinn 2002), Paringit and Nadaoka (2002b,c,d) proceeded to develop a directional reflectance model specific for analyzing coral reef areas, which may be called also "3-D coral canopy model" or "coral BRDF model", emphasizing the importance of shape, form and shadowing of coral canopies as main factors in influencing their appearance in images or real scenes.

Here, coral "canopies" are treated as an assemblage of three-dimensional objects that vary with certain coral component characteristics. To explain the radiance distribution within the coral, a mathematical description for the structure of the coral was devised as a function as total area occupied by branches or facets per area of substrate called the facet area index (FAI). The branch number density and the height, of a single branch of coral, determine FAI. Utilizing this concept of FAI, which is analogous to the notion of leaf area distribution (LAI) in terrestrial vegetation, the reflectance directly from the top of the coral can be computed. We may also generalize the geometry of the coral-covered heap as a turbid medium of an inclined area with a specific volume density and vertical canopy thickness or height to be incorporated in our model simply by the FAI.

The objective of remote sensing analysis is to relate the set of reflectance measurements represented either as *in-situ* spectra or in arrayed image form tiled according to spectral bandwidth, with that of the independent parameters (Paringit and Nadaoka 2002c). It is the exact opposite of

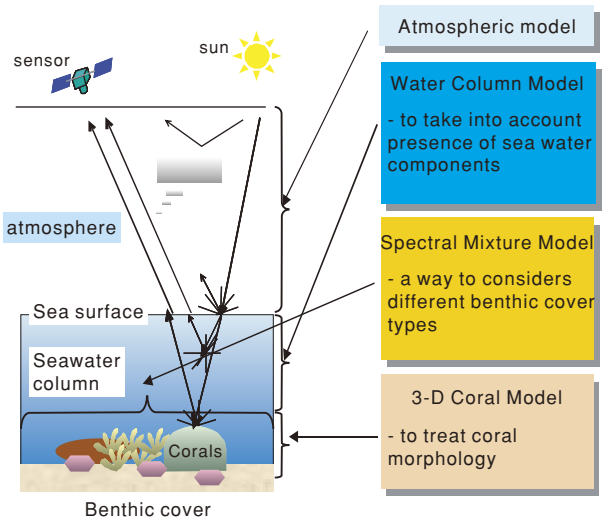


Fig. 4. Coupling of atmospheric, water column, cover and morphology reflectance models.

doing the reflectance modeling and thus called the inverse problem. The inverse problem seeks to test the reflectance, computed based on a set of input geometric and optical parameters by the coral reflectance model against a set of measured coral multidirectional, multiview reflectance values by means of a merit function. The inversion process estimates the inherent optical property (IOP) of the coral components (branches), its structural configuration, the qualitative condition of the seawater at a certain observation time. Since the forward problem cannot be inverted directly, an iterative error minimization scheme is employed instead. The difference between the estimated spectral curve and measured (e.g., from the image) is minimized by adjusting the model values in a predictor-corrector scheme. When the difference reaches a minimum, or the set of variables is optimized, absorption coefficients and bottom depths along with other properties are derived simultaneously.

Use of the inverted coral BRDF model for a transect in 4-band Ikonos image, now masked to contain the coral cover only, resulted in the computed FAI shown on Fig. 5 (b). Maximum FAI values reached up to 3.4 m2/m2 while a minimum was fixed at 1. No exact protocols exist to verify these results. To make reasonable comparisons, we utilize the coral coverage survey from Kayanne *et al.* (2002), which shows the distribution of coral species namely *Heliopora, Porites* (massive), *Porites* (branching), *Montipora* (branching), *Acropora* (branching) and *Pavona* along five (1 km approximate) transects in the Shiraho Reef. Some extrapolations based on the computed morphological characteristics of the corals (e.g., branching or not, if branching, how dense?) are then made in relation to coral

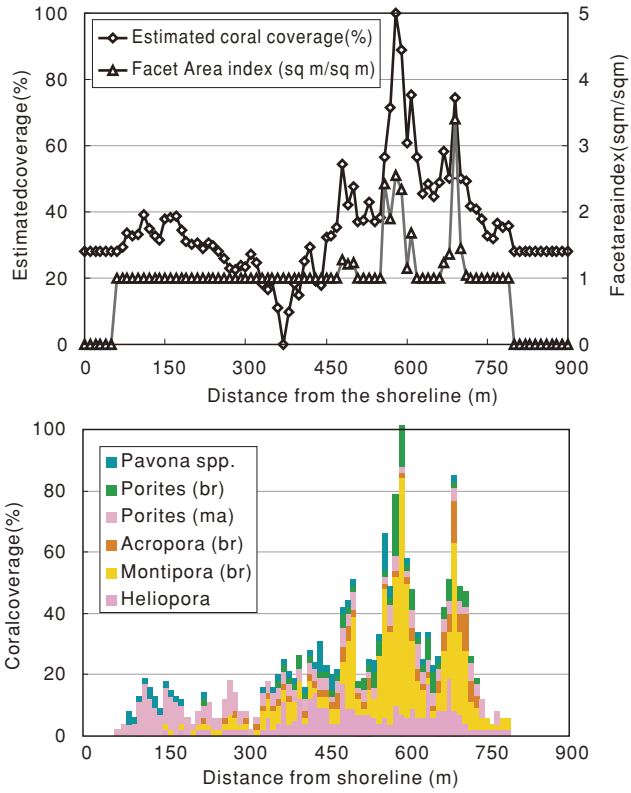


Fig. 5. (a) Coral coverage and facet area index calculations based on the coral layer model applied to Ikonos March 2001 image and (b) coral cover data from field survey in 2001. Note the striking similarities between estimated and actual coverage.

type distribution. To demonstrate, Fig. 5 (b) plots show the actual coverage. It shows a reasonable agreement between presence of coral and FAI, by correctly assigning a value of 1. Furthermore, when branching corals are present (e.g., *Montipora* and *Heliopora*), peaks in FAI occur along the transect. Maximum computed FAI also occurred in a point along the transect where full coral coverage was found. On the other hand, the tendency to underestimate is also apparent. This may be due to the initial threshold step where aerial mixture of substrate (e.g., sand) and coral could result in lower FAIs.

5 Bathymetry Mapping

Earlier studies of passive remote sensing in shallow-water indicate empirical regression as the most common method of extracting bathymetry. This approach provides rapid data processing, but it requires knowledge of a few true depths for the regression parameters to be determined, and it cannot reveal in-water constituents. Bathymetric mapping by remote sensing techniques is possible only down to 25 m in the clearest natural waters due to natural absorption, and the ability to estimate depth remotely deteriorates considerably less in turbid waters. Traditionally, existing methods (Lyzenga 1978; Benny and Dawson 1983; Jupp 1988) are heavily reliant on the diffuse attenuation coefficient of the water column, supposing that water quality does not vary within the area covered by the image, and makes the unrealistic assumption that bottom albedo is constant and exhibits a Lambertian reflectance. Prevailing practices suggest measurements at different depths and creation of a log-liner regression line against the satellite data values (DNs, reflectance or radiance) where the gradient equals the site-specific attenuation coefficient. An examination of the depths versus DN plots for the first 3 bands of Landsat in the Shiraho Reef, however, suggests that the negative exponential relationship is not quite obvious. Therefore, a more sophisticated technique must be developed to derive bathymetry from optical satellite imagery. This is where the coral reflectance model (Paringit and Nadaoka 2002b, c, d) may again come into promising use.

The process of estimating depth starts by modeling remote-sensing reflectance spectrum by plugging in set of values of absorption, backscattering, bottom albedo, and bottom depth. Then the estimated reflectance spectrum is compared with the spectrum from measurements until the error is minimized or a convergence is reached. This time however, the depth parameter, z is included as one of the unknowns to be estimated. Instead of relying on the diffuse attenuation coefficients based on depth measurements, the proposed method computes attenuation based on absorption, and backscattering coefficients as light passes in and out of the water column. These coefficients can be computed from previous bio-optical model that require concentrations of various optically-active constituents and sea surface state.

A constrained linear mixture model was first employed to determine relative proportion of different benthic cover types. The resulting seabed fractional map served as a basis for assigning proper substrate albedo for each pixel in bathymetry extraction for all methods examined. Note that unlike three previous methods, the albedo value of coral-laden regions for each satellite band examined through the present model undergoes further re-computation by the BRDF model iteratively to achieve underwater top-of-the-coral reflectance until such time that the error tolerance for the inversion is achieved.

Figure 6 shows the results of depth estimation in the case of Ikonos image estimated for portions along two of the five permanent transect lines (Kayanne *et al.* 2002) using the

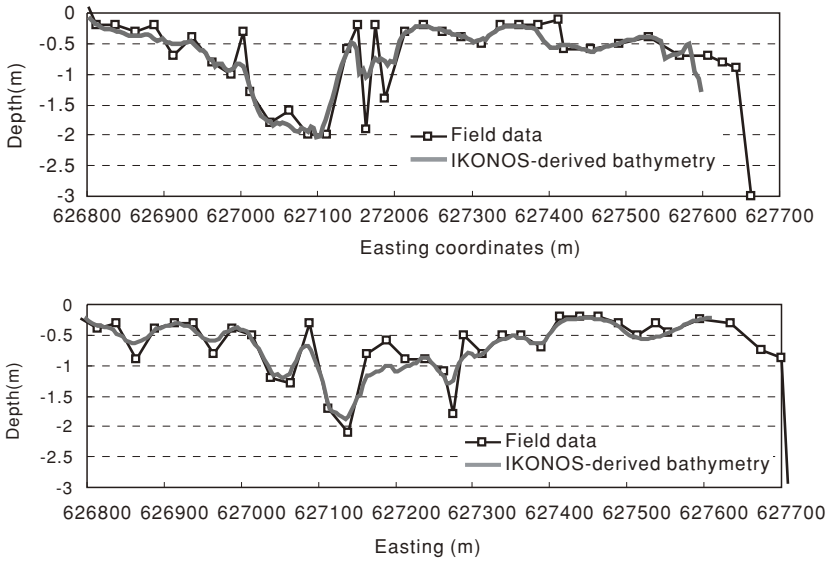


Fig. 6. Comparison of depth estimates derived from Ikonos data processing using the inverted layer model with field bathymetry data along CL permanent transect lines in Shiraho Reef (RMS=0.24). Surveyed depth data is from Kayanne *et al.* (2002).

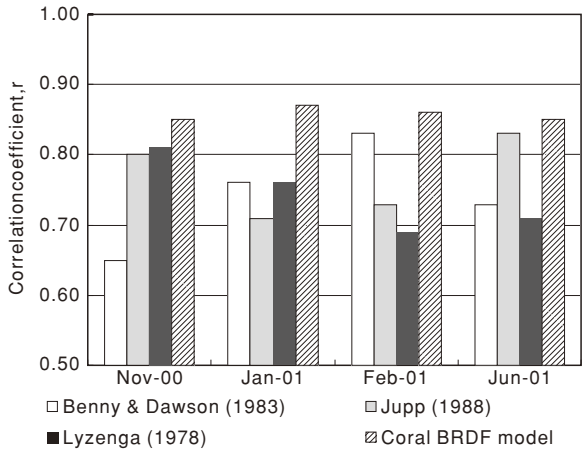


Fig. 7. Comparison of bathymetry mapping algorithms.

proposed model by (Paringit and Nadaoka 2002c; Paringit 2003). With the four meter resolution of multispectral Ikonos, a remarkable improvement in the topographic detail is seen. This quality even exceeds those yielded by sounding devices aboard survey vessels which can sample at slower rate relative to boat speed.

Another positive feature of the method is found in the consistency of its results. For example, although the satellite passes over a certain area in the earth's surface about the same time during the day (10:00 AM JST as in the case of Ishigaki), tidal variations would influence reflectance and alter depth estimates (Fig. 7). The different bathymetry mapping methods as mentioned above, including that of the present model (coral BRDF model) were applied to Landsat ETM+ images acquired in four different dates (November 2000, January 2001, February 2001, June 2001). All of the images were corrected for tidal fluctuations and were referred to a common vertical datum. Obviously, as shown in Fig. 7, the proposed model indicated as "coral BRDF model" gives the highest performance in the bathymetry mapping, regardless of the difference in the time of the image data acquisition.

With the high-resolution bathymetry data for Shiraho reef area and its surroundings obtained by applying the method described above to Ikonos imagery, Tamura *et al.* (2003) succeeded in numerically simulating currents and other hydrodynamic quantities in excellent agreements with field data.

6 Sedimentation mapping applications

The problem of sedimentation is a serious threat to the coral reefs in Japan. Fringing coral reefs suffer from substantial sediment inflows of red silt, called *akatsuchi* discharged from rivers due to intensive agricultural and infrastructure activities prevalent in inland areas surrounded by the reefs. A powerful and relatively simple method to assess seabed conditions is to come up with an index to quantify the levels of sedimentation (Nadaoka and Tamura 1992; Nadaoka *et al.* 1998) by applying an optical theory. The premise is that the differences in the degree of the sediment deposition at the seabed may affect the characteristics of the light reflectivity at the sea bottom. Nadaoka and Tamura (1992, 1993) derived an index, which may be called "sedimentation index *SI* ", and would be sensitive to the seabed reflectivity, without appreciable dependence on the water depth.

Figure 8 shows the results of the *SI* analysis, which gives good agreement with the field survey data. Results of the analysis show that among related factors such as precipitation, land slope and vegetation, red-silt outflow and its deposition in the reef area are most influenced by vegetation cover.

Paringit and Nadaoka (2003c, 2004) proposed another approach to detect red silt sediments in sea bottom surface by use of the spectral mixture algorithm, in which the red

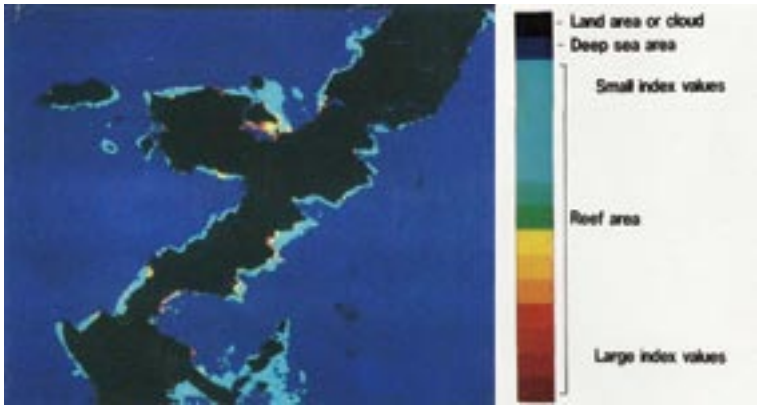


Fig. 8. Classification of the sea-bottom conditions based on the sedimentation index *SI*.

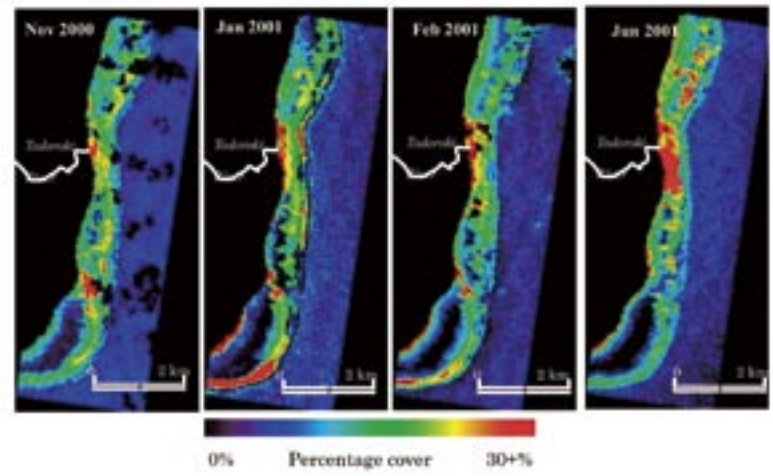


Fig. 9. Satellite-derived sediment deposition distribution map based on mixture analysis (Paringit and Nadaoka 2003c).

silt sedimentation at the bottom surface is estimated as a spatial fraction covered with the red-silt in a pixel together with all other benthic cover element fractions. The method assumes that the composite reflectance of every element in an image can be deconvolved into its components, in terms of cover, usually by assuming a linear model for the occurring spectrally mixed signal. In shallow benthic environments, spectral mixing is considered to occur either by 1) proportional mixing which occur when spectra from contiguous benthic cover combine according to their relative size or area (e.g., when corals and sand occupy the sea bed) or by 2) fusion-type mixing which happens when materials that have different composition blend with one another, the resultant product of which renders the components indistinguishable (e.g., suspended particles and chlorophyll-*a* mixed with seawater). Linear mixing assumes that there is no significant amount of multiple scattering between the different surface covering entities, i.e., every photon reaching the sensor, has interacted with only one surface covering entity.

The sequence of processed images (Fig. 9) reveals abrupt spread in high sediment coverage southward from the Todoroki River after May 31 rainfall event. Over-estimation of sediment coverage occurring on the reef crest found on southern portion in the Jan 2001 map maybe attributed to reduced organic activity in winter season. Concurrent with lower tide conditions which exposed the carbonate materials in the reef pavement surfaces, caused this portion to be confused as sediment deposits. It is noted that this does not occur on the results from other images since tide conditions were relatively higher than that of the November 2000 image.

The spread in sedimentation south of Todoroki River was well-attributed to the meteorological conditions at the time of the sediment discharge in the river mouth. As opposed to the prevalent northerly direction, wind was headed in southerly direction just after the storm event deflecting the sediment-laden river plume from Todoroki River to flow southwards (Nadaoka and Paringit 2002). The outline of the derivation procedure of the sedimentation index *SI* in English is given in Nadaoka *et al.* (1998).

7 Change detection techniques and long-term monitoring

Change detection by an analysis of multitemporal aerial photographs and satellite data have also been conducted. Using Landsat TM data and aerial photographs, Hasegawa (1993, 1998, 2001) and Matsunaga and Kayanne (1997) visually detected changes in seagrass and coral patches at Shiraho and Kabira reefs in Ishigaki Island, respectively. By analyzing aerial photographs taken from 1973 to 1994 and relating to meteorological data, Yamano *et al.* (2000) suggested the changes in coral patch distribution in Kabira Reef (Fig. 10) was due to frequency of typhoon occurrences.

A straightforward comparison between satellite images acquired on different dates is however not reliable since image signals are strongly influenced by tide level at the time of acquisition (e.g., 10:15 ± 10 AM for Landsat) and the magnitude of solar radiation. Variabilities in recorded radiance arising from these factors affect application conventional classification algorithms to multidate satellite images resulting in misclassification. Based on a similar approach to derive the sedimentation index *SI* by Nadaoka and Tamura (1992, 1993), Matsunaga *et al.* (1997) developed a Bottom Index *BI* algorithm based on Lyzenga (1978) to minimize the water depth effect on satellite data. *BI* is a modified reflectance ratio between two bands in satellite data and corresponds to the proportion of benthic community cover in a pixel. *BI* can be computed as the log ratio between two band minus the reflectance at a nearby deep area. The *BI* algorithm was applied to Landsat TM data of Ishigaki coral reefs, Japan acquired from 1984 to 1996 and tested as a method to separate sand and coral/algae/seagrass habitat. The extinction coefficient ratio between two TM bands that is necessary for *BI* algorithm was basically constant there. Temporal variations of the sea floor cover type in Ishigaki from 1984 to 1996 were produced by *BI* maps (Matsunaga *et al.* 2000; Fig. 11). Sea truth survey was conducted in August 2000 to validate the *BI* maps. Matsunaga *et al.* (2001c, 2001d) further tested the adeptness of the *BI* algorithm by combining Landsat TM and data generated from by ASTER VNIR (Visible and Near Infrared) sensor and yielded a 12% precision classification accuracy. The depth limits of both ASTER VNIR and Landsat TM images were investigated using radiative transfer models. The results show that the depth limits depend on variable solar conditions at the time of observation and on the type of sea bottom. Application of the *BI* on the combined ASTER VNIR and Landsat ETM+ result in a more detailed distribution of sea bottom in the shallow waters that becomes more uncertain towards deeper waters.

Significant bleaching event, probably due to anomalously high sea surface temperature (SST), was occurred in the summer of 1998. Attempt to detect bleaching corals was made by Yamano and Tamura (2004) as described before. Using a radiative transfer simulation and an analysis of multitemporal Landsat TM images, they showed that Landsat

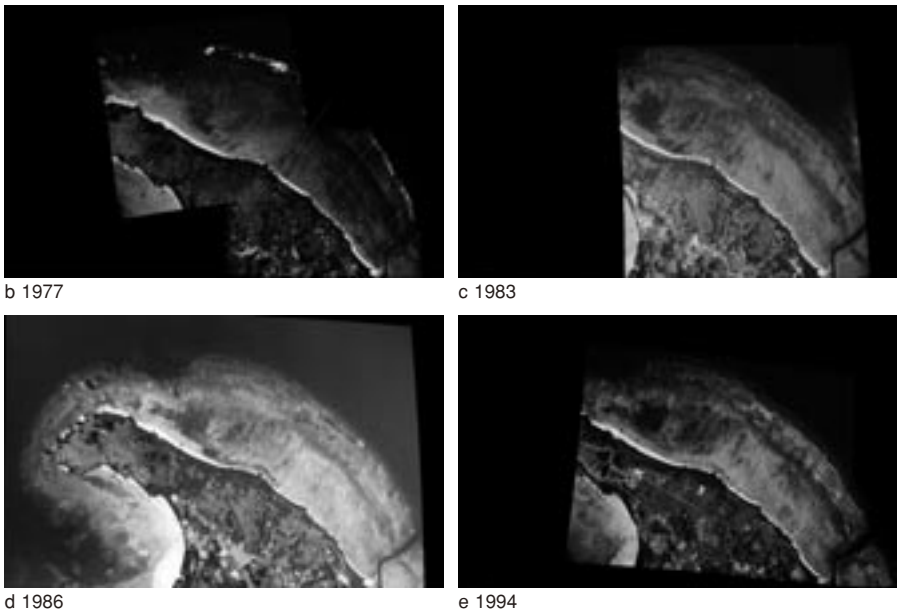


Fig. 10. Change in coral reef patch distribution as revealed by historical aerial photographs (Yamano *et al.* 2000). (Kabira Reef, Ishigaki Island).

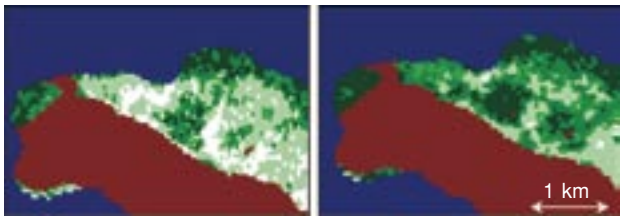


Fig. 11. Change in coral reefs as revealed by Landsat TM. (left: December 14, 1984, right: December 31, 1996, Kabira Reef, Ishigaki Island). Provided courtesy of Dr. Matsunaga.

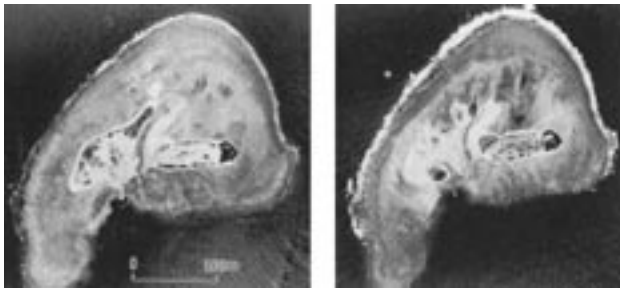


Fig. 12. Change in coral sand cays as revealed by historical aerial photographs (left: 1970, right: 1984, Chiibishi, Okinawa).

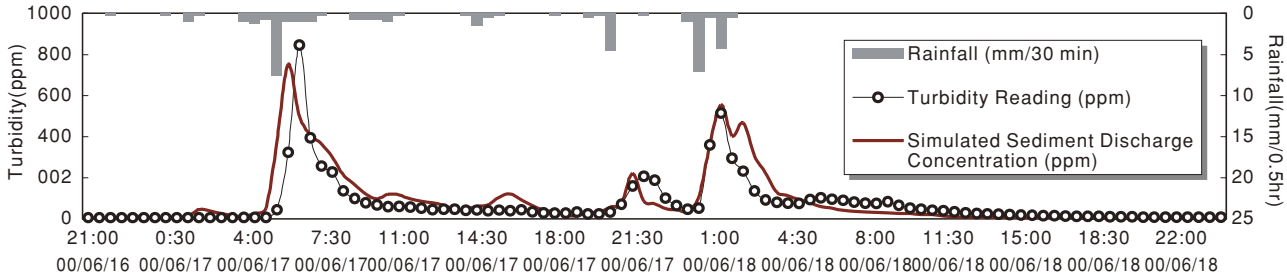


Fig. 13. A comparison of the simulated and measured sediment discharges watershed for a rainfall events in the Todoroki River, Ishigaki Island.

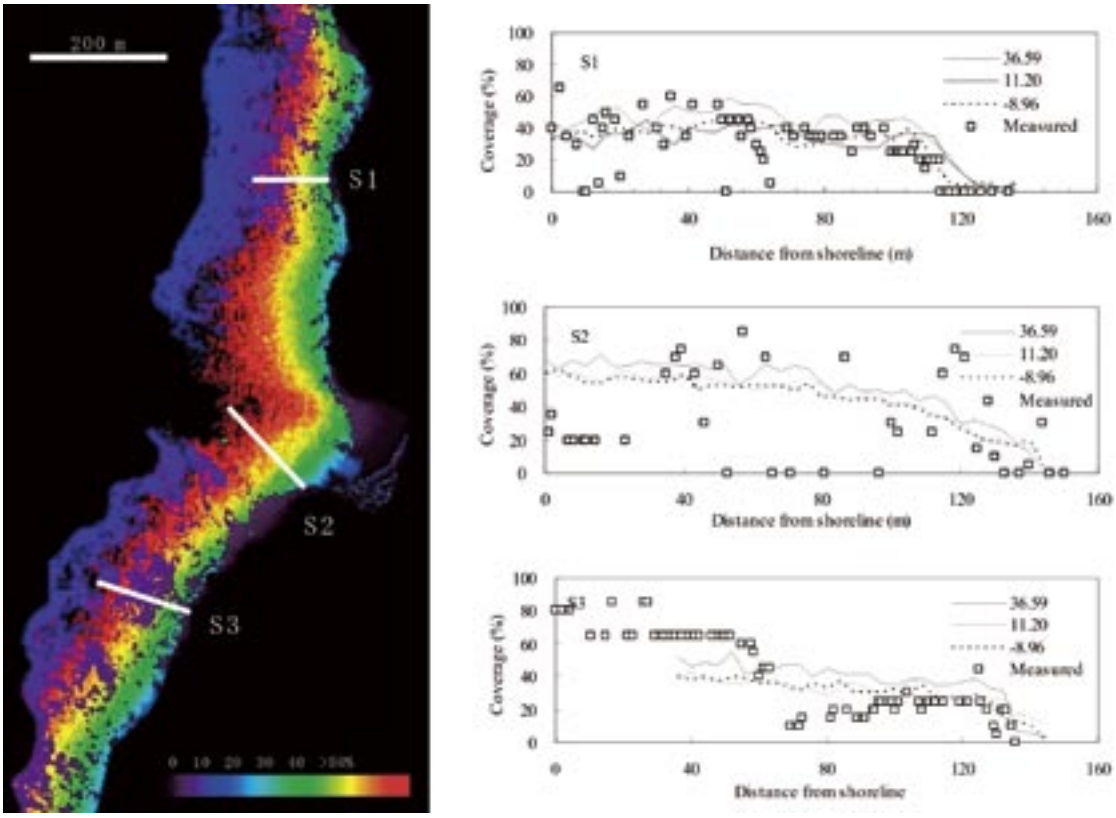
TM could detect bleaching if at least 23 % of the coral surface in a pixel has been bleached at Ishigaki Island. They also succeeded in detecting sites where 25 to 55% of coral coverage was bleached by analyzing Landsat TM data obtained from 1984 to 2000.

In addition to monitoring changes in coral reef benthic organisms, changes in reef-associated topography were detected by analyzing historical aerial photographs. Hasegawa (1990a, b) showed the changes in sand cays in Kume Island and near Okinawa Main Island (Fig. 12). The changes in the cay of Kume Island were attributed to typhoons.

8 Monitoring adjacent land area

Reefs around the Ryukyu Islands suffer from extensive sedimentation. In Ishigaki Island, e.g., the red-soil-dominated watersheds contribute substantial sediment discharge to fringing coral reefs. This is caused mainly by intense agricultural activity in the inland area. Surface soil removed by tillage are carried by surface runoff contributing to severe soil erosion. There have been efforts to examine this relationship between coral reef degradation and remote sensing. For example, Miller and Cruise (1995) describes a study wherein remote sensing technology is integrated with a hydrologic model to analyze possible linkages between land processes and coral reef growth rates in an area on the west coast of Puerto Rico. However, assessment of erosion levels utilize the USLE (Universal Soil Loss Equation) technique. A drawback of this method is that it is highly empirical and would need extensive field surveys to parameterize properly.

Paringit and Nadaoka (2001, 2003a) demonstrated the application of remote sensing techniques in the retrieval of vegetation and soil parameters from combined aerial photography and Landsat TM data to implement a distributed soil-loss modeling in small agricultural catchments. Using numerical solutions of overland flow simulations and sediment continuity equations, an analysis of the variation in erosional patterns and sediment distribution during rainfall events was performed. To account for the spatial as well as temporal variability of selected parameters of the soil-loss equations, they proposed use of Leaf Area Index and land cover component to account for the variability of associated vegetation cover based on their spectral characteristics as captured by remotely sensed data. To allow for complete spatial integration, modeling the movement of sediment is accomplished under a loose-coupled GIS (Geographical Information Systems) computational framework. With the model indicating general agreement with field data for sediment concentration (Fig. 13), this study lends an important theoretical support and empirical evidence to the role of vegetation as a potential agent for soil erosion control.



(a) (b)

Fig. 14. (a) Estimates of seagrass coverage showing distribution, and (b) modeled versus measured seagrass canopy coverage.

9 Seagrass mapping

A method (Paringit and Nadaoka 2003b) to process high-resolution multispectral satellite data for seagrass mapping has been implemented based on an inversion of a bidirectional reflectance distribution function (BRDF) developed particularly for seagrass beds (Paringit *et al*. 2003). The BRDF simulates radiative transfer from seagrass canopies approximated by assuming certain principles of geometric-optics and photon transport. Reflectance from seagrass canopies are considered to be linear mixtures of leaves and background signatures, which are moreover influenced by parameters of such as seagrass leaf architecture and transmittance, seawater column inherent optical properties and substrate reflectance. To validate results of model estimates, transect line surveys along seagrass meadows were conducted to obtain actual seagrass percentage cover, species distribution, shoot density and abundance. Likewise, spectral profiles of the bottom cover, together with pigmentation and turbidity through the water column were obtained by field underwater spectrometer and *in-situ* instruments. High-resolution satellite (Ikonos) data taken at multiple angles were processed according to the inversion model protocol. Results from model simulations show reasonable agreement between values of modeled and observed spectral reflectance from *in-situ* and space sensors (Fig. 14). Comparison of modeled versus *in-situ* reflectance data reveals that a relatively parsimonious set of variables is enough to assess seagrass biophysical properties with reasonable accuracy.

10 Sea surface temperature applications

Data products from processed satellite-based imagery are finding complimentary roles in coral reef applications. For example, sea surface temperature (SST) product derived from the NOAA AVHRR (National Oceanic and Atmospheric Administration Very High Resolution Radiometer) was used to determine the extent of decrease in water temperature after the onset of a typhoon in relation to the hydrodynamic and thermal environments of a fringing reef (Nadaoka *et al*. 2001a). They found that the decrease in SST before and after a typhoon event, measured seven days apart, is almost identical to the value observed at one measurement station

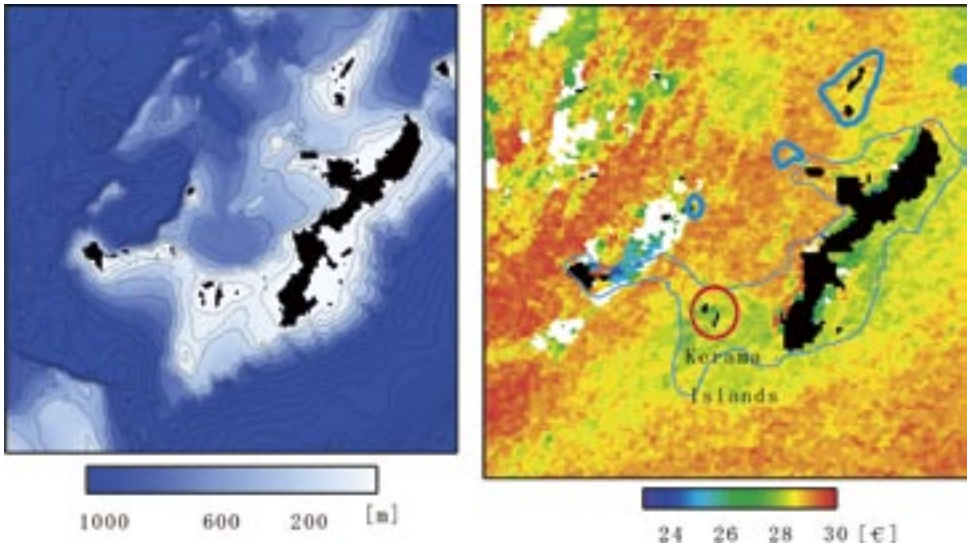


Fig. 15. Left: bathymetry of the Okinawa Islands showing prominence of the shallow shelf region around the island.
Right: A NOAA/SST plot taken June 24, 1999 depicting relatively lower temperature on the shelf area.

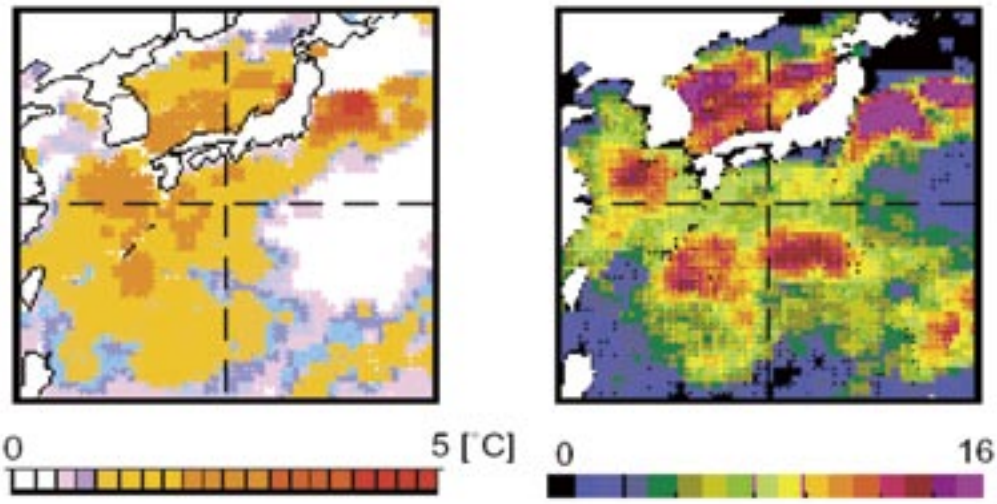


Fig. 16. Chart of composite indices of bleaching related thermal stress around the Ryukyus Islands in the summer of 2001. Hot Spots (left) and Degree Heating Weeks (right). Provided through the courtesy of U.S. NOAA Coral Reef Watch Program.

just outside the reef and gave clues to vertical mixing process in the surface layer.

In another study, NOAA-SST and SeaWiFS data, in aid to numerical modeling techniques, were used to clarify the relationship between the regional variability of water temperatures and spatial non-uniform appearance of coral mass bleaching and consequent mortality (Nadaoka *et al.* 2001b) around the Okinawa mainland and adjacent islands. A series of SST/NOAA images revealed that portions of the image with lower SST nearly coincide with the shelf region west of the Okinawa mainland where the Kerama Islands are located (Fig. 15). From the result of the numerical experiment and others, they suggested that this presence of shelf around the Kerama Island caused relatively cool water in the area by blocking incoming warm water from the Kurushio current.

As described above, since the 1980s, SST has been monitored globally by NOAA AVHRR, and has served as an early warning tool for bleaching (Strong *et al.* 1997). In addition to 1998, bleaching occurred in the summer of 2001 around the Ryukyu Islands, though the damage was small relative to that of 1998. As with that of 1998, the bleaching in 2001 was attributed to anomalously high SST indicated by Strong *et al.* (2002) who showed anomalously high SST around the Ryukyu Islands by analyzing *in-situ* temperature and NOAA AVHRR data (Fig. 16).

Fig. 17. Aerial photograph of coral slicks near Tokashiki Island in the Kerama Islands (Nadaoka *et al*. 2002a).

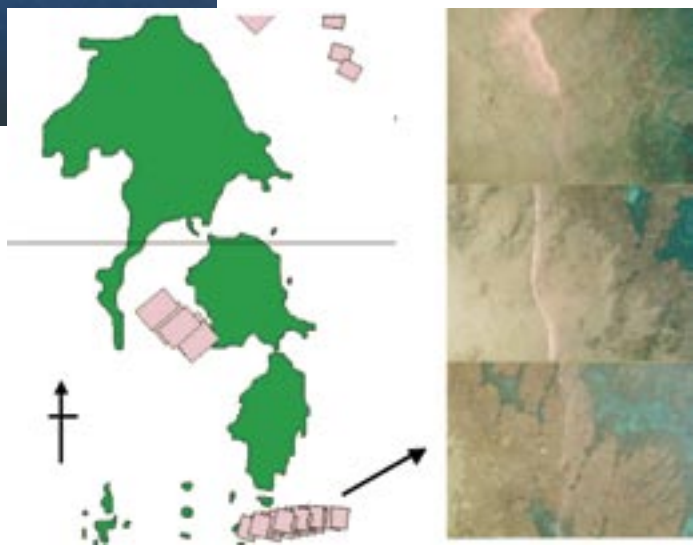


Fig. 18. Modsic photo of coral slicks (Nadaoka *et al*. 2002a).

In addition to SST, significant wave heights in oceans have been monitored by the TOPEX/POSEIDON satellite altimeter (Fu *et al*. 1994), and relationship between coral reef development and significant wave heights was examined (Yamano *et al*. 2003c). Flow line patterns in a backreef moat were extracted from aerial photographs based on an arrangement of coral patches (Yoshida *et al*. 2004).

11 Other remote sensing applications

For purposes of defining conservation measures, the environmental aspects of coral reproduction have attracted significant attention. A notable effort along this query is how remotely-sensed data can be used in tracking coral larvae dispersal (Nadaoka, *et al*. 2002a, b). Oblique and nadir-looking photographs taken with small-format aerial cameras on low-altitude airplanes captured the linear-like patterns of coral larvae slicks in Kerama Islands during the period of mass spawning in summer of 2001(Fig. 17). By co-locating the photographs using the GPS onboard the plane, exact location of the slicks were determined (Fig. 18). Relating slick occurrences with other environmental parameters such as current and meteorological conditions, improved the understanding of larvae distribution over large areas.

Novel forms of remote sensing have also been explored to determine features coral larval transport. Small drifting devices (0.3 m in diameter) installed with a custom-made GPS and mobile phone were deployed in areas where slicks were initially found. Calling up the drifters telephone numbers results in answering back their geographic positions. This provides a low-cost system, as compared with a satellite communication system, to locate the current drifter s position and to enable the retrieval of the drifters. GPS log data gives the detail of drifters routes (Fig. 19). Simultaneous with the investigation of larval transport with GPS drifters, Nadaoka *et al*. (2002b) attempted to monitor broad-scale distribution sea surface flow velocity by use of an HF ocean radar system. Figure 20 shows an example of HF radar data. It can be seen that although the flow in the Kerama region varies and corresponds to the trajec-

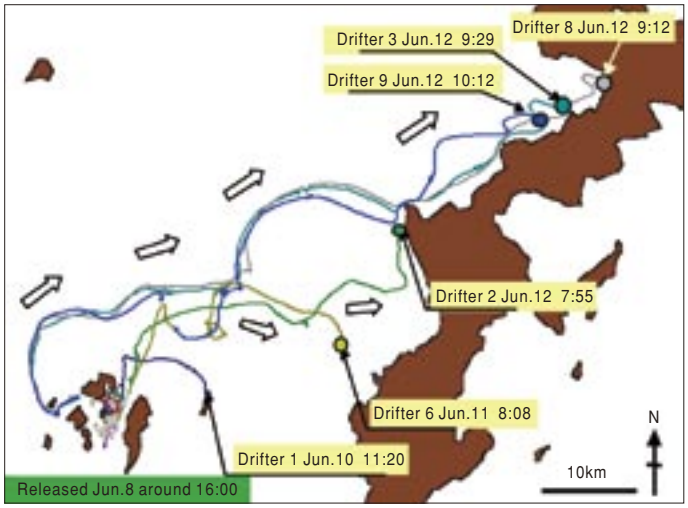


Fig. 19. Trajectories of drifters released in the Kerama Islands (Nadaoka *et al*. 2002b).

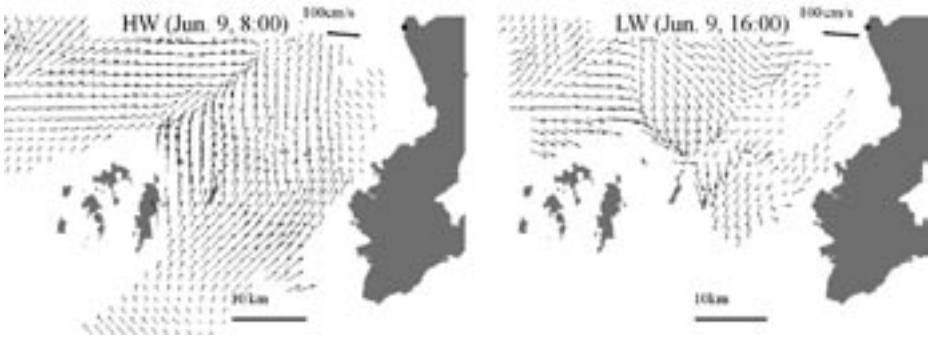


Fig. 20. Examples of sea surface flow observed by an HF ocean radar system.

tory of the above-mentioned drifters, it turns out that it actually drifts east or in generally, northeast. The effect of topographic feature has been a crucial factor. The presence of the continental shelf southwest of the Okinawa main island causes this eastward flow, suggested by the result of numerical simulation analysis performed by Nadaoka and others (Suzuki *et al*. 2004). Concurrent with these field surveys, indoor experiments were conducted to observe the crawling rate of coral larvae, which was found to show its peak around four days after spawning and fertilization. The trajectory plots shows not only that a sea surface particle may be conveyed to the Okinawa main island west coast region from the islands, but also that a living thing such as a coral larvae may be transported from Kerama Islands in four days to the main island. The latter is consistent in the period with that for coral larvae to show the peak crawling rate. These results prove that the Kerama Islands act as a source area of coral larvae for coral reefs of the west coasts in Okinawa main island and give a scientific basis for protecting the coastal region of the Kerama Islands as a preservation zone.

12 Concluding remarks

As described in the previous sections, remote sensing has a great potential to contribute to coral reef science and management. Despite the advances that have been made with regards to remote-sensing analysis methods and the accessibility of imagery data notwithstanding, the scientific community at large may still hesitate ot use remote sensing. This is supported by the fact that at present, there are only a handful of specialists which directly utilize processed remote sensing datasets to support their scientific findings from data gathered by other means. Besides, some sectors still prefer to do traditional field surveys over image processing to obtain coral or benthic cover. The remote sensing community should exert effort to reach out to the management sector by explaining the practical benefits as well as laying down proper guidelines and reasonable expectations in use of the technology.

Column

Toward the revival of Miyakejima after the latest volcanic eruption

Satoko Seino

Miyakejima suffered a large volcanic eruption in 2000. The volcano has erupted repeatedly, on a 20-year cycle, and its inhabitants have adapted to 'coexistence with the volcano'. Nevertheless, the eruption in 2000 was the largest in 2,500 years, and came as a shock to the islanders, as well as to researchers on the island. It prompted us to begin a major project, that is, to see what we could do to help with the revival of Miyakejima.

Miyakejima is a volcanic island in the middle of the Izu Islands; it is surrounded by open sea. The scars of past volcanic activity are visible here and there, but the residents have endured the hardships and the island has remained inhabited. Nevertheless, the eruption in 2000 forced the inhabitants to leave the island, and they have not been allowed to return as of 2004.

It is difficult to think about restoring the natural environment when restoration work on infrastructure and dwellings should have top priority. However, the rich marine ecosystem, especially the coral community, is an important resource for Miyakejima. Corals are found, mostly, in the southwestern part of the island, which is exposed to the northward flowing Kuroshio Current. Divers observed that the area around Tomigahama suffered little damage from the deposition of volcanic ash and crustal movement, while Igaya in the west and Chotaro-ike to the south underwent enormous change. Restoration of the ecosystem can proceed in two ways: by means of artificial methods, in the main, or by conservation and allowing nature to take its course. Either way, a practical discussion of the recovery program is necessary. Those of us who use the ocean at Miyakejima (researchers, divers, etc.) have just started to explore ways to contribute to the recovery by drawing upon our combined knowledge, experience, and expertise.

Miyakejima lost a valuable member of its community in the spring of 2004, when Dr. Jack T. Moyer passed away. Dr. Moyer came to Japan during the Korean War while serving in the U.S. Air Force. He was assigned to a medical research institute and studied the role of birds as vectors of Japanese encephalitis virus. One day, he noticed a Japanese Murrelet (*Synthliboramphus wumizusume*), a rare species, building a nest on Sanbondake, southwest of Miyakejima, a spot the U.S. Air Force used for target practice. He started an initiative to get the upper echelons of government to protect the nesting ground. This triggered the long relationship between Dr. Moyer and Miyakejima. He studied birds in Japan continuously while serving in the military, and emigrated to Miyakejima in 1957. He is remembered with great affection for his deep compassion toward the people and environment of Miyakejima, which he called his home. When he came to the island, few people believed that it was worth immigrating to the island, as the population was declining. Gradually, with Dr. Moyer's involvement and research, people started to realize the value of their natural treasure and became proud of it.

Recently, environmental education has received considerable attention and Miyakejima is surely a model, in this respect, for Japan. Dr. Moyer organized a summer school for children on Miyakejima. He hoped that children would come to realize the 'joy of living with nature'. He used to say, "our responsibility is to seek a good relationship that allows human beings and nature to live together; we have to pass on the message that we humans are a part of nature to the next generation". Dr. Moyer's program did not simply mediate important ideas, it was also full of fun. The children who participated were thoroughly delighted to be out in the field, playing with marine organisms on the shore.

Dr. Moyer spread the word about Miyakejima's beautiful environment to many people at large, as well as to the academic community through his many research publications. This work may well contribute to Miyakejima's revival.

Chapter 4

Sustainable use and conservation of coral reefs

Coral reefs have been providing us with many blessings such as fishery products and tourist resources. This is highly dependant on its high diversity where innumerable organisms inhabits in the complex ecosystem, and thus, on the other hand, is susceptible to disturbances. Once it is utilized inappropriately, coral reefs can be degraded easily, but takes considerable period, or never, to be recovered to original state. Therefore, for continuous and sustainable use of coral reefs, a strict conservational management is necessary, including environment education for enlightenment of its importance, and constitution of related legal systems that can act to restrict the degradation. This chapter introduces the current status of usage and conservational activities on coral reefs in Japan.

4-1 Coral reef conservation and management in Japan

Tatsuo Nakai

1 Resource use

Sustainable use is the goal of the modern conservation movement. Without regulation of resource use, natural ecosystems and the services and resources that they provide to humanity deteriorate. Resource use here refers to the use of all natural resources, including land, water, biological resources, and minerals. Modern societies have been utilizing natural resources well beyond what is sustainable. The following management foundations are necessary to achieve the sustainable use of natural resources.

a) Establish baselines defining ecosystems, and monitor the condition of these systems.
b) Understand and recognize the adverse effects of excessive, irreversible, and destructive use.
c) Limit uses defined as excessive, irreversible, or destructive.
d) Assist recovery of deteriorated ecosystems.
e) Develop techniques and systems that enable the sustainable use of natural resources.
f) Through socializing the above elements, build a conservation ethic that is backed up by law.

The goal of management is not to manage nature, which is an impossible task, but rather to manage the human use of natural resources. It is necessary to think about management on a global scale, but its foundation, as outlined above, should be achieved on a local scale. Cooperation between and among regions and nations, however, is indispensable.

These tenets apply to coral reef management; in this respect, a variety of attempts have been made toward the sustainable use of reefs in various regions of the world. This chapter focuses on coral reef conservation in Japan in relation to the above-outlined management goals. More details pertaining to each goal can be found throughout this book [e.g., a) Chapters 1, 3, and 6; b) and c) Chapters 2 and 6; d) Chapter 5; and e) and f) this chapter].

2 Negative anthropogenic impacts

1. Fisheries

Fishing has been an important part of Japanese culture since ancient times. Japanese fisheries, however, have declined owing to overfishing in neighboring waters, and fisheries management in Japan is an important issue, as it is in other regions of the world (see 4-2). Fortunately, Japan developed laws at an early stage against directly destructive fishing techniques, such as the collection of corals and the use of dynamite and hydrocyanic acid. However, these practices constitute important on-going problems for Southeast Asia and other regions.

2. Coastal development

Civil engineering projects in Japan have had irreversible, destructive impacts on coral reefs. 'Reclamation' projects have been conducted in many areas to create land for urban districts, sightseeing facilities, and for public facilities such as airports. The accompanying dredging works have created harbors and sea routes. In addition, breakwaters have been built along coastlines in many locations (see 2-4). An example of what ensues from this kind of development can be seen in Okinawa Island, where only 57.3% of the entire coast is natural shoreline, with no human alteration (Nature Conservation Bureau, Environment Agency 1998). Moreover, development such as farming, deforestation, road building, and military exercises, together with modification of the drainage systems of rivers, have caused accelerated runoff of red clay, which has negatively affected many Okinawan reefs (see 2-5). The background for these problems lies in geography, history, and in social values. Geographically, Japan's reefs often form small islands and fringing reefs, adjacent to coastal urban areas and farmland. Japan is densely populated, and possesses highly advanced, large-scale engineering technology that is at the center of well-funded regional promotion plans. These factors are especially important in Okinawa Prefecture, which was governed by the U.S.A. for 27 years after World War II. Since its han-

dover to Japan, Okinawa has sought to catch up with the more advanced economy of mainland Japan. Unfortunately, little consideration has been given to conserving the coral reefs and the natural environment during this period.

3. Tourism

The aforementioned engineering projects were undertaken, in the main, for the construction of facilities relating to tourism and recreation. Intensive use of coastal areas by large numbers of people constitutes a serious problem in Japan (see 4-5). An important issue that has recently arisen is the growth of diving tours for the purpose of coral transplantation. While the aim behind these efforts to contribute to coral reef recovery may be laudable, the collection of coral fragments from reefs for transplantation negatively impacts healthy coral communities, and potentially destroys genetic structure by mixing different regional coral populations. At present, most of such projects have been initiated on a commercial basis, without the support or cooperation of appropriately qualified scientists.

It is necessary to recognize that Japanese tourism and recreational activities affect coral reefs in other countries, as well as in Japan. Many Japanese tourists and divers visit coral reefs throughout the Pacific Ocean and Southeast Asia. Direct impacts to reefs from this kind of tourism include the trampling of coral by divers; there are also indirect impacts, for example, with respect to water quality, which is affected by the effluent from accommodations, the construction of sightseeing facilities, and other forms of coastal development. The growing home aquarium industry in Japan should also be recognized as a significant threat to reefs. Although the collection of corals is limited in Japan, many reef organisms from elsewhere in the world are sold in Japanese pet shops. Such practices continue because irresponsible individuals, who profit from coral reefs, take advantage of opportunities to achieve personal gain at the cost of the natural environment; the negative attitude of related industries toward coral reef conservation is also a factor in the continuation of these detrimental activities. It is time to promote a deeper understanding of coral reefs, and to investigate industrial activities that are compatible with reef conservation.

3 Current issues in Japanese coral reef management

1. Historical background

As noted above, conservation was given a very low priority in Japan during the period of post-war economic expansion. What attention that was given to conservation by researchers, institutions, and the public, was focused, mainly, on terrestrial systems, such as forests. Following environmental pollution problems, including the very serious problem of Minamata disease in the 1970s, marine pollution that directly influenced human health came under close scrutiny, and a variety of legal systems and measures were established to deal with such matters. The general deterioration of marine ecosystems, however, was not considered. Similarly, concerns about reclamation works around Tokyo and Osaka were limited to their effects on fisheries only, with no regard for the ecosystem as a whole.

The situation was similar for coral reefs. The corallivorous crown-of-thorns starfish (*Acanthaster planci*) increased explosively in the Ryukyu Islands in the 1970s, causing widespread damage to reefs. Although the impacts of this event were widely reported, the causal relationship between the *A. planci* outbreak and human activities was not clarified, and mitigation measures were limited to management of the *Acanthaster* population. When a project for the construction of an airport on the coral reefs of Shiraho, Ishigaki Island, Okinawa Prefecture, became controversial in the late 1980s and early 1990s, opinions such as 'coral conservation is unrelated to human life' and 'how can you make a living with corals?' were commonly expressed. The airport project was publicized in Okinawa and throughout Japan by the IUCN (International Union for Conservation of Nature and Natural Resources), and by national and local conservation groups (e.g., Planck *et al.* 1988; Doumenge *et al.* 1990; Nature Conservation Society of Japan 1991); this generated wider recognition of the ideas behind, and necessity for, coral reef conservation. As a result, the filling of this reef was avoided.

Later, in June 1992, the United Nations Conference on Environment and Development (UNCED, or the Earth Summit) was held in Rio de Janeiro, Brazil. This conference focused the attention of Japanese society at large, along with the government and the business establish-

ment, on the importance of environmental conservation. Economic stagnation in Japan and government deficits also stimulated progress in conservation. Following the U.S.-Japan on bilateral summit in 1994, the Japanese Government joined the International Coral Reef Initiative (ICRI) and, in February 1997, the 2nd East Asian Seas Regional Workshops in Okinawa focused more attention on reef conservation.

Societal awareness of the importance of coral reef conservation in Japan is thus increasing. However, problems remain; a new U.S. military base is planned, which is to be built on coral reefs in Okinawa, and new concerns, such as the aforementioned coral transplantation tours, are emerging. However, conservation practices in the last decade or so have changed; confrontations with construction interests have given way to cooperative activities with government, local residents, NGOs/NPOs, and researchers. Such cooperation makes possible the formulation of systems and rules for a local society and economy that are based on the sustainable use of nature (Nakai 2002).

2. Need for comprehensive coastal management

A comprehensive coastal management plan that includes entire watersheds as well as the myriad human uses of coastal areas is necessary for effective coral reef conservation. The U.S. Coastal Zone Management Act (CZMA) offers an example of such a management plan (Vernberg and Vernberg 2001). Japan, so far, lacks such a plan. Coastal management in Japan is enforced through three separate laws: the Fishery Act, which affects marine industries, the Harbor Act, and the Coast Act, for coastal disaster prevention. Local ordinances are similarly divided, and government agencies in charge of coastal management are separate from each other. Therefore, despite the fact that development laws have begun to include conservation measures, and conservation projects are underway in some areas, legal plans or institutions to effectively control them do not exist.

The framework for a comprehensive coastal management plan should be made at the national or the prefectural level; however, rules and operations for each region should involve local stakeholders, including individuals and industry. Education will play an important role in ensuring that such local involvement can result in a regionally relevant plan.

3. Role of MPAs

Marine protected areas (MPAs) and no-take areas (NTAs) are effective conservation tools at the local level; they also provide insurance, at least potentially, against more widespread impacts, such as coral bleaching events (e.g., GBRMPA *et al*. 1995; Hughes *et al*. 2003). Most of the Great Barrier Reef, an area stretching over 2,000 kilometers, is now a protected area. The reef is finely divided into zones allowing different uses, including NTAs, with satisfactory results. Japan has a total of 64 marine parks that were established under the Natural Parks Law; 13 of these contain coral reefs. However, these parks are extremely small and the boundaries have not been defined with any consideration for the regional ecosystem. Moreover, despite some limited educational activities, implemented by the Ministry of the Environment and the municipalities, there is a lack of information and education on the natural environment and usage rules in the parks. Consequently, some reefs endure heavy anthropogenic impacts, even in the marine parks of Japan. MPAs must take local factors into account, including ecology and the physical and chemical environment. Monitoring of reef ecosystems, enforcement of use restrictions, and the education of local residents and visitors are integral to the success of MPAs in Japan.

In coral reef regions in Southeast Asia, the top-down establishment of NTAs triggered strong protests from local fishermen (Akimichi 2002). Akimichi pointed to the necessity of education for coastal area residents and to the promotion of 'fisheries that don't catch fish', such as eco-tourism. Wells and White (1995) have also emphasized the importance of community-based management in the establishment and operation of MPAs, an emphasis that is based on their experience in such matters. Under this model, local residents who are educated to have a full understanding of the importance of coral reef conservation are integrally involved in the MPA establishment process. This prevents the problems caused by top-down decision-making.

Coastal use restrictions, including zoning, have existed in Japan since ancient times; these restriction were implemented for the purpose of avoiding overexploitation of natural resources, as well as the friction with neighbors that ensued from such exploitation. These historical rules have evolved into the current system of fishery rights and the Living Aquatic Resource Protecton Law. If this unique system were to be expanded to include the

entire coral reef ecosystem, as well as the management of other activities, such as non-commercial fishing, sightseeing, and educational activities (Hamamoto *et al*. 1996; Simard 1995), it could constitute a global model for coral reef conservation.

4. Restoration technology

Coral reef restoration projects are now beginning in Japan (Chapter 5). Law promoting reef restoration was established in 2001, in response to widespread damage to reefs by mass bleaching events. Hughes *et al*. (2003) invoked the possibility of technology to promote the establishment of bleaching-resistant symbiotic algae (zooxanthellae) and coral species, based on findings that some zooxanthellae are resistant to temperature and to other environmental changes that cause coral bleaching. In view of the current state of coral reefs, the development of this technology and its practical application is very important. Japan, with its highly developed technological capabilities, could contribute to domestic and global coral reef conservation in this area.

As noted earlier, however, technological fixes can sometimes unintentionally cause problems. Guidelines and rules for their use, within the framework of the aforementioned comprehensive coastal management plan, are necessary. Research to establish such guidelines should take place concurrently with the development of the technology. However, when taking into consideration the possibility of the international use of these potential technologies, it is necessary to consider whether local communities can effectively implement them.

5. Role of the academic society in coral reef conservation

The Japanese Coral Reef Society (JCRS) was established in 1997, in part to promote research in, and projects on, coral reef conservation. Previously, coral reef researchers in Japan did not have an effective voice in conservation decision-making, largely owing to the lack of a forum for systematic information exchange and discussion, rather than to a lack of individual concern. There were only a few coral reef researchers involved in the government's decision to join the ICRI; this lack of involvement was the impetus for establishing the JCRS. The Japanese Coral Reef Society includes a wide range of members interested in corals and coral reefs, including public citizens and NGOs/NPOs, as well as researchers and government agencies. JCRS involvement has resulted in the decision to host the 2004 International Coral Reef Symposium (ICRS) in Okinawa. Coral reef conservation was an important theme at the last ICRS, and will be a dominant theme at the Okinawan Symposium as well. Cooperative relations between government and civil organizations for the purpose of promoting conservation have been stimulated by plans for the symposium; in addition, the JCRS formed a coral reef conservation committee in 2002 in order to retain the momentum begun with the planning of the ICRS in Okinawa.

It should be clear from the above that diverse approaches are necessary to achieve sustainable resource use in coral reef regions; these approaches include biological and socio-economical research, environmental education, and the involvement of society as a whole, from those at the administrative level to local residents. The JCRS has an important role to play at all these levels.

4-2 Legal systems

Keisuke Takahashi, Tadashi Kimura

1 Introduction

In Japan, laws, which are related to conservation and to fisheries management, restrict some activities, such as capture/ harvest of certain sea organisms, reclamation or dredging in certain areas. Consequently, those laws contribute to conserve coral reef ecosystems. Okinawa prefecture, southernmost part of Japan has unique regime relevant to coral reefs. For example, in the Okinawa Promotion and Development Plan, coral reef conservation is highlighted. In addition, Government of Okinawa prefecture established the "Red Soil Prevention Ordinance" which also contributes to coral reef conservation. This section explains about laws and ordinances related to the management and protection of coral reefs in Japan.

2 Legal systems aiming at nature conservation

1. New National Biodiversity Strategy of Japan

In March 2002, the Japanese government formulated the 'New National Biodiversity Strategy', with the aim of achieving a society that can coexist with nature. This strategy presents a future of Japan as "across the coral reefs of the southern islands, myriad brightly colored fish will form schools, while herds of dugong will pass through lush seagrass". In the Strategy, the government proclaim of implementation nature restoration projects to rehabilitate degraded environment, while strengthening conservation efforts to preserve healthy environment.

2. Natural Parks Law

Some areas are protected as Marine Park Zones that are designated based on the Natural Parks Law. Activities such as collection of marine fauna and flora specified by the Minister of the Environment, reclamation, and dredging are regulated inside marine park zones. Corals are a specific conservation target, both for their inherent aesthetic value and because their protection is key to conserving the biodiversity of reef communities. As of December 2003, there are 64 Marine Park Zones (totally 2664 ha) in Natural Parks, and 13 of those (1616 ha) contain coral reefs. Besides those 13 zones, 29 (718 ha) contains coral communities (see Appendix '1-6'). However, the area of many Marine Park Zones are not big, and most of the sea areas inside Natural Parks are designated as Ordinary Zones, where regulation is lenient. In addition, even within designated Marine Park Zones, fish and marine mammals are not subject to protection, which may threaten the conservation of intact ecosystems (Nature Conservation Bureau Environment Agency 2002c).

3. The Nature Conservation Law

Areas worth protecting for both environmental and social reasons are designated as Nature Conservation Area under the Nature Conservation Law. In the case of marine waters, this law states that Natural Conservation Areas should include 'areas that sustain well-preserved nature including native fauna and flora, e.g., tropical fishes, corals, and seaweeds'. In addition, Nature Conservation Areas which are thought to deserve special protection, such as those inhabited by rare species, biota of particular value, or unusual ecosystems, may be designated as Marine Special Areas. In these areas, collection of marine fauna and flora specified by the Minister of the Environment reclamation and dredging are prohibited. A part of Sakiyama Bay off Iriomote Island, Okinawa (totaling 128 ha), is an example of a Marine Special Area, designated for its diverse coral communities (Sakiyama Bay Natural Environment Conservation Area).

4. The Law for the Promotion of Nature Restoration

In December 2002, the 'Law for the Promotion of Nature Restoration', which alms to make human coexist with nature by preserving biodiversity was estabilished. The law provides a framework for nature restoration by defining restoration as a joint effort among various actors (e.g., administrative bodies, local authorities, local residents, non-profit organizations, and experts). More specifically,

it aims to recover lost or degraded ecosystems, to implement conservation and the restoration or creation of natural spaces, and to manage such natural environments. This law specifies that restoration should be undertaken (1) co-operatively and with the input of affected stakeholders, (2) using the best available scientific information, (3) with the inclusion, where possible, of monitoring of the outcomes of restoration following implementation, and (4) with the inclusion of feedback, in a context of adaptive management. Preliminary researches for restoration of coral communities are underway in Sekisei Lagoon in Okinawa Prefecture, and in Tatsukushi Bay in Kochi Prefecture, respectively (see also Section '5-2').

3 Trade of rare wild fauna and flora

The 'Law for Conservation of Endangered Species' regulates the capture and trade of rare species from wild sources, as specified by the cabinet order. Coral reef related species of which trade and capture is restricted include sea turtles and dugongs, which are categorized as "International Endangered Species" (the same species as in Appendix I of the Washington Treaty). Import of those species is prohibited by the Import Trade Control Order. In addition, the Order requires people who want to import hermatypic corals, which are listed in Appendix II of the treaty, to have permission from the governing authority of the exporting country.

4 System to protect fishery resources

Coral reef organisms, including hermatypic corals, are also protected by three regulations in Japan: the Living aquatic Resources Protection Law, the Fisheries Law, and the Fishery Adjustment Rule.

The Law for Conservation of Aquatic Resources aims to protect and sustain fisheries resources, and governs procedures for mariculture and aquaculture. The law prohibit destructive fishing methods such as blast-fishing (in Article 5) and poisoning (in Article 6). This law also promotes sustainable fisheries and establishes the protected waters. The protected waters are designated by the Minister of Agriculture, Forestry and Fisheries, based on Article 14-18 of the law. The measures pertaining to these areas are implemented by the appropriate prefectural governments to protect the spawning and nursing grounds of aquatic plants and animals. In the designated water areas, developmental projects such as reclamation and the capture of species specified by the governor are restricted. The designated water areas that support coral communities are: Kabira Bay and Nagura Bay in Ishigaki, Okinawa Prefecture, and Kuro-shima (Ushibuka) and Fukami in Kumamoto Prefecture. The specified species in the Kabira Bay area are; *Pinactada margaritifera*, *Tridacna* spp., *Panulirus versicolor*, *P. ornatus*, *Melicertus latisulcatus*, and *Tripneustes gratilla*. In contrast, the harvest of all aquatic plants and animals is prohibited in Nagura Bay and Kuroshima, and all except *Undaria* spp. and *Monostroma nitidum* are also prohibited in the Fukami area.

The Fishery Adjustment Rule, established by the governor, regulates the collection of biota, as well as the permissibility of particular fishing gears and boats. The rule also regulates the close seasons, and the minimal size and weight for target catches. In line with the Fishery Adjustment Rule, collection of hermatypic corals is completely prohibited in Okinawa and Ogasawara Islands, which administratively belongs to the Metropolis of Tokyo. In many prefectures, fishing methods for leisure fishermen are strictly restricted. Even for professional fishermen, fishing using scuba is controlled with license system. The collection of aquarium fish is also controlled in Okinawa and requires special licensing.

The marine environment of Okinawa which has coral reefs with high biodiversity is a precious national heritage. Comprehensive conservation of the marine and land environment and multiple utilization of marine resource and space should be promoted.

5 Related systems in Okinawa

The Okinawa Promotion and Development Plan (established in 2002) specifies the direction and basic policies of Okinawa Prefecture. In this plan, Okinawa is cited as having 'beautiful coral reefs with a clear contrast of blue sky and white sands'. The plan, therefore, sets out conservation and sustainable utilization of the marine environment as basic directional concepts for the prefecture. It states that "coral reef environments of high diversity are a national property, and integrated conservation is necessary to include land areas with sea areas, as one united body. Multiphase and comprehensive utilization of marine resources and marine space should be promot-

ed." In addition, the law also states that we should aspire to conserve, rehabilitate, and create coral reefs, seagrass beds, tidal flats, and mangrove forests, in order to sustain the function of self-restoration and purification, along with their diversity. Specific strategies to achieve these objectives include preventing soil run-off/erosion, controlling the crown-of-thorns starfish (*Acanthaster planci*), and fostering responsible eco-tourism in coral reefs.

The Okinawa Prefecture Red Soil Prevention Ordinance is a local ordinance that was enacted in 1995 by Okinawa's Prefectural Governor. Its purpose is to prevent contamination of public waters by controlling soil outflow from enterprise projects, and to promote appropriate land-based management. In this ordinance, developmental works of 1,000 m^2 or more are obliged to implement countermeasures that prevent soil run-off, using grit chambers or filtering devices. Consequently, sedimentation from construction works has been reduced. However, since farmlands are not obliged to take measures, effective improvements remain to be seen.

6 Conclusions

A diversity of laws exists to conserve coral reef ecosystems in Japan, and have had some positive effects. Further success in the conservation of coral reef ecosystems may be achieved by coordinating the various available systems. As a first step, it will be necessary for the full cross-section of stakeholders (e.g., the administrative bodies associated with fisheries and nature conservation, local authorities, non-governmental organizations, local citizens, and scientists) to cooperate in order to generate a consensus on the measures needed for the conservation of coral reef ecosystems.

4-3 Environmental education related to coral reefs

Yoshikatsu Nakano, Keisuke Takahashi

1 Maritime culture and education

When talking about the maritime culture in Japan up to the early modern age, the well-developed traditional use of coastal areas is known world-wide. However, in spite of this cultural climate in an island country, the industrial activities and development of modern society have caused significant degradation of the coastal areas that should serve as cultural settings. This is a result of an increasing disrespect for traditional culture and an overemphasis on modernization and economic growth since the Meiji Restoration. As a result, traditional culture cannot be expected to be effective, and a new way of life has developed in which people have turned their backs on the sea as a source of culture. One cause of the decline in maritime culture up to now must be its exclusion from modern education. This omission is a contributing factor in the rise of various types of pollution.

The need for environmental education in the public education system in Japan has been recognized as an approach to addressing the environmental pollution issue that became obvious by the 1960s with the rapid economic growth of the post-WWII period. Environmental education was provided in individual schools at various levels, while the issue of environmental pollution was considered in relation to individual regional matters. However, education treated pollution events as exceptions and the emphasis was on subjects that favored development. While some attempts at social education, including citizen courses on the environmental pollution issue, achieved significant results during this period, most civic actions focused on solutions that minimized the problems, leaving them to future generations. Thus, there were only a few general books and other educational materials available, and those were difficult to use in environmental education or were heavily biased in content. There is, therefore, room for research and overall reorganization.

The situation is no different in Okinawa Prefecture, a center of coral reef distribution. During the rule of modern Japan after 1879 and of the U.S. military in 1952-1972, education meant no more than a course in the school curriculum with nothing at the level of the general public. After its reversion to Japan in 1972, Okinawa was integrated with the Kyushu block, administered together with Kagoshima Prefecture, including the Amami Archipelago in the north of the Ryukyu Islands. This reduced the importance of the geographic and climatic features of coral reefs, and there were few opportunities to include coral reefs in public education. Moreover, while the Japanese Archipelago extends north to south from the subarctic to subtropical zones (45°33”N to 20°25”N), science education curricula are standardized to the temperate zone where the population is concentrated. This is problematic, because education establishments are not uncommon in coral reef regions.

This chapter describes recent environmental education programs that focus on the integrated understanding and conservation of coral reefs.

2 Current state of school education

As mentioned above, it cannot be said that much time was spent on education about coral reefs in Okinawa, but some notable activities were developed. What systematic approaches were seen in school education (Ohwan 2003), however, were not in a curriculum but were either based on the efforts of individuals or took considerable time to be incorporated into a curriculum. This situation is expected to change following the implementation in 2002 of the so-called New Teaching Guidelines. These include a period for integrated study, making it possible to find enough time for experiential study outside the school, not limited by the framework of conventional subjects. However, there are not many schools with enough experience to make the best use of this opportunity, and most still lack direction. Against this background, this section describes some attempts to find a new direction, and compares them with examples from other areas.

1. An approach taken in Nago and Sakieda elementary schools

One systematized approach has been taken by Nago Elementary School in the city of Nago (Yasuda in press). Its aim is the students' acceptance of the coral reef islands and their natural environment as part of their lives, through steps carried out over seven years from the start in the adjoining Nago kindergarten to graduation from elementary school. The goal is the establishment of an attitude of caring for nature as part of the culture through closer interaction with nature, an emphasis on play and recreation, and the opportunity to absorb knowledge of the natural environment by doubling the work-study in the latter half of the curriculum (Nago Elementary School and Nago Kindergarten 2001).

The first graders enjoy playing with kindergartners on the safely managed artificial public beach and, after they become second graders, they have fun with tidal organisms on the same beach. The third graders touch marine organisms in the touching pool in the aquarium and listen to explanations, while wanting to visit the natural coast nearby. They go to the coast immediately after that, to feel the breath of nature and living organisms in their hands. The fourth graders, after prior scientific study, relate the living organisms and their habitat to the geographical features of coral reefs. The fifth graders aim to understand the physical distance between coral reefs and other island habitats, and to attain a concept of the diverse and close relationships between them, by ascending a river in Yambaru, the northern forest on Okinawa Island. As a conclusion to the above study, the sixth graders go to the mouth of an urban river, interact with local people through cleanup activities, and observe coral reefs and the people who live near them. They become junior high school students with an awareness and understanding of the transition of human activities and what accompanied it. These steps are expected to nurture an understanding that cannot be gained from a transient event such as an occasional cleanup activity.

In parallel with that, children of the fourth grade or higher experience marine leisure activities such as banana boat rides, coming in contact with the adult world and developing their recreation experience in nature from memories of playing on the beach in lower grades. The fifth and six graders try sea kayaking and dinghy sailing as marine sports, and realize that experiencing the richness of nature is important in forming a personality. In addition, acquiring safety skills through sports is expected to increase their familiarity with nature and to deepen their understanding of it. In New Zealand and other countries that boast a rich maritime culture, such marine sports and recreation are now popular, and, together with tradition, they play a key role in the acquisition of this knowledge and insight (Tani *et al*. 2003). It is thought that such an attitude toward play and learning contributes to a culture of environmental conservation and to educational activities at the level of the general public.

While the development of a long-term curriculum corresponding to children's development was partly owing to the size of Nago Elementary School, which has some 100 students per grade, there is a concentrated effort to involve the entire region in a smaller school. In the Sakieda Elementary School in the city of Ishigaki, which has fewer than 20 students, a year-long experiential study of the environment of the region was planned as a large unit of 100 hours, aimed at improving the prevailing low level of awareness of the richness of nature (Ohmine 2003). The motivation to visualize and implement the plan came from local residents, who had a high level of awareness and involvement in environmental education. In addition, the cooperation of the Ministry of the Environment Okinawa Amami District Nature Conservation Office, the Okinawa Prefectural Institute of Health and the Environment, local fishermen, environmental not-for-profit organizations (NPOs), eco-tour organizers, and others was a critical factor.

This background has allowed the development of thinking on environmental studies. The case of Nago Elementary School is expected to create a new awareness of the environment and to establish it as cultural property in the process of raising children in the regional society. The supportive framework of the Ministry of the Environment, which serves as the backbone of these activities, is described below.

2. Activity of the Ministry of the Environment

The International Coral Reef Research and Monitoring Center was established by the Ministry of the Environment at Ishigaki Island in Okinawa. This institution develops educational materials and conducts joint programs with elementary schools on coral reef matters, in addition to public services such as providing information on a website and giving explanations to visitors.

Educational materials include 'Coral reefs in Yaeyama'

(Nature Conservation Burean Ministry of the Envilonment 2002b), which provides a brief introduction to the coral reefs of the region; a teachers' guide for educating children about coral reefs (International Coral Reef Research and Monitoring Center 2002a), and 'The coral book for kids' (International Coral Reef Research and Monitorfing Center, Ministry of the Environment) which contains a coloring book and puzzles that children can enjoy while learning. These materials are distributed to local schools. The teachers' guide includes various examples of teaching activities. It consists of a pre-site program (for classroom lectures before going out in the field), an on-site program (field guidance for observation, learning, and snorkeling, etc.), and a post-site program (for activities based on the on-site program), to be used in combination in any kind of situation.

Using this teaching guide during the period of integrated study in elementary school, an education program on coral reefs was started in fiscal 2002 with the support of the Ministry of the Environment. This program was applied in Sakieda Elementary School (3-6 graders, totaling nine students) in fiscal 2002 and in Shiraho Elementary School in Ishigaki (5 and 6 graders, totaling 44 students) in fiscal 2003, respectively. At the end of the program, students presented their year's accomplishments to the local people. The expected outcomes of this program are: 1) the students come to recognize the beauty and diversity of coral reefs through snorkeling, which is often avoided in school programs for safety reasons; 2) the flexible application of a variety of programs, made possible by the cooperation of teachers, experts, and ministry officials; and 3) the encouragement of overall community understanding, and an awareness of coral reefs as their own community property, through the public presentations to local residents.

The effective application, dissemination, and continuation of this program will require the implementation of training sessions for teachers, the provision of necessary support and advice, and the establishment of a backup framework involving local residents.

2. Environmental Class in Hentona High School

In the Okinawa Prefectural Hentona High School an environmental class was established in fiscal 2001 with the aim of sharing the social challenge of the accumulated environmental problems with the school students and developing the next generation's behavior based on nurtured understanding. The school, however, has experienced problems in developing a curriculum, maintaining a laboratory, and counseling on college choices, and is searching for solutions (Yamashiro 2003). The background of the situation is that social attitudes as a whole toward environmental problems have not been settled. Therefore, the systematization of environmental education has just begun, and certified teachers and established guidelines are needed. It is a problem not only in school education but in social education as a whole.

3 Current state of social education

The Act for Arranging Integrated Recreational Areas (the law for integrated resort area maintenance) was enacted in 1987 to review the leisure sector of the nation. Under this law, large-scale resort development was planned nationwide, but the plans did not predict social and economic changes, and one after another were frustrated by heavy debt. The basic policy was finally reviewed in 2004 (Kyodo News Service, Feb. 25, 2004). The enactment of the law specified the whole of Okinawa Prefecture, which aims to base its development on sightseeing, as a designated area for the 'Okinawa Tropical Resort Plan'. In 2004, when the basic policy of this law was reviewed, 202 of the 341 facilities included in the resort plan remained undeveloped (Ryukyu Shinpo, Feb. 26, 2004).

The social and economic situation that emerged from the review of the law was one of economic stagnation and the frustration of many plans when the expected numbers of tourists were not realized. In Okinawa Prefecture, however, inbound tourist numbers continue to increase and exceeded 5 million in 2003 (Ryukyu Shinpo, Jan. 16, 2004). This shows that tourists find the charm of Okinawa outside the many facilities planned under the law. The charm is the distinctive and vividly developed culture and the natural environment of the coral reef islands.

Eco-tourism, in which tourists experience nature and culture, is a key element in recent sightseeing in Okinawa. Many of the school excursions from the Japanese mainland have adopted observation of coral reefs with professional guides as a part of environmental studies. Some of these school excursions have produced excellent supplementary readers and a website (Seishin Girl High School*[1]). It should be noted that contributions to these activities have been made by local municipalities, such as prefectural museums, and the Environmental Health Department of Okinawa Prefecture, through publications produced for local nature study, as well as general books

on nature (Ikehara 1984, Nishihira 1991, 1992).

A fusion of conventional nature observation and eco-tourism is expected to develop as environmental education for citizens. However, the natural sightseeing experience of many school excursions and general tourism easily fall into so-called 'mass tourism', disturbing the environment through unregulated use, even in coral reef regions such as Yabiji Reef of the Miyako Archipelago (Ryukyu Shinpo, Apr. 10, 1998). Eco-tourism originally developed as a new use of natural resources that escaped development in developing countries. It is based on various rules, the main feature of these being the restriction on entrance to an area. It is surprising that Okinawa lacks a system and teachers to properly address the increasing demand for a nature experience among citizens. Fortunately, various groups including NPOs, Okinawa Prefecture, and other municipalities have started to examine the rules and to encourage teachers, but the process has only just begun.

4 Views and problems in the future

At Chamonix, in the French Alps, a national training school has been established for mountain guides. The guides trained there are expected to have high levels of cultural understanding and ethics, as well as excellent mountain climbing skills. In addition to mountain climbing safety and rescue, they play a key role in local education and nature conservation in the alpine environment. This is related to the fact that the guides have a good understanding of the natural environment of the region and that sightseeing in the mountains is an important part of the regional economy. The mountain guides are therefore leaders in the local society. Over time, a regional consensus has established that the environment and culture should be conserved and that the way of life should be maintained entirely by these resources. By promoting this idea, protected areas (eco-museums) have been established in various parts of France (Tsuchiya 1999). The National Trust in Britain, which was ahead of the rest of world in the field of developing protected areas, also focuses on education related to the environment and culture. In addition, national park rangers in the United States may have various qualifications, including doctoral degrees, and are leaders in environmental education with a high level of authority and involvement in park management, from the early planning stages. They are key persons in national parks and the surrounding areas. In these cases, there is commonly an established consensus about an environmental culture, and education is included in the management operations of authorized organizations. From a broader perspective, the close relationship between coral reefs and islands should be considered as a valuable environment for humans. The above examples should be referred to in that context.

When considering environmental education about coral reefs, teachers should be required to have qualifications similar to those of mountain guides and park rangers. The system that is required to develop such teachers does not yet exist. In building such a system, the cooperation of various groups of sports and recreation guides, the Maritime Safety Agency, fire departments and other crisis-management bodies, medical institutions, educational and academic experts, and NPOs may be indispensable.

Helpful examples of individual safety management skills include the practice of the Nago Elementary School mentioned above, the experience of swimming while fully clothed to simulate a drowning emergency that is tried in various places, and the Water Wise Movement which proved successful in New Zealand, introduced by Tani *et al.* (2003). Moreover, the standardization of what should be taught in such a system and the development of necessary teaching materials are pressing needs. The Great Barrier Reef Marine Park Authority of Australia*2 and the Florida Keys National Marine Sanctuary of the United States*3 have produced educational programs and many publications on coral reefs. In Japan, the Ministry of the Environment produced the educational program (International Coral Reef Research and Monitoring Center, Ministry of the Environment 2002a).

In Okinawa, an educational system that involves many teachers has been established in the field of the traditional performing arts, and it is expected to be enhanced by the opening of the national theater in 2004. Moreover, there are also many excellent sports instructors for juveniles in Okinawa. Now that the Environment Basic Law has highlighted the promotion of environmental education, there is a splendid opportunity to establish a new culture of marine environmental education in the coral reef regions of Japan.

Referenced websites:

*1: http://www.nd-seishin.ac.jp/bio/index.htm

*2: http://www.gbrmpa.gov.au/index.html

*3: http://www.fknms.nos.noaa.gov/

4-4 Fishery

Shinichiro Kakuma

1 Introduction

The Okinawa region supports the predominant coral reef-associated fishery in Japan. This chapter describes the sustainable exploitation of this fishery, the features of coastal fishery management in the tropics and subtropics, and the state of fishery management in Okinawa.

2 Coral reef fishery off Okinawa

The Department of Agriculture, Forestry, and Fisheries of the Okinawa General Bureau issued the 31st Annual Report on Agriculture, Forestry, and Fisheries Statistics for Okinawa. This report states that the fishery and aquaculture in the waters off Okinawa produced a total of ~40,000 tons of marine products in 2001. Specifically, offshore fisheries contributed ~7,000 tons; coastal fisheries, ~13,000 tons; and marine aquaculture, ~20,000 tons. The production of deep-sea fisheries and inland aquaculture was relatively low; coastal fisheries and marine aquaculture accounted for more than 80% of the total harvest. The statistics for coastal fisheries include catches by small fishing boats (10 tons or less) with fixed nets, and thus include the semi-offshore fisheries catch by fish aggregating device (called *Payao*) fishery and *Thysanoteuthis rhombus* (a large deep-sea squid) fishery. The catch accounts for most of the 5,000 tons of both fisheries caught in 2001. Coral reef fishery includes the use of hook-and-line, bottom long lines, gill nets, fixed nets, drive-in nets, and SCUBA fishery, as well as shellfish gathering.

3 Coral reef fishery management

The differences between coral reef and temperate fisheries must be taken into consideration during the formulation of management strategies. The unique properties of coral reef fisheries include: 1) many fish species, 2) numerous remote islands, 3) high ratio of subsistence

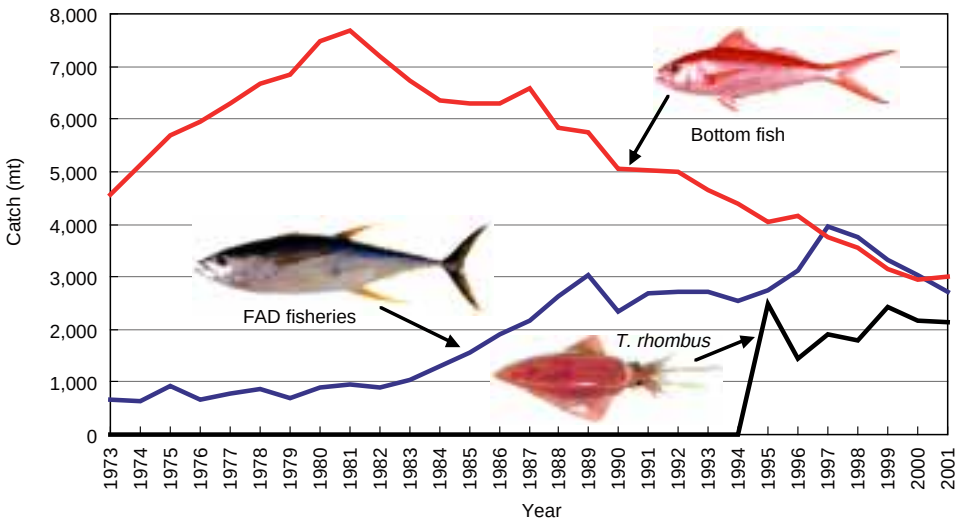


Fig. 1. shows the trends in the coastal fisheries catch for Okinawa. Until 1981, catches of bottom fish such as snappers, emperors, and groupers increased in proportion to increased fishing effort (number of fishing boats, operational days). However, catches of bottom fish sharply declined after 1981, partly because of over-fishing. Instead, the harvests from the fish aggregating device fishery and the *Thysanoteathis rhombus* fishery increased rapidly, sustaining the coastal fishers.

fishers, 4) a lack of research, and 5) strong community spirit (Kakuma 2000a). Subsistence fishery is lower and recreational fishery is higher on Okinawa than on other islands, but the other four conditions apply to fisheries on Okinawa.

Temperate zones have limited numbers of economically important fish species, while a typical coral reef fishery can yield more than 100 valuable species. Western-type management, characterized by government-controlled management based on surveys of individual stocks, cannot readily be applied to reef fisheries because resources are assessed and managed as separate species. The Okinawa Prefectural Fisheries Experiment Station conducted a multi-year research project on a single fish species; the effect of a management plan was assessed using large amounts of data from length measurements, otolith aging, reproductive organs, and detailed fishing statistics for each region, and a computer simulation of the management model was developed. Without the effort and expense of obtaining this type of scientific information, it is difficult to establish management plans that are supported by the local fishers. For a multi-species fishery, however, the time required to gather information may prevent the timely implementation of suitable management plans.

The implementation of 'top-down', or government-controlled, resource management is difficult when fishers are distributed among remote islands. Management plans, even those with strong biological merit, are not effective without compliance from fishers and regulation enforcement by local authorities (Adams 1996). An effective policing and enforcement system is crucial; however, in developing countries with many remote islands, it is difficult to deploy sufficient law enforcement personnel. Few researchers and a high ratio of subsistence fishers also pose challenges to government-led management. A study by Dalzell *et al.* (1996) showed that subsistence fisheries accounted for greater than 80% of the coastal catches of Pacific island countries. Subsistence fisheries are not usually monitored, making resource management by quotas difficult to implement. The resources of coral reef fisheries are therefore more appropriately managed with a community-based, co-management approach that involves both the community and the government (Pomeroy and Williams 1994). Co-management arrangements vary in terms of the relative influence of the community versus the government; the role of the government in research and management is greater in Okinawa than in other countries and regions engaged in coral reef fishery.

In addition to being classified according to the distribution of responsibility between government and community, resource management can also be considered in terms of 'pre-emptive management' versus 'retrospective management' (Adams 1996). Pre-emptive management is initiated only after extensive research into the ecology and catch statistics of the species of interest and the creation of a model to predict the management outcome. Alternatively, retrospective management involves management modifications based on the results of the current management plan as assessed by existing data and information from fishers. This method is similar to 'adaptive management' (LMMA Network Web site: http://www.lmmanetwork.org), whereby the resource management plan is improved during a cycle of monitoring, analysis, discussion, planning, implementation, and more monitoring. Given the unique conditions of the coral reef fishery mentioned above, the retrospective approach would seem to be more effective, depending on the location and target species.

4 Resource management tools and Marine Protected Areas

Resource management tools include closed seasons, size limits, restriction of fishing gear and methods, restricted fishing areas, limitation of entry into the fishing areas, and catch limitations. Chapter 3 of the Fishery Regulation of the Okinawa Prefecture (Fisheries Division of the Department of Agriculture, Forestry, and Fisheries, Okinawa Prefecture 2002) describes species-specific regulations such as closed seasons and prohibited sizes. For example, it is prohibited to harvest spiny lobsters during their spawning season, from April 1 to June 30 (Fig. 2), and to collect *Tridacna crocea* with a shell length of 8 cm or less (Fig. 3). In addition, the use of 28-mm or smaller mesh in drive-in nets, and trammel gill nets is prohibited between June 1 and September 30 to prevent the degradation of the catch during the hot summer. The collection of reef-building corals is also prohibited. Fishery restrictions and management plans are currently designated and implemented by the government. In the future, it may be advantageous to shift to a co-management plan in which local communities participate more actively.

The Common Fishery Rights system also limits the harvesting of marine products from coral reefs. It is some-

Fig. 2. An example of a closed season for giant clams and lobsters in Okinawa region according to the Fishery Regulation of Okinawa Prefecture. (From the Web site, http://www.pref.okinawa.jp/suisan/sangogakkou/sangogakkou5.htm)

Fig. 3. An example of the size limitations on important benthic fishery resources in Okinawa region, according to the Fishery Regulation of Okinawa Prefecture. (From the Web site, http://www.pref.okinawa.jp/suisan/sangogakkou/sangogakkou5.htm).

times considered a violation of fishery rights for a person who is not a union member of the managing fishery cooperative to collect benthic resources in the designated common fishery rights district.

The Total Allowable Catch (TAC) system began in 1997 in Japan. This common Western-style management method controls fisheries by output, or catch, rather than by inputs such as fishing effort. The harvesting of eight important species in Japan is currently regulated by TAC; however, these species are rarely caught in the waters off Okinawa, so TAC limits have not yet been set in Okinawa.

Marine Protected Areas (MPAs) have recently received attention as a valuable resource management tool. Often, the objective of an MPA is to conserve coral reef and mangrove areas. There are many reports on the qualitative effects of MPAs, and the quantitative impacts have recently been investigated as well. MPAs are an effective resource management technique in the tropics for several reasons. 1) Areas can be designated based on the knowledge of local fishers, especially as regards spawning grounds and the breeding seasons of important species, without detailed research. 2) MPAs can simultaneously protect many species. 3) MPAs protect ecologically important habitats such as coral reef and mangrove areas. 4) The regulations within an MPA can be changed after its initial designation. 5) MPAs can provide hands-on management opportunities for local communities. 6) The participation of local communities in the MPA planning process can increase the awareness of local fishers (Crosby *et al.* 2000). There are two MPAs designated by the Ministry of Agriculture, Forestry and Fisheries in Okinawa on Ishigaki Island. One MPA covers Kabira Bay, which contains 275 ha of coral reefs, and the area outside the bay. This MPA is regulated by the Fishery Reguration of the Okinawa Prefecture, which prohibits the harvesting of seven kinds of marine flora and fauna, including the giant clams. The other MPA is in Nagura Bay; it protects 68 ha of coral reefs and sea-grass beds by prohibiting the collection of all marine flora and fauna. The Okinawa Prefectural Fisheries Experiment Station has compiled annual reports on the protected areas of Kabira and Nagura bays based on more than 25 years of research. The management of officially designated Marine Protected Areas reflects the character of government-led management systems, such as the inflexibility in regulation modification. However, local communities in Okinawa (for example, the Onna Village, Nakijin, Itoman, and Yaeyama Fishery Cooperatives) have established community-based MPAs based on discussions with fishers.

The 'stock enhancement projects' are part of coral reef fishery management in Japan. The projects mass-produce larvae of important fishery species in hatcheries, releases them to the sea as juveniles, and catches the adult fish. Stock enhancement projects do not include aquaculture in the strict sense. The stock enhancement projects in Okinawa deal with marine organisms such as Spangled Emperor (*Lethrinus nebulosus*), *Trochus niloticus*, *Portunus pelagicus*, and *Tripneustes gratilla*. The biggest challenge to the stock enhancement project is increasing the survival rate of juveniles after release.

5 Sources of alternative income

Fishery resource management regulations will limit harvests. It is therefore important to secure alternative or supplementary income and food sources for local fishers, especially during the initial stages of implementation. A few possibilities are discussed below.

1. Aquaculture

Aquaculture is usually initiated first for the alternatives. The cultivation of Mozuku (*Cladosiphon okamuranus* and *Nemacystus decipiens*), edible brown algae, is important in Okinawa. These algae can be cultivated with comparatively negligible impacts on adjacent ecosystems because no supplemental food and only simple facilities are required. Moreover, because there is no need for advanced techniques or a large amount of capital (as compared to aquaculture of fish and prawns), algae aquaculture provides a suitable alternative income source in the tropics and subtropics. The cultivation of an edible green alga *Caulerpa lentillifera* in land tanks has recently become an active venture. The cultivation of Kuruma prawn (*Penaeus japonicus*) and some fish species are also important in Okinawa. It should be noted, however, that the construction of prawn and fish aquaculture ponds became problems in Southeast Asia, owing to the associated deforestation of mangroves and the environmental impacts on reefs caused by the input of excessive nutrients.

2. Fish Aggregating Device (FAD)

The installation of FADs, or Payao (Photo 1), seems to be a promising alternative income source. The FAD fishery may also relieve fishing pressure in the overexploited coastal areas (Kakuma 2000b). More FADs are being installed now in tropical regions around the world. The FAD fishery in Okinawa is not managed by the government but by fishery cooperatives and fishers. The fishers are responsible for designing the floats, selecting the installation points, constructing and installing the floats, making repairs, improving fishing gear and methods, preventing fishery conflicts, and improving product distribution. The biggest concern associated with FADs is the loss of FADs caused by storms such as typhoons, but these losses are decreasing as the number of sub-surface (about 50 m depth) Payao in Okinawa increases. This technology may spread worldwide in the future.

3. Tourism fishery

In Okinawa, the diversification of income sources for fishers is also expanding through the development of a 'tourism fishery'. This includes fishing guides, diving guides, and experimental fishery by tourists. Marine ecotourism is also on the rise.

6 Examples of coral reef fishery management

1. Onna Village

The Onna Village Fishery Cooperative in the northern part of Okinawa Island created a Regional Fishing Plan through the Fishery Extention Project in fiscal year 1982 (Kakuma and Higa 1995). As part of this project, a management plan for benthic fishing resources was mapped out for the first time in Okinawa. The target species were shellfish, sea-urchin, and related species, and the establishment of MPAs was a foundation of the management plan. Support from the government included the dispatch of extension officers, the provision of hatchery-produced spat of shellfish, and guidance for spat-releasing techniques. As this was a community-based, self-imposed management plan, the regulations were flexible and had been revised three times by 2000 (Onna Village Fishery Cooperative 2000). This management plan appears to be successful partly because the fishers in Onna Village were obtaining most of their income from Mozuku aquaculture, rather than from benthic fishing resources. The self-imposed regulations also incorporated the confirmation and addition of the Fishery Regulation of the prefecture. Fishery regulations have already been enacted in almost all areas and countries in the Asia-Pacific region; however, the problem lies in the lack of effective operation and enforcement. Thus, the confirmation and addition of the government regulations by the communities as co-management seem to be an effective solution.

2. Yaeyama

The Okinawa prefectural government implemented the Comprehensive Project for the fisheries co-management of the Pacific Yellowtail Emperor (*Lethrinus atkinsoni*) around the district of Yaeyama in fiscal years 1995-1997. It was the most pre-emptive management in Okinawa, and the Okinawa Prefectural Fisheries Experiment Station conducted a variety of stock assessment research. The management plan called for a closed season within the MPAs that are located in four main spawning grounds. The fishery was closed for all fishing methods and fish species during the main spawning season in April and May. This plan was not easily determined, but a consensus was reached after many meetings of a fishers' study committee. The committee also asked recreational fishers for cooperation with the management regulations as a large quantity of *L. atkinsoni* is caught by the recre-

ational fishery. The Okinawa Prefectural Fisheries Experiment Station proposed that if the catches were cut by 10%, the fish stock would rise by 23% in five years (Ebisawa 1998). However, annual catches decreased to the targeted level in only three of the five years of restrictions. The catch per unit effort (CPUE), the most general indication of the resource status, also remained unchanged. The restricted areas were probably too few or too small; however, despite not achieving the target result, this resource management plan is considered a success. The rapidly decreasing trend in CPUE stabilized, fishers observed the regulations, the organization was strengthened, and the level of management awareness rose. Increasing fishers' awareness provides a foundation for future improvements in the *L. atkinsoni* management and for the expansion of the management to include other fish species and fishing methods.

3. Other regions

Prior to the management of *L. atkinsoni* in Yaeyama, *T. rhombus* was targeted for resource management throughout the Okinawa region. Although the fishery of *T. rhombus* occurs offshore, this project represented the beginning of co-management in which the government offered extensive scientific information and established management plans through frequent dialogue with fishers. The plan combined several elements such as license and zoning of the fishery, the restriction of fishing gear, and catch size limitations. However, the primary restriction was the closure of the fishery from July through October to protect small squid and to prevent the "growth overfishing" (Gulland 1983).

Photo 1. A fish aggregating device (*Payao*) established by the Ie Fisheries Cooperative off Iejima Island (photo taken by K. Maeda).

After the *L. atkinsoni* project, similar plans for *L. nebulosus* management were implemented off Nakijin Village and Haneji in the northern part of Okinawa Island. The project implemented a closed season in two MPAs from August to November to protect juvenile fish. Subsequently, projects implemented by the Haneji, Nakijin, Motobu, and Nago Fishery Cooperatives, in the same northern part of Okinawa Island, targeted Coral Trout (*Plectropomus leopardus*) and Black Spot Tuskfish (*Choerodon shoenleinii*) by the SCUBA diving fishery. Weight limits prohibited taking Coral Trout or Black Spot Tuskfish weighing 1 kg or less, and the fishery cooperative market would not accept fish smaller than this. The limits were applied year-round in all marine areas of the Common Fishery Rights districts. When the Okinawa Prefectural Fisheries Experiment Station proposed the size and weight limits, they presented fishers with extensive data on the length-weight of the fish, reproductive status and the ratio of the juvenile fish catch. In fiscal year 2004, management of the SCUBA diving fishery will be proposed for the Yaeyama district.

7 Postscript

Overfishing has been pointed out to be one of the disturbing factors on coral reefs (Russ 1991; McClanahan and Kaunda-Arara 1996; Horrill *et al.* 2000). Coral reef is a complex ecosystem composed of diverse organisms, and therefore, fishery resource management mentioned in this section also plays an important role in coral reef conservation. Further advancement of such integrated resource management and sustainable use of fishery resources are expected to be achieved as our future tasks.

4-5 Tourism

Kenji Kajiwara, Hisashi Matsumoto

1 Introduction

Tourism is a major industry in Okinawa. According to income statistics for Okinawa residents, the largest proportion of income from outside the prefecture is the local grant tax at 52.7%, with tourism income coming in second at 17.1%. Third and fourth are military income (7.8%) and petrochemical production (6.0%; Okinawa Prefecture Tourism Division 2000). Tourism is clearly very important for the regional economy of Okinawa, and coral reefs are one of the region's most important tourism resources. However, tourism-related activities are causing major disturbances to the coral reefs. Recently, certain procedures aimed at limiting the damaging impact of tourism on coral reefs have been implemented. For example, dive shops and fishermen in Zamami Village have restricted their activities on certain damaged reefs (Taniguchi 2003), and some tourist agents, such as the Iriomote Eco-tourism Association (established in 1996), follow self-imposed restrictions on activities. However, many users and stakeholders do not participate in conservation efforts, and there is no enforcement. It must be said, therefore, that sustainable coral reef tourism is still in its developing stages in Japan.

In terms of the number of participants, the 'Yabiji Landing Tour' in the Miyako Islands is probably the largest coral reef tour activity in Japan. We present this tour as a case study for the actual state of sustainable-use tourism in Japanese coral reef environments.

2 Outline of Yabiji Reef and the Landing Tour

The Miyako Islands are located in the middle of the Ryukyu chain. Yabiji Reef consists of ~100 table and platform reefs, within an area of ~10 km × 6.5 km north-south and east-west, respectively (Fig. 1). The area has been utilized by fishermen since at least 1350 AD (there are quite few written records of old Miyako culture), despite the fact that it is ~6 km off the northern coast of Ikema Island. Historically, more than 140 named reefs and features have been recognized. This indicates that fishermen viewed Yabiji Reef as a diversified environment, not as a homogeneous fishing area. The main, traditional methods employed were line fishing, shellfish gathering, and dive-in fishing. Today, other activities such as game fishing, leisure diving, and boat tourism also take place in the area. By far the largest scale event is the landing tour, which is co-sponsored by the local tourism association. Two shipment services run the necessary

Fig. 1. Map of Yabiji Reef. The reef names are translated literally from old dialect.
Words written in capital letters are those whose original meaning is unclear.

Photo. 1. The landing tour at Yabiji Reef.
Tours are arranged individually by two ferry services. ~150-500 people per ferry land on the reef during the lowest spring tides in April. This event is conducted once a year for two/three days.

ferry boat services for 2,000-3,000 tourists, who land on Yabiji Reef during the lowest parts of the spring tide for about three days in April (Photo. 1). The landing tour was first performed in 1983 and has grown to be one of the main tourism events of the Miyako Islands, as other tourism resources such as subtropical forests or rivers are lacking. However, there is concern about possible disturbance to the coral reef ecosystem through physical damage (trampling of live corals) and a lack of constraints or rules governing marine organism collection.

Legal requirements for reef preservation during the landing tour are inadequate. Although Yabiji Reef is neither a marine park zone nor a marine protected area, the Nature Conservation Bureau, Ministry of the Environment (2002a) has designated the area as one of the 500 Important Wetlands in Japan, in recognition of the abundance of corals on the reef. Regretfully, this does not imply any legal restriction with respect to use or conservation. In effect, the Fishery Regulations of Okinawa Prefecture constitute the only controls on tourist activity during the landing tour. These regulations forbid the taking of reef-building corals; in addition, the need for the preservation of important fishery resources is also explicitly stated. There is, however, no statement referring to the destruction of corals and, in any case, what rules there are, are only rarely observed in practice. Local fisheries cooperatives charge landing tour participants a fee (the reason for this fee is not clear), and the limitations, if any, to collecting are not apparent. In addition, it is difficult to explain the regulations to the large numbers of tour participants (~500 people per ferry), or to enforce them, once they are walking around freely on a huge reef site.

Since 1998, the city of Hirara has investigated these issues in a conservation study of the landing tour. The project aims to promote sustainable tourism through conservation of reef ecosystems and fishery resources. The necessary steps are: 1) to clarify the current status of reefs in the area and at the actual tour location; 2) to evaluate the negative impacts of the landing tour; and 3) based on these results, to make proposals for changes to the landing tour procedure. Legal regulation is not possible, because one of the shipment services has its base outside Hirara and, under Japanese law, the city has no authority to control activities on the sea. In any case the distance between Yabiji Reef and land means that practical monitoring would be difficult. The project's findings and progress are described below.

3 Reef status

Prior to this study, there were few reports on the status of the Yabiji coral reefs. Anticipated negative impacts of the landing tour on the reefs were: 1) trampling of live corals and collection of reef organisms on the reef flats; 2) coral destruction on the reef edge by ferry landing gear; and 3) coral destruction on the reef slope caused by ferry anchors. The largest negative impact of these was expected to be that of the tourists themselves as they walked on, and collected from, the reef flats. Coral distribution on the reef flat and reef edge areas was surveyed from 1998-2000.

Line transects (200 m; 400 m at one point) running from reef flat to reef edge were surveyed at 27 stations on Yabiji Reef. Observations of coral fauna and status were carried out carefully, but it was assumed that damage caused by people or ferries could be easily identified. In addition, research into coral growth rates was carried out using four experimental stations on the reef. At each station, 4-m^2 quadrats were established at 1 m depth (reef edge) and at 3 m depth (reef slope). The reef slope at one station was not 3 m deep, so the total number of quadrats was seven. Coral growth rates were estimated from the changes in coral coverage within quadrats. Quadrats at 1 m depth were exposed to air during the lowest spring tides, and were potentially landed on or trodden on during the landing tours. At 3 m depth, however, exposure never occurred, and since water temperatures were more stable and light exposure sufficient, it was assumed that this would be a more suitable environment for coral

growth. The results of these surveys are outlined below.

(1) One hundred and seventy-four species of hermatypic corals (of 37 genera and 13 families) were observed at reef flat and reef edge habitats on Yabiji Reef. Branching *Acropora* dominated coverage at most stations, although the majority of colonies were small, with large colonies occurring only rarely.
(2) Coral coverage and community composition differed greatly between stations, but in general, coral coverage was high on reef edges and decreased towards the inner reef flat, where carbonate and/or rubble habitats were found instead.
(3) Obvious human-induced disturbance to coral colonies (e.g., due to trampling during the landing tour) were not observed.
(4) Coral coverage was less than 20% at the most of the stations where tourists could easily land.
(5) The coral communities of Yabiji Reef could be divided into five areas: north, south, east, west, and central (see '6-1-6 Miyako Archipelago' for details).
(6) In shallow reef flat areas, the growth and death rates of corals were approximately equivalent, even where it was considered to be free from human disturbance (Fig. 2).

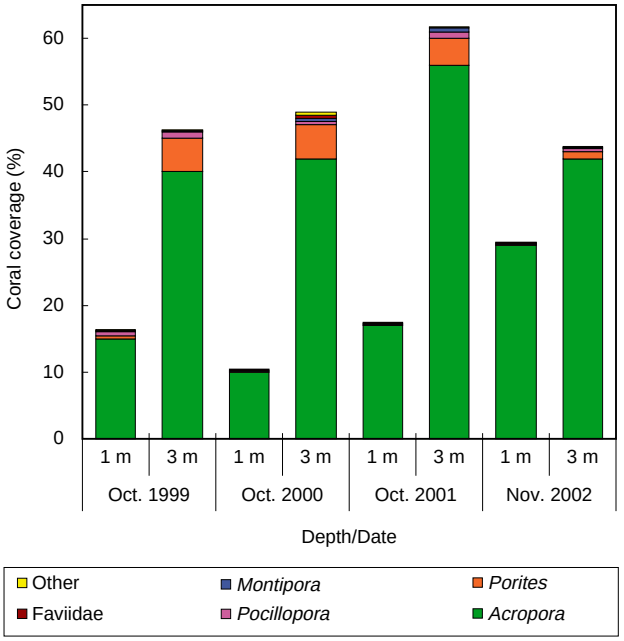


Fig. 2. Coral coverage monitoring at Kanamara ('Head Reef') on Yabiji Reef.
4-m² quadrats were set at reef edge (1 m depth) and at reef slope (3 m depth).

4 Investigation of the actual landing site

On-site visits during the landing tours, each year from 1998, and surveys targeting the tourists, were undertaken over the period 1999-2002. The results are outlined below.

(1) Most of the tourists were on a package tour conducted by a tour agency. Most were in their 50s or 60s (73.6%), and 72.4% were women (1999 questionnaire survey: 163 responses out of ca. 1,500 landing tour participants).
(2) Very few of the tourists knew anything about corals or coral reef ecosystems. In many cases, they could not distinguish live corals from dead ones, or from carbonates. This was also the case for local residents (according to interviews during on-site visits).
(3) Only 8.6% of tourists wished to collect shellfish, corals or other organisms. 86.1% wanted to see the natural landscape and to learn about coral reef ecosystems (1999 questionnaire survey).
(4) Many tourists had a strong interest in coral reef conservation or protection, and some expressed reservations in this regard about the landing tour in which they were participating.
(5) The economic contribution of the landing tour to the Miyako region was estimated to be 89,000 yen per tourist (1999 questionnaire survey). This constitutes a considerable amount.

5 Trial introduction of coral reef guides

Following the research results, it was considered desirable to reduce the anthropogenic disturbances to the reef flat as much as possible because, under natural conditions, rates of coral growth and death were almost balanced. Coral distribution on Yabiji Reef was found to be not uniform, and there were many places with low coverage (below 20%). By positioning landing points away from healthy high coverage areas, and educating tourists to avoid live corals, excessive trampling and damage to reef flat areas might be avoided.

Many tourists visiting Yabiji Reef were expecting to see a natural landscape and to learn about coral reef ecosystems. However, most people lacked any preliminary knowledge about corals or reefs, and no guides were available to instruct them. It seemed that people often

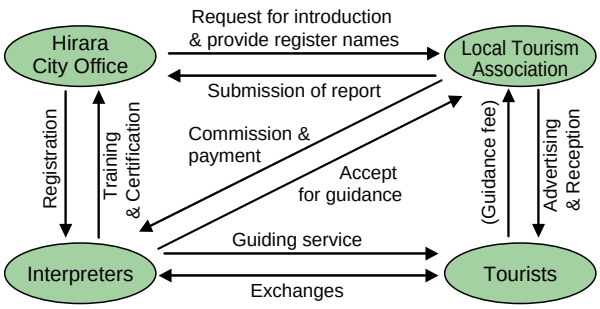


Fig. 3. Diagram of relationship of parties involved in a reef guiding system during the landing tour on Yabiji Reef. The service fee was not charged in the test introduction.

Photo. 2. A reef guide explains certain reef organisms to the tourists during the landing tour at Yabiji Reef.
Many citizens who were interested in reef conservation and sustainable use participated in the reef guide system.

Table 1. Lecture subjects of the volunteer reef guide training program for the Yabiji Reef landing tour, held January-March 2003. Each class was two hours long, and they ran every weekend; the classes covered coral reef-related subjects such as natural science, folk culture, fishery, tourism and history. The subject material was designed to be understood by ordinary people, without basic knowledge of these topics.

Class	Content
Explanatory meeting	Explanation of the project's policy of Hirara City
Indoor lecture 1	Biology of corals and of ecosystem of coral reefs
Indoor lecture 2	Geologic and anthropic history of Yabiji Reef
Indoor lecture 3	Coral reef associated ecosystems (including mangroves forests, sea grass beds, and tidal flats)
Indoor lecture 4	Marine organisms in shallow coral reef areas
Indoor lecture 5	Coral reef and regional human activities - local folk history and fishery regulations in Yabiji Reef
Indoor lecture 6	Case examples of conservation measures in Yabiji Reef and future perspectives
Fieldwork trainings 1-4	1) Identification of major organisms and their habitat and ecology in intertidal zone 2) Contrast of the large scale reef and micro-scale reef organisms 3) Demonstrative guiding practice
Evaluation meeting	Evaluation, presentation and opinion exchanges of the guidance

stepped on corals unknowingly, or only noticed after breaking the colonies, as the majority of the tourists here could not distinguish live corals from dead corals, or from carbonates. In response to this, the city of Hirara, with the cooperation of citizens and the local tourism association, carried out a trial introduction of a 'Coral Reef Guide System' in 2001-2003 (Fig. 3). Reef guides would provide information about the reef and reef organisms to tourists, and would try to shift attention toward issues of reef conservation. It was expected that the reef guides would be effective in producing a more sustainable form of tourism for Yabiji Reef. Citizens of Hirara responded to advertisements for volunteers to be trained as reef guides. The training program was limited to the fundamentals of conservation philosophy, reef ecosystems, traditional knowledge, fishery regulations, and associated aspects (Table 1). Trained participants started working as reef guides on the next landing tour. Within three years, seventy-three people had finished the lecture course and performed interpretation activities during the landing tour (223 guides have participated in a total of 11 days' landings; Photo. 2). Although quantitative evaluation has not been undertaken, the guide system is thought to be effective with respect to reef conservation. The scheme has also been good for tourism promotion, since it improves tour quality and has a positive effect on tourists. When the reef guide explains to the tourists about corals and associated marine organisms, they become aware of their potential impact and try to avoid stepping on corals. The reef guides also appeal to them to refrain from collecting reef organisms. Most of the tourists understand the conservation intention and respond favorably. Guiding activities also work as a line of communication between local residents and tourists, something that is appreciated by many tourists. This trial introduction shows that the presence of guides can contribute to conservation of the reef, and that higher quality tours are possible with the full-scale implementation of a guiding system. Increasing general consciousness about the need for conservation, together with the fact that most tourists want to experience an

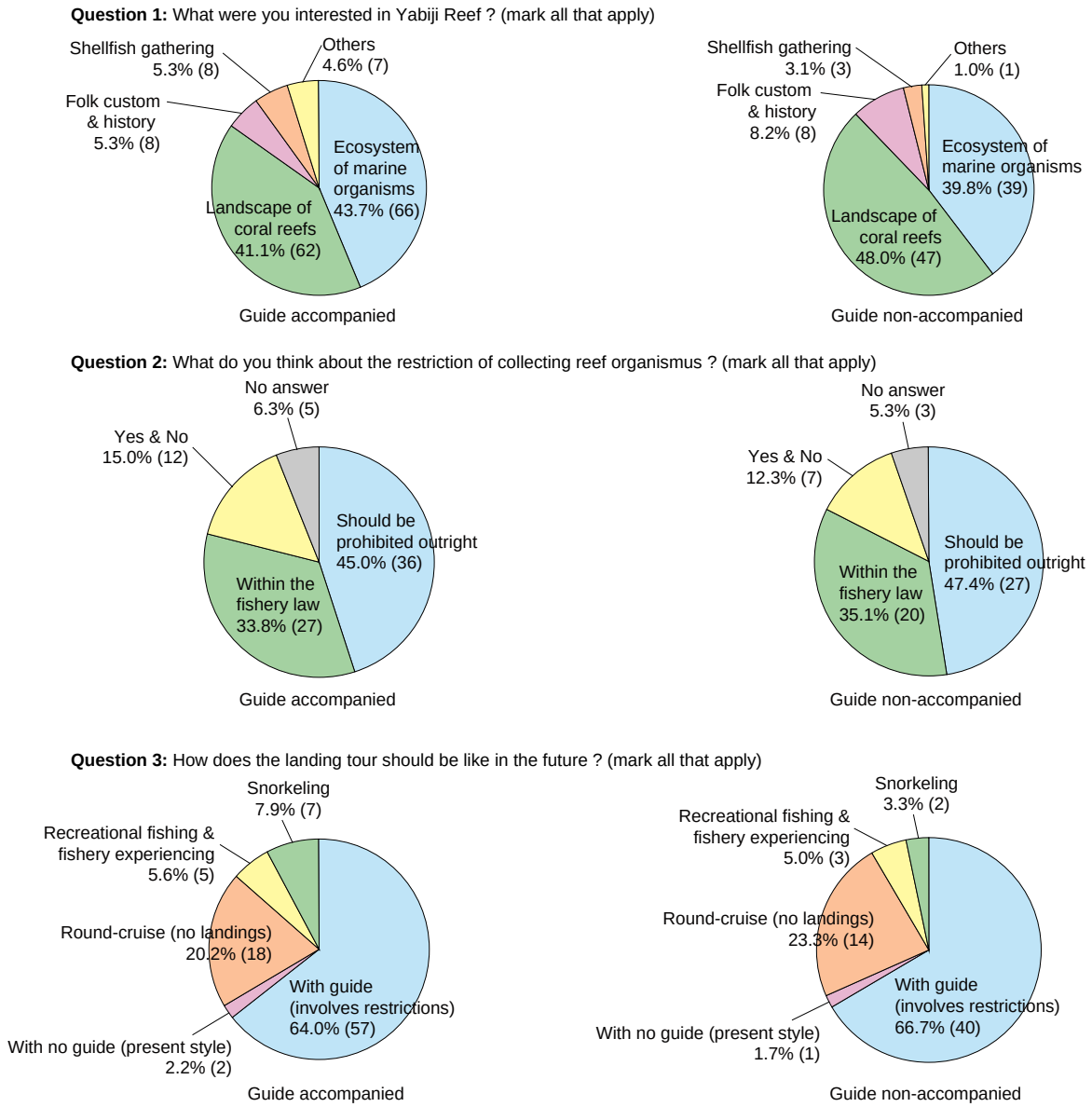


Fig. 4. Results of a guide/no guide questionnaire regarding the landing tour on Yabiji Reef (conducted in April 2002). Eighty tourists from the ferry with the guide responded, while 57 responded from the ferry without a guide.

undisturbed natural environment, bode well for tourism promotion/conservation schemes such as the reef guide system.

To support the validity of this initiative, reef guide test trials were undertaken. Reef guides accompanied one ferry out of two on a trial basis, and all the tourists completed a questionnaire after the landing.

The reef guides were expected to stimulate the tourists' awareness of coral reef conservation issues but, surprisingly, interest levels were little different for the accompanied and non-accompanied ferries (Fig. 4). It was apparent that many tourists were already conscious that certain measures were necessary for the tour itself, and for reef conservation in general. These results suggest that tourists had a higher awareness than expected; therefore, from the tourists' point of view, conservation measures would appear to be both necessary and desirable.

6 Issues that emerged following the trial introduction

In attempting to establish sustainable tourism on coral reefs, alternatives to the present style of tourism (landing

tours) should be put forward so that more people will be able to participate in the conservation framework.

There is another good example of how much value a quality guide service can add to a tour. In 1999 a trial ecotourism tour called the Yabiji Reef Program was run. This day trip was accompanied by a skilled guide and involved half a day spent fishing and half a day spent snorkeling. Tour participants evaluated the trip as being worth 8,000-20,000 yen (15,000 yen was the most frequent answer; Transport Department, Okinawa General Bureau, Okinawa Development Agency 2000). Despite this possible economic incentive, guides have not been included in normal Yabiji Reef Program tours to date. This may be partly due to fact that the trial tour was not based on the usual tour. However, the formal introduction of reef guides to the landing tours should be straightforward, and would convey clear advantages to the tour operators. In addition to the other justifications mentioned above, reef guides receive valuable feedback information from tourists that would otherwise not be accessible to tour agents. Not only are reef guides effective in reef protection, they also improve tour quality.

However, shortfalls in the numbers of voluntary staff and in their training levels were recognized as being limiting factors for the system. Because the system depended on volunteers, whose scheduling with tour dates was not always possible, the guide:tourist ratio was only 1:10-1:20. Raising the volunteers' level of environmental knowledge within a limited lecture/training program was not an easy task, and some reef guides could not perform the required role. Moreover, it also became clear that the guiding system alone was not sufficient to promote reef conservation. The largest issues were:

(1) There are insufficient legal grounds for marine organism preservation.
(2) The main focus of the landing tour differs among the travel agencies; some tours are for gathering shellfish, while others are for observation of the reef landscape and ecosystems. This leads to big differences in awareness and intent among tourists.
(3) From the tour fee of 8,000 yen per person (as of April 2003), 2,100 yen is charged by three fisheries cooperatives (each cooperative receives 700 yen). It is not clear whether this fee is compensation to the cooperatives for collection of reef organisms; the collection of this fee, therefore, undermines the guides' request that tourists not collect anything.
(4) The present tour style cannot avoid the obvious destruction of corals on the reef edge by the landing gear of the ferries.

7 Building of consensus towards regulatory guidelines

As previously mentioned, city-level government agencies have almost no legal grounds for the authorization or enforcement of measures relating to reef conservation. Given this situation, the most effective management strategy would be to introduce reef use guidelines, based on stakeholder consensus.

The stakeholders include two shipment services, travel agencies, local tourism associations, three fisheries cooperatives, governmental agencies, and local residents who regard Yabiji Reef as their communal property. It seems that there are considerable gaps between the stakeholders, not only with respect to interest in, or awareness of, the need for reef conservation, but also with regard to the level of understanding and/or view of reef ecosystems and the regional economy.

An open symposium, aimed at building up common recognition of the issues associated with the landing tour, was held in July 2003. More than 100 people participated in the symposium. Over a four-hour period, the keynote report of the city of Hirara's investigations, a panel discussion, and a plenary open discussion were conducted (Photo. 3). Although this symposium did not reach a concrete conclusion or proposal, it was agreed that a subsequent public roundtable conference would be organized, with the objective of formulating guidelines for sustainable tourism on Yabiji Reef.

8 Perspectives

Of the many sticking points that occur in discussing reef conservation and the landing tour, the bottleneck, with respect to establishing a conservation framework, is most likely to be a lack of understanding of coral reef ecosystems. This ignorance applies to most of the tourists, tourist agents, local residents, and administrative officials. Since environmental conservation groups and economic promotion groups tend to lapse into confrontational modes of contact, emotional and unconsidered pro and con discussions, based on imprecise information and mis-

Photo. 3. Symposium on tourism use of Yabiji Reef.
The landing tour was recognized as a subject of importance to the local community, and not simply as an issue for the tourism industry.

apprehension, often occurred around 1998, when the city of Hirara started the Yabiji Reef Project. However, during the symposium there were almost no confrontational discussions. Instead constructive opinions were put forward as to how conservation and exploitation could coexist. The atmosphere of constructive debate was thought to be owing to practical recommendations stemming from the volunteer reef guides' hands-on experiences, and from the fact that the city of Hirara had been openly announcing the research results through publications and lectures. It must be said, however, that the landing tour was a relatively easy subject through which to generate discussion about coral reef conservation. Yabiji Reef has a symbolic existence for people in the Miyako Islands, thereby making it easy to attract people's interest, and the small time-window of the landing tour – two or three days, once a year – meant that there were no subsistence stakeholders to add pressure to the discussions. The Yabiji Reef landing tour is a topical issue in reef conservation. Establishment of a conservation framework here will serve as a good example and reference point for all other coral reef conservation issues in Japan.

Another beneficial aspect of the guiding scheme involved the social education of the volunteer citizens. It seems that ordinary local residents have a rapidly fading relationship with the ocean; many of them cannot distinguish live corals from dead ones. Appreciation of public properties such as coral reefs by the residents in these areas is essential if future generations are to inherit natural, culturally important environments.

4-6 International Cooperation

Keisuke Takahashi, Tadashi Kimura

1 Introduction

Coral Reefs and related ecosystems, such as mangrove forest and seagrass bed, retain great biodiversity, and therefore constitute an important common property. However, those precious ecosystems have being depleted by global threat such as mass coral bleaching caused by anomaly of seawater temperatures, as wall as local event such as effect of destructive fishing and soil flows from land-based development. In addition, most of coral reefs are distributed in developing countries in tropical and sub-tropical regions, and sustains people's life by providing food and livelihood. Considering those situation, the importance of international cooperation in coral reef conservation is obvious.

Japan cooperates in various international coral reef conservation efforts, mainly those occurring in a multilateral framework, such as the International Coral Reef Initiative (ICRI) and the Global Coral Reef Monitoring Network (GCRMN). In addition, the Japanese government provides technical and financial support, including training programs for developing countries. The following discussion presents some of Japan's international cooperative activities that are related to the conservation of coral reefs.

2 International Coral Reef Initiative (ICRI)

1. Background

Agenda 21 is a global-scale action program that aims to achieve sustainable development in the 21st century. It was adopted at the Rio Earth Summit (UNCED: United Nations Conference on Environment and Development) in June 1992. Agenda 21 describes the current status of various aspects of the global environment, notes points at issue, and outlines future preventative or remedial programs for problems such as atmospheric pollution, deforestation, desertification, marine conservation, and the protection of freshwater resources. Coral reef conservation is treated in Chapter 15 (conservation of biodiversity) and Chapter 17 (conservation of coastal areas). In Section 85 of Chapter 17, it is stated that each nation should prioritize the promotion of conservation projects for important ecosystems by specifying regions with high biodiversity and productivity, and then legally designating them for protection. Ecosystems intended to be the target of conservation in this manner include coral reefs, tropical and temperate wetlands including mangrove forests, seagrass beds, river estuaries, and other spawning and breeding grounds.

In addition, the Barbados Plan of Action for Sustainable Development of Small Island Developing States (SIDS) was adopted in 1994 (in April-May at Bridgetown, Barbados). At this meeting it was stated that the promotion of coral reef conservation was essential for SIDS, from the joint perspectives of preserving coastal resources and biodiversity. Following these documents, coral reef conservation was stated as being an important item on the Japan-U.S. Common Agenda for Cooperation in Global Perspectives at bilateral summit in November 1994. ICRI was established in line with this agreement, founded by eight governments: Australia, France, Jamaica, Japan, the Philippines, Sweden, the United Kingdom, and U.S.

The first international ICRI workshop was held at Dumaguete City, in the Philippines, in May 1995, and was attended by participants from 33 countries and related international organizations (e.g., World Bank and UNEP). This workshop resulted in adoption of a 'Call to Action' and a 'Framework for Action' for coral reef conservation. The Call to Action provided broad unifying principles intended to fashion ICRI into a forum for international partnership; this objective set the direction for the workshop. Four points were particularly emphasized: 1) coastal management, 2) research and monitoring, 3) capacity building, and 4) review. The Framework for Action responded to the aforementioned four points, and was developed to

mobilize stakeholders in order to implement the Call to Action.

2. Management

ICRI functions as a worldwide network for reef conservation, involving 80 or more member countries or international organizations. Each member participates in the framework and works towards conservation of coral reefs, in accordance with the ICRI documents mentioned above. Cross-sectional networks such as GCRMN, which promotes coral reef monitoring, and the International Coral Reef Action Network (ICRAN), which aims to strengthen reef management by exchanging traditional knowledge and current research, and by sharing experiences.

The ICRI Coordination Planning Committee (CPC) meets to make decisions, approximately twice per year, generally in conjunction with major coral reef conferences or workshops in Asia, the Pacific, or the Indian Ocean, in order to enable wider participation on the part of members. The ICRI Internet Forum allows supplemental CPC discussions, deeper discussions of certain themes, and offers a place for input and debate to those not able to participate in the CPC. ICRI is co-ordinated by a Secretariat voluntarily hosted for two years by the governments of member countries. The first secretariat was administered by the U.S. in 1994-1996, the second by Australia in 1997-1998, and the third by France in 1999-2000. In order to ensure that the opinions and viewpoints of developing countries are adequately presented, the head office is now jointly administered by one developed and one developing country. Sweden and the Philippines were in charge in 2001-2002, and the United Kingdom and the Seychelles took over in 2003 (concluding July 2005).

The roles of the Secretariat include; developing a Plan of Action, organizing and charring General Meetings, representing the Initiative to international conventions.

3. ITMEMS

The International Tropical Ecosystems Management Symposium (ITMEMS) provides a forum for managers of coral reefs and related ecosystems to discuss and share experiences. It is held every four years by ICRI, and is attended by relevant administrative officials and researchers. The first symposium was held in Townsville, Australia, where 'The New Call to Action' was adopted. At this meeting, it was clear that the decline of coral reefs was continuing, due to the 1998 worldwide bleaching event in particular, in which 40-50% of coral reefs were affected. However, some of the positive achievements of ICRI include the deployment of local action plans, improved coordination between scientists and non-governmental organizations, and advances in coral reef monitoring owing to implementation of GCRMN and Reef Check, among other programs. The second symposium was held in the Philippines in March 2003, where the ITMEMS II Action Statement was adopted; this statement contained resolutions related to marine protected areas (MPAs), sustainable fisheries, mass bleaching events, and the role of the private sector in conservation.

4. Regional workshops

Regional ICRI workshops, at which regionally relevant strategies are formulated, have been held in various regions (e.g., tropical America, the Pacific, South Asia Seas, East Asia Seas, East Africa, the West Indian Ocean, and the Middle East). The first East Asia Seas Region (including East Asia and Southeast Asia, and Japan) workshop was held in Bali, at which the 'East Asia Seas Region Regional Strategy' was adopted. This strategy encouraged the participation of more countries in GCRMN, and regional bases for the promotion of monitoring were established (The Ministry of Foreign Affairs of Japan 1997). The second workshop was held at Ginowan in Okinawa, at which the 'Okinawa Declaration' was adopted (The Environment Agency, the Goverment of Japan 1997). The third workshop was held at Sebu City in the Philippines in 2001.

5. GCRMN

GCRMN was established within ICRI as a network for the integration of monitoring data from regional nodes; this initiative aims to achieve coral reef conservation and sustainable use. The Australian Institute of Marine Sciences (AIMS) and the World Fish Center in Malaysia have cooperated to secure funding, provide advice on monitoring methods, and manage the data collected from nodes and the resulting database; they have also been making biennial reports on the state of world coral reefs since 1998 (GCRMN 1997).

In 2000, Ministry of the Environment, Japan established the International Coral Reef Research and Monitoring Center in Ishigaki Island, Okinawa prefecture. The center is promoting GCRMN in the East Asian Sea Region, by compiling the monitoring date of East Asian Countries, as well as assisting South East Asian countries. In this context, Ministry of the Environment has been holding work-

shops on monitoring method, database management with cooperation of GCRMN and Worldfish Center. The details of the workshops are as follows.

a) The socio-economic monitoring workshop: This workshop was held in Bolinao City in the Philippines in 1997. A manual for socio-economic assessment was developed (The Environment Agency, the Government of Japan 1998).
b) Capacity building workshop on coral reef monitoring methods: This workshop was held in Nha Trang in Vietnam 1999, and field training in monitoring methods for coral reefs (e.g., manta tow and line transects) was provided (Marine Parks Center of Japan 1999).
c) GCRMN meeting of the East Asia Seas Region: This meeting was held at the International Coral Reef Research and Monitoring Center in 2002. Monitoring information was exchanged and database issues were discussed; in addition, the 'Ishigaki Agreement' was adopted (Ministry of the Environment, Government of Japan 2002).
d) International workshop on database and data management: This workshop was held in Penang in Malaysia, in cooperation with the World Fish Center, in 2003. Methods of exchange of national databases were discussed, and a policy for the development of a common database, useful for all member countries, was agreed.

The Japanese government has also assested to hold workshop for the establishment of domestic monitoring and database systems for the Philippines (in 2002), Malaysia (in 2002), and Cambodia (in 2004).

3 Cooperation by the ODA

1. Bilateral cooperation

In terms of bilateral cooperation, the Japan International Cooperation Agency (JICA) offers 'technical cooperation', in which an expert is sent to the developing country to facilitate human resources development and technology transfer, and 'Grant Aid' to support the construction of facilities for coral reef conservation is negotiated.

Japanese Grant Aid funded the construction of the Palau International Coral Reef Center in January 2001; this is an international center for conservation-oriented research and education about coral reefs and related ecosystems in Palau. The Center has three divisions: management, research division, and exhibition and education division.

The research division studies corals and crown-of-thorns starfish, and promotes the monitoring of coral reefs in Palau; it also serves as a node for GCRMN in Micronesia, compiling monitoring data from surrounding countries. The exhibition and education division operates the 'Palau Aquarium'. This aquarium exhibits various marine organisms from around Palau, and tries to emphasize the tight ecological relationships and continuity of coral reefs, seagrass beds, and mangrove forests. It is also used for the education of children and tourists. The Japanese government has assisted in its management, from the initial construction to present day operations, by providing experts and human resources development.

In 1995, funds were granted for the repair of facilities and technical equipments for the expansion of the Albion Fisheries Research Center in Mauritius. A five-year project (Coastal Resources and Environment Conservation Project) was conducted from 1995, with a strong emphasis on research training, in order to invest equally in environmental conservation and human resources. Databases and field guides were developed and ecological surveys (e.g., studies in population ecology) were conducted.

Besides those projects, Japanese Government send experts and conduct scientific and socioeconomic research and develop management plan in several coral reefs; Marine Parks in the Kingdom of Tonga (Marine Parks Center of Japan 1997), Tubataha Reef in Philippines (DENR and MPCJ 1996), Northern Sulawesi in Indonesia (JICA 2002), the Red Sea in Saudi Arabia (JICA 2000).

2. Capacity building through training

The Okinawa International Center of the JICA has run a training course on the sustainable use of coral reefs and conservation management since 1995 (Photo. 1). The course is aimed at administrative officers and experts from developing countries who are engaged in coral reef research and planning. During the about 80 day course, participants acquire general knowledge about, and techniques for, the conservation, sustainable management, and utilization of coral reefs. They attend workshop courses about coastal management and designing educational materials, as well as lectures on coral ecology, taxonomy, and restoration methods. In addition, they receive training in fieldwork research and monitoring, which includes underwater filming. In the past eight years, 53 participants from 24 countries have completed the train-

Photo. 1. JICA Group Training Course "Conservation and Sustainable Management of Coral Reefs " Trainees learning about coral taxonomy.

ing program.

4 Conclusion

In May 2002, the Japanese government established the 'New National Biodiversity Strategy '. International activity was set as one of the four basic national policies for the conservation of biodiversity. With particular regard to coral reefs, Japan will cooperate and be actively engaged in international monitoring programs, and will also be active in research and the conservation of important biodiversity components (e.g., tropical rain forests, coral reefs, wetlands, and the stopping points of migratory birds). Additionally, the Japanese government will cooperate with relevant countries, international organizations, and local residents on important issues related to the conservation of coral reef ecosystems (such as total coastal management, capacity building, implementation of research and monitoring, and the monitoring and assessment of conservation).

Japan is located in one of the central regions of coral reef biodiversity. As one of the few developed countries which has coral reefs, Japan has played a role in global coral reef conservation through such activities as the promotion of ICRI, GCRMN, bilateral cooperation, and group training. Further active participation in these matters is expected, following the 10th International Coral Reef Symposium, which is to be held in Okinawa in June 2004.

Sekisei Lagoon. (photo by Tatsuya Suzuki)

Spawning behavior of brooders

Saki Harii

Many corals spawn their eggs and sperm (i.e., their gametes) simultaneously in the water column at night at almost predictable times of the year. This type of reproductive mode is classified as broadcast spawning. Brooders, on the other hand, release their planula larvae directly into the water column after fertilization and growth in the coral polyps. All corals were previously regarded as brooders until it was discovered that the majority of corals were actually spawners (Harrison *et al*. 1984). More recently, some corals, such as *Goniastrea aspera*, appear to possess both reproductive modes (Sakai 1997).

Reproductive studies on brooding corals undertaken at the Palau Tropical Research Station in the 1940s revealed that Pocilloporidae and *Acropora brueggemanni* (*Isopora*) released their planulae into the water column (Atoda 1947a,b; 1951a,b). Pocilloporidae released planulae almost every month, throughout the year, in synchrony with the lunar cycle. This is in contrast to broadcast spawning corals which release gametes only once a year. In the other regions of the world, many brooders have also been observed to release planulae almost every month – for example in Hawaii, Guam, Australia (Great Barrier Reef), Red Sea, and Caribbean Sea (Richmond and Hunter 1990). In the vicinity of Ishigaki and Iriomote Islands, southwestern Ryukyu Islands, Japan, there is no data on the reproductive schedules of brooding corals, but if we extrapolate from data collected in (nearby) Taiwan (Dai *et al*. 1993), corals may also release planulae every month.

In Okinawa Island, which is located at a slightly higher latitude than Ishigaki and Iriomote Islands, reproductive schedules differ among Pocilloporidae: *Pocillopora damicornis* release their planulae for 8 months a year (May to December), while *Stylophora pistillata* and *Seriatopora hystrix* release for 3 months a year (May to July or June to August) (Yamazato 1991; Yamazato *et al*. 2000a, b; Permata *et al*. 2000).

While broadcast spawners release a great number of (tiny) eggs and sperm into the water column, where fertilization takes place, and the larvae require a few days to settle, brooders on the other hand release few planulae, more than 1 mm in length, and are well developed and ready for immediate settlement. But they don't always necessarily do so, yet the literature suggests that brooders have a narrower dispersal range than broadcasters because they usually recruit within the source area (Harrison and Wallace 1990). Yet, brooded planulae vary considerably in settlement-competency periods. *Pocillopora damicornis*, *Stylophora pistillata* and *Seriatopora hystrix* (Photo. 1a) planulae have zooxanthellae and can swim actively. While *P. damicornis* planulae can settle within a few hours after release, they can also settle after 100 days after release (Richmond 1987; Harii *et al*. 2002). Therefore, if these planulae do not find suitable habitats for settlement within a short time frame, they appear to have the potential to continue their planktonic life, disperse, and settle on distant reefs. However, genetic analyses of *P. damicornis* and *P. pistillata* populations in the Ryukyu Islands showed significant genetic differentiation among some populations which indicates that gene flow is not as high as expected (Adjeroud and Tsuchiya 1999 Nishikawa *et al*. 2003). Other brooding corals, such as *Acropora palifera*, *A. bruggemanni* and *Heliopora coerulea* (Octocorallia, Photo. 1b) do not have zooxanthellae. The less buoyant planulae of *H. coerulea* (blue coral) are usually found in the vicinity of substrate, and have the potential to immediately settle after release. They have been observed settling near parent colonies *in situ* (Harii *et al*. 2002; Harii and Kayanne 2003). These planulae appear to have a low dispersal potential because of their azooxanthellate nature, the low lipid concentrations, and short larval competency periods recorded (Harii *et al*. 2002). *Alveopora japonica*, once a year releases both 'positively buoyant type' and 'benthic type' planulae, which are clearly at different stages of development (Igarashi *et al*. 1992; Harii *et al*. 2001). Benthic type planulae can settle immediately after release, but it generally takes positively buoyant type planulae a few days to settle. The latter have competency periods exceeding 100 days, suggesting that they have a different dispersal ranges compared with benthic type planulae. Although many studies suggest that the dispersal range of brooders is generally narrower than broadcast spawners, larval dispersal patterns are also dependent on the 'mother' colony's locality on the reef, settlement-competency periods, and local and regional currents patterns.

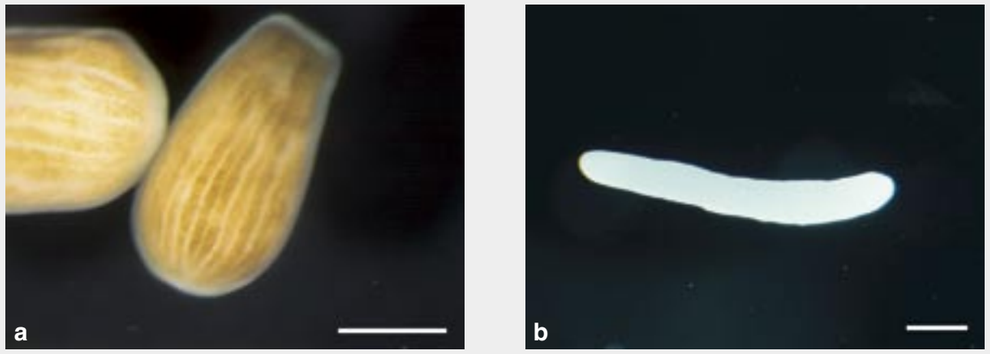


Photo. 1. Planulae of brooders: *Pocillopora damicornis* (a) and *Heliopora coerulea* (b). The scales are 0.5mm.

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

Shuichi Fujiwara, Makoto Omori

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 (Pandolfi *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.

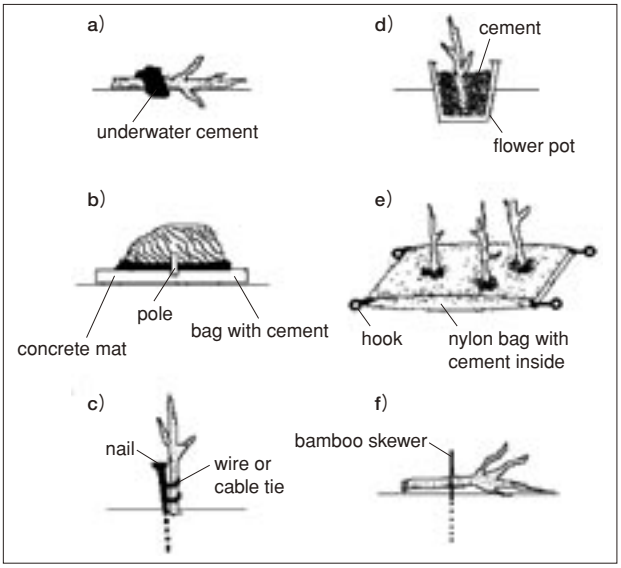


Fig. 1. The transplantation of fragmented colonies (Okubo and Omori 2001).

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*. in press).

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

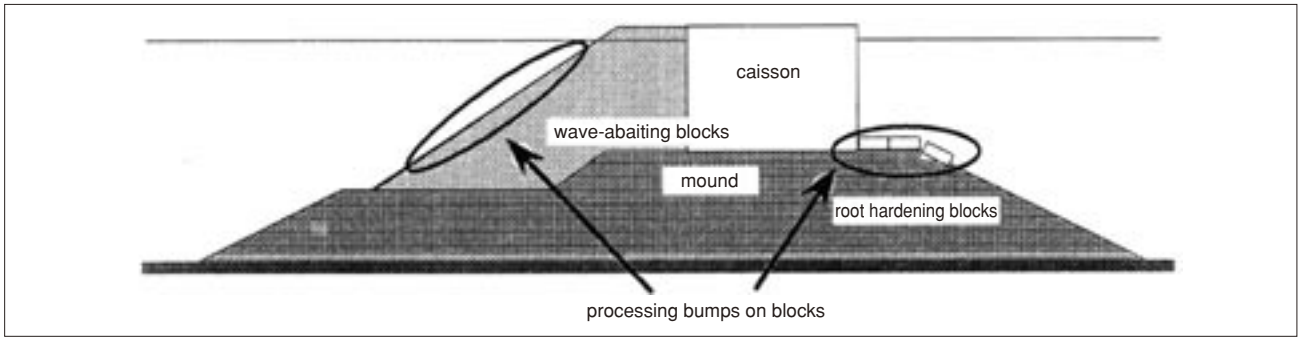


Fig. 2. Target area for substrate processing on a breakwater to induce coral larval settlement (Port and Marine Environment Research Institute, and Waterfront Vitalization and Environment Research Center 1999).

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

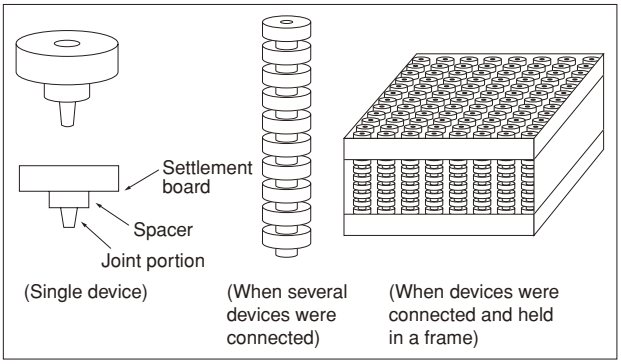


Fig. 3. Diagram of the larvae settlement device (Okamoto and Nojima 2003b).

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,

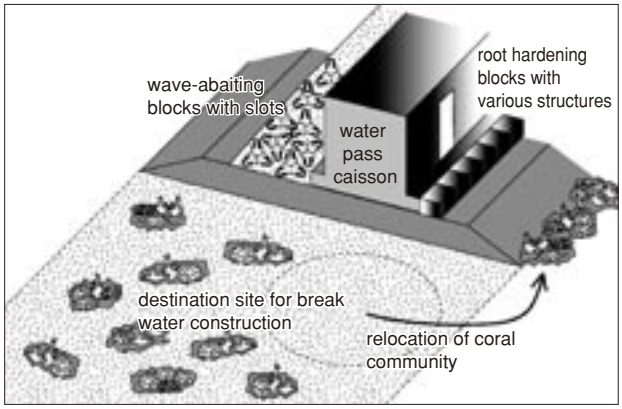


Fig. 4. General description of the relocation procedure used for coral communities in an 'environmentally friendly breakwater' (Ishii *et al.* 2001).

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.

5-2 Approaches for restoring coral reef ecosystems

Keisuke Takahashi

1 Introduction

Today, environmental deterioration is occurring in local regions and on a global scale. Coral reef ecosystems, along with tropical rainforests, harbor the highest biodiversity on Earth, but these ecosystems are currently in a critical situation, and action is necessary. This report introduces two coral reef ecosystem restoration projects conducted by the Japanese Ministry of the Environment. It also presents 'The New National Strategy on Biological Diversity', which triggered the promotion of nature restoration projects in Japan, and 'The Law for the Promotion of Nature Restoration', which stipulates the concept and framework of nature restoration projects in this country. The term 'coral reef ecosystem' in this report is used to indicate an ecosystem centered on hermatypic coral (hereafter coral) communities, including those in temperate zones.

2 The New National Biodiversity Strategy of Japan

'The New National Biodiversity Strategy of Japan' was formulated in March 2002 and was intended by the Japanese Government to plan and achieve a society that co-exists with nature. Together with the enhancement of conservation and sustainable use, nature restoration was specified as one of the three main pillars of this strategy, and the policy statement for nature restoration was as follows.

"Humankind has been overexploiting natural resources and destroying the natural environment beyond the level at which the environment can restore itself. Biodiversity, which is indispensable for human existence, has consequently been depleted. Under these circumstances, we have to change the way that we interact with nature: from a single-sided deprivation of natural resources and destruction of the environment, to contribution to the environment from the human side. These efforts should commence while sound ecosystems, which will serve as models and also as sources of species re-supply, still exist around us. The Japanese government has therefore begun positive restoration and rehabilitation projects aimed at enhancing the resilience of our natural environment. In this process, it is necessary that stakeholders share their information based on scientific knowledge and reach a consensus in terms of goal-setting in each project. Adaptive management practices should ensure that healthy ecosystems are not damaged in the process of restoration projects. Simultaneously, the projects themselves must be monitored properly, flexibly re-examined and conducted carefully over the long term. In this way, and by accumulating experiences and expertise, restoration and rehabilitation methods appropriate to the environments and regions of Japan will be established. Nature restoration projects will actualize consensus-based, comprehensive implementation of this policy on behalf of the Japanese Government and with the participation and cooperation of various actors such as citizens, researchers, and the private sector."

3 The Law for the Promotion of Nature Restoration

Following the above national strategy, 'The Law for the Promotion of Nature Restoration' came into force in 2003. This law defines nature restoration as a joint effort among various participants to implement conservation, restoration, creation, and management of natural environments including wetlands, tidal flats, seaweed beds, '*satoyama*' (coppice), '*satochi*' (rural landscapes), forests, and other environments that have been lost or degraded by human activities.

Specified in the law are five principles. Nature restoration should: 1) aim at realizing a society that can

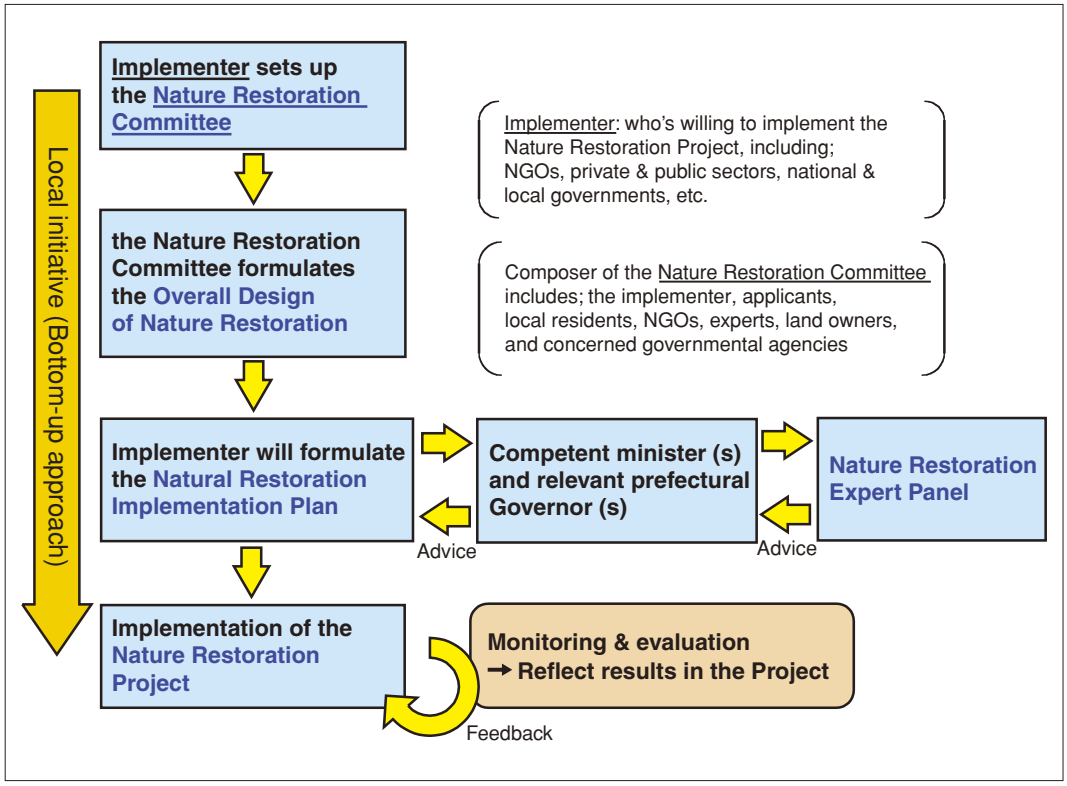


Fig. 1. Flow chart of planning and implementation for nature restoration projects, under the Law for the Promotion of Nature Restoration enacted in December 2002.

co-exist with nature through secure biodiversity; 2) be carried out in such a way that feedback from monitoring results is reflected in the project (adaptive management); 3) be carried out based on scientific knowledge; 4) be carried out in a flexible manner that adapts to the monitoring results; and 5) take opportunities to use projects for public environmental education.

Those wishing to implement nature restoration projects must organize a 'Nature Restoration Committee' that consists of stakeholders who are willing to participate in the project, such as local residents, nongovernmental organizations (NGOs), experts, land owners, and relevant government administrative bodies. Committee members must: 1) discuss and cooperate in the planning of an 'Overall Design of Nature Restoration' ; 2) act upon the drafted 'Nature Restoration Project Implementation Plan'; and 3) coordinate correspondence and consensus-building on relevant matters for project implementation. The overall design document serves to indicate the overall direction of the project and integrates the diverse stakeholders' wishes and efforts through the determination of the project goals, target area, roles of committee members, etc. Based on this design, an implementation plan must be formulated that specifies the target area, project description, advantageous outcomes, and significance of the project (Fig. 1).

4 Projects for restoring coral reef ecosystems

Nature restoration projects have been initiated by the Ministry of the Environment in line with the above-mentioned national strategy and law. As of December 2003, two projects and 15 preliminary studies are in operation (Fig. 2).

Two of these preliminary studies involve the restoration of coral reef ecosystems. The ultimate goal of this research is to enable the resumption of the sustainable use of coral reefs by local communities. These studies are being conducted in Sekisei Lagoon in Okinawa Prefecture, which is the largest coral reef in Japan, and in Tatsukushi Bay in Kochi Prefecture, which will serve as an example of a high-latitude coral community. In addition, the prefectural government

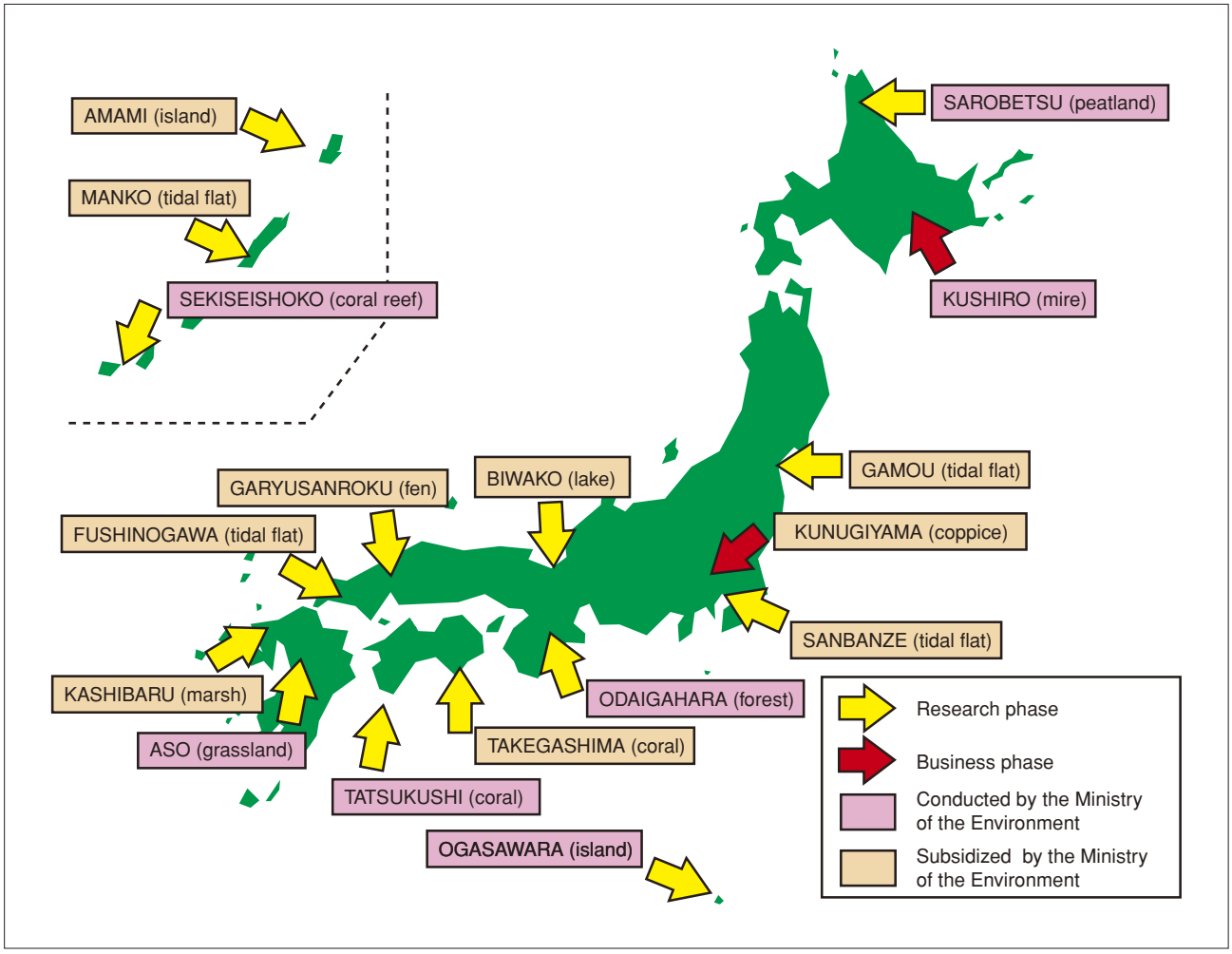


Fig. 2. Sites and targeted environments (in brackets) in the Japanese Nature Restoration Project, December 2003.

of Tokushima, subsidized by the Ministry of the Environment, is conducting research in coastal areas around Takegashima Island. Scientific committees, as well as consultative groups of local stakeholders such as fishermen, residents, and NGOs, are involved in the planning and conduct of these studies.

There are six stages in the performance of these projects: 1) preliminary research; 2) consideration and consultation; 3) planning; 4) project operation; 5) monitoring and evaluation; and 6) feedback and modification. The two preliminary studies mentioned above are now at stage two. At the first stage, the current status of each region's reef ecosystems must be understood and the causes of their degradation identified. Research parameters include surveys of coral distribution, sea currents, land use, terrestrial outflow of soils and pollutants, fisheries and tourism, and any other relevant factors. At the second stage, based on consideration of the above inputs and consultation, specific goals for each case, the critical area requiring protection, coastal management measures (including terrestrial areas), and appropriate protective measures are established. In the third stage, an execution plan is formulated that includes specific techniques for the restoration of regional coral communities, conservation and management of the sea area, management of terrestrial discharges, post-monitoring, and outreach programs to raise public awareness.

5 Sekisei Lagoon

Sekisei Lagoon lies between Ishigaki Island and Iriomote Island in the Yaeyama Archipelago. The reef measures approximately 20 km east-west and 15 km north-south, and more than 350 coral species have been recognized in this area (Nishihira and Veron 1995). For this reason,

Sekisei Lagoon, along with the virgin forest of Iriomote Island, has been designated as the Iriomote National Park. Within the park area, four Marine Protected Areas have been designated. The lagoon is important not only scientifically but also for local economies through fishing and tourism activities such as diving and glass-bottomed boat tours.

Despite this protection, there have been several severe disturbances to coral communities in Sekisei Lagoon, including the crown-of-thorns starfish (*Acanthaster planci*) outbreaks in the 1970s and 1980s, a mass coral bleaching event in 1998, and soil sedimentation caused by terrestrial erosion. Given these circumstances, in 2002 the Ministry of the Environment commissioned research in order to formulate a management and rehabilitation plan for the recovery of this sound and significant coral reef ecosystem. This plan is expected to cover a wide variety of issues such as conservation, management, appropriate use, a rehabilitation program, and environmental education.

Aerial and field surveys to identify the distribution of coral communities were conducted in 2002 and 2003. Comparisons of these results with those of surveys in 1980 and 1990, prior to the later *A. planci* outbreak and bleaching event, respectively, led to the identification of areas resilient to these negative impacts. In addition, the sources and transport routes of coral larvae have been identified through examination of regional sea-surface currents. Socio-economic surveys have identified areas important for fisheries and tourism.

Based on these scientific and socio-economic data, consensus-building meetings were held among participants, who included coral reef scientists, related national and local governments, and local stakeholders such as diving associations, fishery cooperatives, tourism agents, and local NGOs.

6 Tatsukushi Bay

Tatsukushi Bay, with an area of approximately 3.7 km^2, is located in the southwestern part of Shikoku. Coral species are relatively abundant, despite the high latitude, owing to the influence of the eastward-flowing Kuroshio Current. The bay is part of Ashizuri-Uwakai National Park, and contains four Marine Park Zones (Nos. 1 to 4). Huge, scientifically important colonies of *Pavona decussata* occur, especially in Zone 4. Many tourists visit this area and enjoy the underwater scenery by scuba diving, snorkeling, and glass-bottomed tour boats.

However, coral communities have deteriorated in recent years for several reasons. In Marine Park Zones 2 and 3, corals were damaged by the predation of coral-eating gastropods (such as *Drupella fragum*) and have not yet shown signs of recovery. Furthermore, a localized torrential downpour that hit this area in September 2001 caused severe soil erosion and outflow to the neighboring coasts, and corals were killed as a result of burial and sedimentation.

To counter these problems and to recover the healthy coral communities, the Ministry of the Environment began research in 2003 with the aim of restoring the coral reef ecosystem. Field surveys investigating the sea-bottom topography and coral community distribution were conducted. In addition, attempts have been made to follow the transport of soils into the ecosystem; regional sea-surface currents were examined, and the degree of sedimentation was recorded for different areas. Methods for the physical removal of accumulated sediments have been considered. As in the case of Sekisei Lagoon, diverse stakeholders were consulted during the planning and conduct of these studies.

These studies in Sekisei Lagoon and Tastukushi Bay provide us with scientific information about the status of coral communities and the influence of human activity on coral reef ecosystems, as well as socioeconomic information regarding the appropriate structuring of projects to allow each stakeholder to contribute initiatives and cooperate in problem-solving. We would like to share this information, and we believe that these projects could serve as useful models for coral reef restoration projects elsewhere.

Mass spawning of acroporids

Takeshi Hayashibara

Reef building scleractinian corals propagate and maintain their populations, in part, through sexual reproduction. Passive dispersal of the gametes, fertilization in the water column, and dispersal of planktonic larvae play a major role in genetic exchange among reefs. Coral spawning patterns were relatively unknown until the discovery, 20 years ago, of the peculiar spawning behavior – simultaneous mass coral spawning – of corals on the Great Barrier Reef. Before that time most researchers believed brooding and the release of live larvae into the water column was the most common mode of coral reproduction in the Pacific Ocean. Reports of simultaneous mass coral spawning on the Great Barrier Reef attracted the attention of the world. Over 45 coral species spawned their gametes synchronously, at night, following the full moon in October or November, corresponding to early summer in the southern hemisphere. Following this remarkable discovery coral spawning patterns were examined at other localities around the world. However, such highly synchronous behavior has not been observed in other localities. The pattern of coral spawning in Japan has been studied for over 15 years.

Around Okinawa, the spawning patterns of about 100 coral species are known. The spawning period is long, compared with the Great Barrier Reef, extending from May to September, and some species have protracted spawning patterns extending over two to three months. Thus spawning synchrony is lower than on the Great Barrier Reef. Nevertheless, mass spawning by genus *Acropora*, which is the main constituent of the coral communities on the southern reefs, is still highly synchronized both within and between species and the number of participants is quite large compared to other genera. Yet, it is still difficult to predict the exact date of mass spawning; it varies considerably, some years it occurs a few days before full moon and in other years 7-8 days after full moon. It is speculated that some cues, other than the lunar cycle, affects the timing of coral spawning.

Spawning information on high latitude coral communities has also accumulated over the last 15 years. Tabulate coral *Acropora hyacinthus*, which are widely distributed from Yaeyama Islands in the south to mainland Japan, spawns in April to May in the Yaeyama region, May to June around Okinawa, and July to August in Kushimoto, Kii Peninsula (Misaki 2001), in the north (Photo. 1). These spawning patterns appear to follow sea surface temperatures that progressively increase toward the north with the on coming summer. Interestingly, spawning of this species has been observed in August in the Ogasawara Islands (Inaba 2003), although its latitude is almost the same as Okinawa.

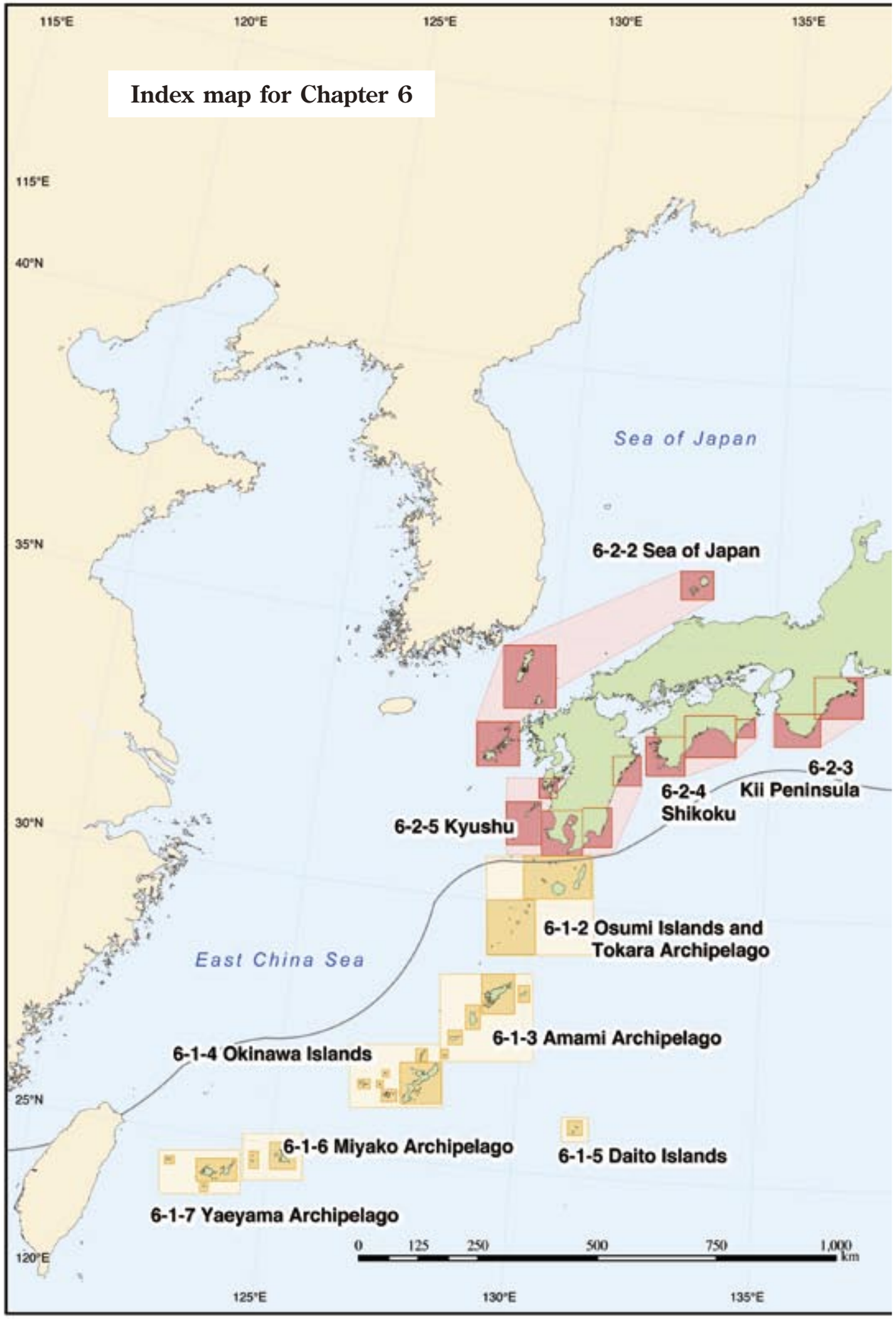
The process of sexual reproduction has recently gained considerable attention as a means of coral community recovery following such destructive affects as terrestrial soil runoff, mass bleaching events, and crown-of-thorns starfish (*Acanthaster planci*) outbreaks. There are basically two ways to restore coral communities via sexual reproduction; first, to utilize recruits and transplant them to damaged localities, and second, to release a large number of competent larvae near damaged coral communities. There has been considerable attention on *Acropora* corals recently because these corals are very vulnerable and susceptible to disturbance, but also because of their fecundity and rapid growth rates renders them potential target species for restoration projects.

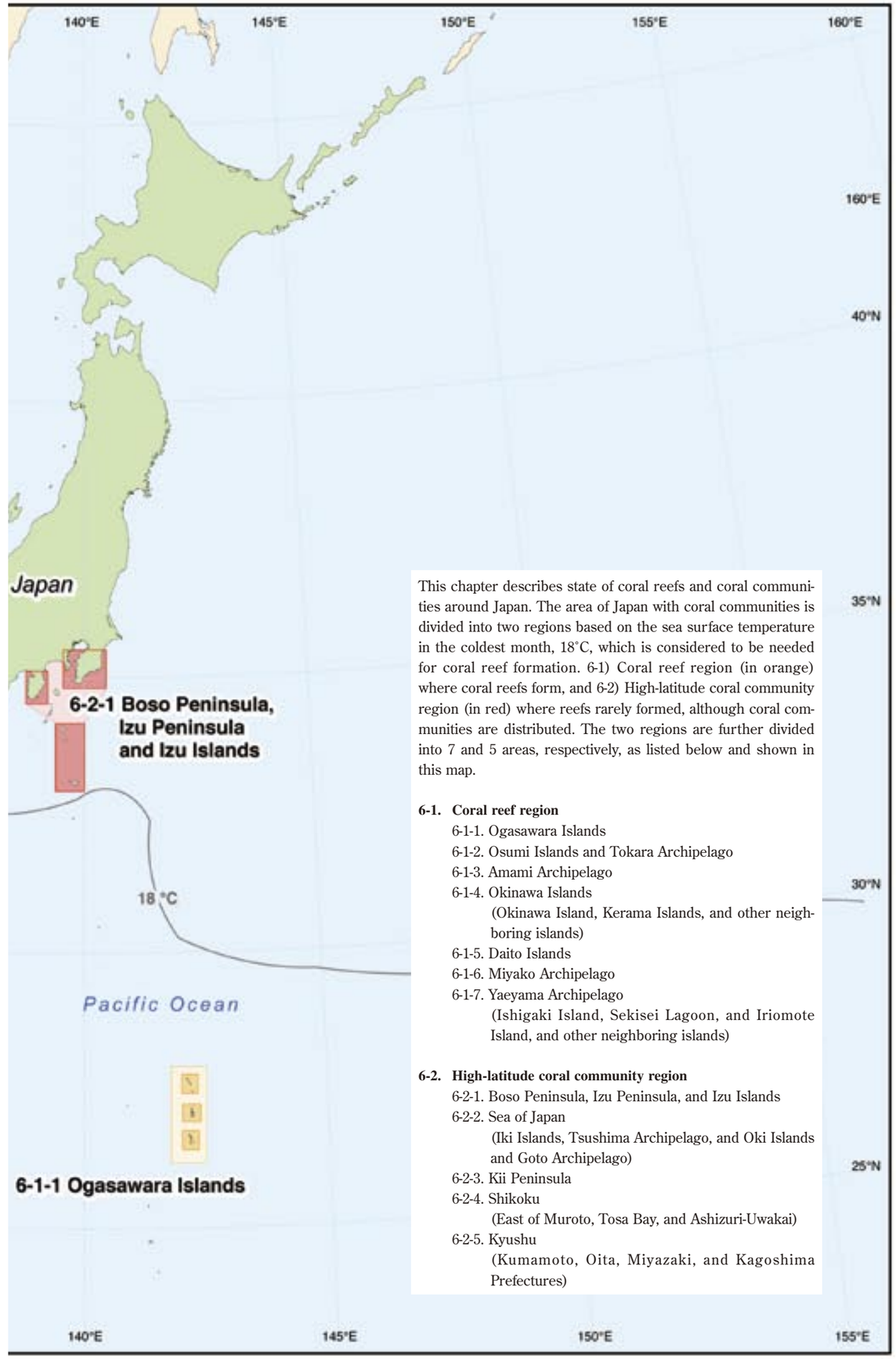
Photo. 1. Spawning of *Acropora hyacinthus*. (Photo taken by K. Shimoike)
Each particle seen in the photograph is not one egg but an egg-sperm bundle, which contains about ten eggs and millions of sperm. Each bundle is approximately 1 mm.

Chapter 6

Status of coral reefs around the country

Coral reefs in Japan develops on various environments, therefore many of the communities, to greater or lesser degree, are under influence of human activities. This can be said as a privileged environment for us coral reef researchers because it enables to conduct researches from various angles. However, the situation in recent years is not that light-hearted, suffering various disturbances. We are on the point of urgent discussion on how we should be involved with coral reefs through better understanding of its characteristics. In this chapter, various types of coral reefs and coral communities throughout the country will be explored, showing the uniqueness of each nature, their relationship with human activities including disturbances, and what measures are to be made on them. Hope that by this exploration, containing various locations and situations, will give readers a clue to think about how we should be involved with coral reefs in the future.





This chapter describes state of coral reefs and coral communities around Japan. The area of Japan with coral communities is divided into two regions based on the sea surface temperature in the coldest month, 18°C, which is considered to be needed for coral reef formation. 6-1) Coral reef region (in orange) where coral reefs form, and 6-2) High-latitude coral community region (in red) where reefs rarely formed, although coral communities are distributed. The two regions are further divided into 7 and 5 areas, respectively, as listed below and shown in this map.

6-1. Coral reef region

- 6-1-1. Ogasawara Islands
- 6-1-2. Osumi Islands and Tokara Archipelago
- 6-1-3. Amami Archipelago
- 6-1-4. Okinawa Islands
  (Okinawa Island, Kerama Islands, and other neighboring islands)
- 6-1-5. Daito Islands
- 6-1-6. Miyako Archipelago
- 6-1-7. Yaeyama Archipelago
  (Ishigaki Island, Sekisei Lagoon, and Iriomote Island, and other neighboring islands)

6-2. High-latitude coral community region

- 6-2-1. Boso Peninsula, Izu Peninsula, and Izu Islands
- 6-2-2. Sea of Japan
  (Iki Islands, Tsushima Archipelago, and Oki Islands and Goto Archipelago)
- 6-2-3. Kii Peninsula
- 6-2-4. Shikoku
  (East of Muroto, Tosa Bay, and Ashizuri-Uwakai)
- 6-2-5. Kyushu
  (Kumamoto, Oita, Miyazaki, and Kagoshima Prefectures)

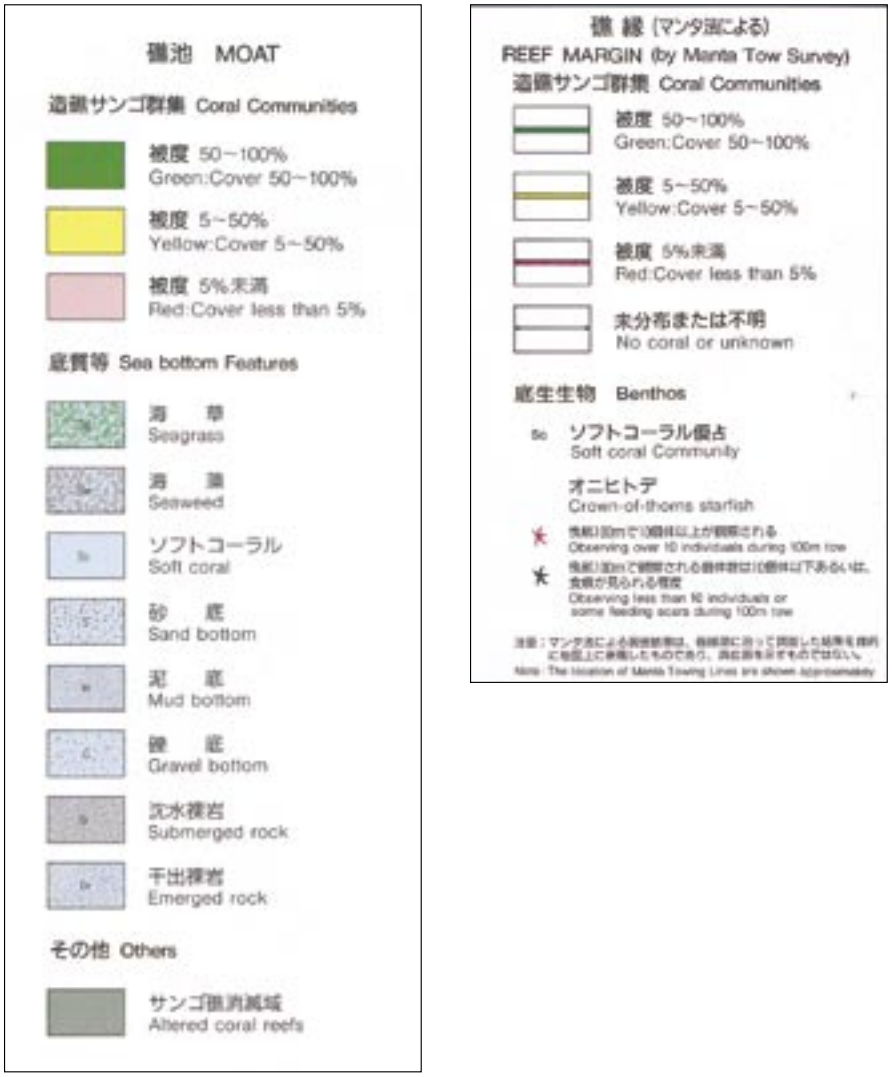


Fig. 1. Legend for the coral distribution map of the Coral reef region.

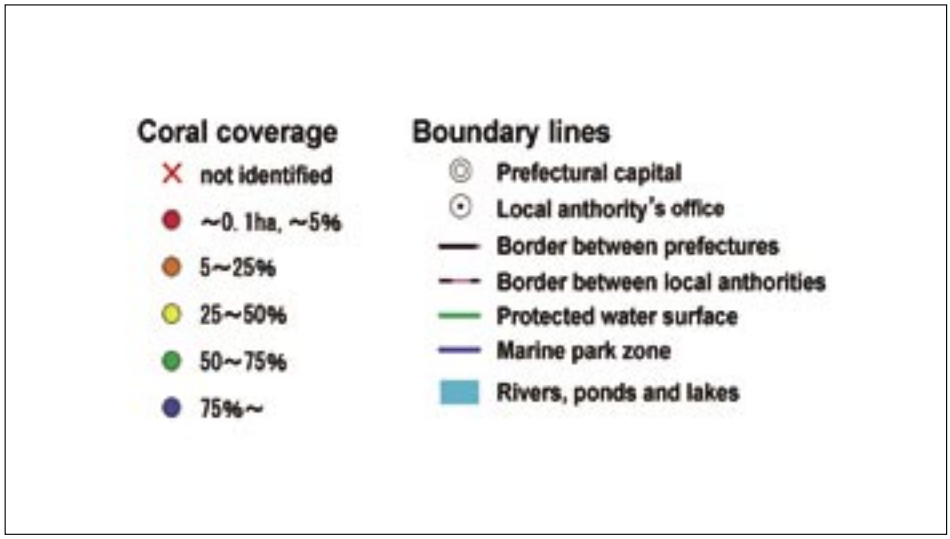


Fig. 2. Legend for the coral distribution map of the High-latitude coral community region.

In each area, general information is shown in the first two (or four) pages with the base maps, followed by detailed information written by scientists and researchers who are familiar with the area.

The general information includes coral distribution, meteorological condition, human population, and protected areas with their number, along with the base maps that show coral distribution and the location of protected areas. The legends for the maps are indicated in Figs. 1 and 2. Detailed statistics such as the number of tourists and the transition of fish catch are listed at the end of the book as Appendix 1.

The detailed information basically includes 1) Corals and coral reefs, 2) Situation of usages, 3) Threats and disturbances, 4) Monitoring, 5) Conservation, and 6) Necessary measures.

Source for the general information

Maps

The base maps of the Coral reef region are from the Marine Biotic Environment Survey (1989–1992) in the 4th National Survey on the Natural Environment (Nature Conservation Bureau, Environment Agency 1994), while the maps for the High-latitude coral community region are newly drawn for this book based on the data from the Marine Biotic Environment Survey.

Coral distribution

Coral distribution data is cited from the 4th National Survey on the Natural Environment (Nature Conservation Bureau, Environment Agency 1994). The survey was undertaken in 15 prefectures and one metropolis (Okinawa, Kagoshima, Miyazaki, Kumamoto, Oita, Nagasaki, Kochi, Ehime, Tokushima, Shimane, Wakayama, Mie, Shizuoka, Kanagawa, Tokyo and Chiba), where hermatypic corals are distributed (see index map in the previous page).

In the Coral reef region, except for Ogasawara, coverage of coral communities on reef flats were estimated by color aerial photography, and total length of the reef edge and colony morphologies was accessed by the manta tow method. In the High-latitude coral community region and in Ogasawara, the location of coral communities and the total community coverage were described only at the sites with > 5 % coral cover and > 0.1-ha area of coral communities.

Meteorological condition

All the meteorological data are from the Japan Meteorological Agency. Annual average (during 1971–2000) of the air temperature, precipitation and seawater temperature at each area are indicated.

Human population

The population data are based on the national census (in fiscal 2000).

Protected areas

Natural Parks, some of which have the Marine Park (MP) Zones in it, Nature Conservation Areas, and Protected Waters are indicated.

6-1-1 Ogasawara Islands
(Map 6-1-1)

Province: Metropolis of Tokyo **Location:** ca. 1,000 km south off the Tokyo urban center **Features:** Consists of some 30 islands (including Mukojima, Chichijima and Hahajima Archipelago). Chichijima and Hahajima are the only manned island. Okinotorishima (Is.) locates at southern most and Minamitorishima (Is.) at eastern most of Japanese territory **Population:** ca. 3,000 **Air temperature:** 23.0˚C (annual average, at Chichijima) **Seawater temperature :** 24.8˚C (annual average, at east off Hahajima) **Precipitation:** 1,276.8 mm (annual average, at Chihijima) **Total area of coral communities:** 456.0 ha **Protected areas:** Minami Iwojima Wildness Areas: whole Minami Iwojima (Is.); Ogasawara National Park: whole islands of Mukojima, Chichijima and Hahajima Archipelago as special zones, and their coastal areas (~1 km) for ordinary zones; Ogasawara Marine Park Zone: in Chichijima and Hahajima Archipelago.

＊“号”on this map means“site”.

6-1-1-③

＊“号”on this map means“site”.

Ogasawara Islands

(Maps 6-1-1-①～③)

Makoto Inaba

1 Corals and coral reefs

Ogasawara Arcipelago

1. Geographical features

The Ogasawara Archiperago ware formed by submarine volcanic activities in the first half of the Tertiary period (about 50 million years ago). Shortly after the formation of the islands there was a widely distributed shallow zone that included some well-developed coral reefs, judging by the fossils and the accumulated strata. Ancient influences are apparent in the drowned karst topography of Minamijima (Is.), the karst topography of the Sekimon area of Hahajima (Is.), and the fossil of extinct foraminifera, *Nummulites boniensis*, found on Miyukinohama, Hahajima (Kaizuka 1979).

Discontinuous apron-like reefs surround Ogasawara Archipelago, but their size is locality dependent. The topographic features of only three of these reefs have been thoroughly assessed at Nagasaki, Tatsuminishi, and Kitahatsune beach on Chichijima (Is.) (Nakai *et al.* 1988). Clearly, the wave-eroded shelves that surround the islands and the existing coral reef features (< 20 m) were formed through the Holocene (Wada *et al.* 1979).

2. Coral distribution

Approximately 200 species of hermatypic corals (here after, corals) are reported for the Ogasawara archipelago (Tachikawa *et al.* 1991). Information on coral community structure and distribution are extremely limited, except for some parts of Chichijima. The main coral areas include Futami and Tatsumi Bay, Chichijima, the coast facing strait and Takinoura Bay, on Anijima (Is.), and Higashi and Kita Port on Hahajima (Inaba 2003).

Acropora (staghorn and tabulate) colonies are relatively scarce, yet massive and encrusting coral colonies are plentiful (Fig. 1). At localities were coral cover is high, the following coral species are dominant: *Porites lutea*, *Galaxea fascicularis*, *Lobophyllia hemprichii*, *Platygyra deadarea*, and *Cyphastrea* spp. Among the *Acropora*, *Acropora florida*, encrusting morphs of *A. gemmifera*, and tabulate *A. hyacinthus* are common. Branching corals,

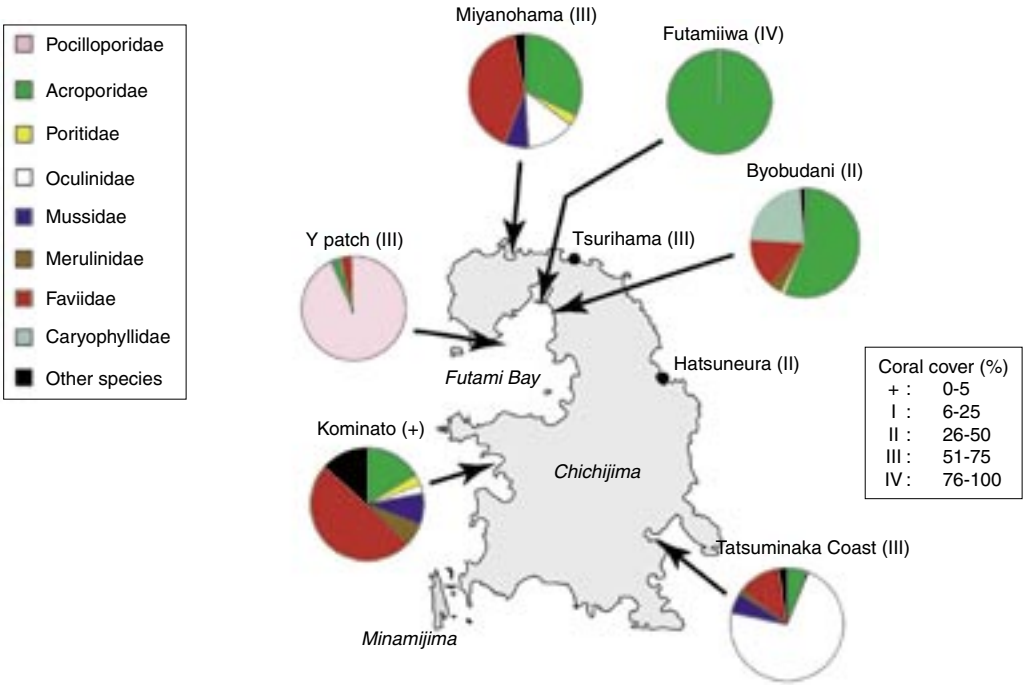


Fig. 1. Coral community composition and hermatypic coral coverage on Chichijima (Is.). The number in bracket indicates mean coral cover of the area (from Inamba 2003).

such as *A. formosa*, are found in Futami Bay, Chichijima (Inaba 2003).

Well developed reefs supporting extensive coral communities are evident on Hahajima, especially in the western bays. Coral community structures are similar to those on Chichijima, however *Acropora donei* (identified by Wallace 1999), which is rarely seen in Chichijima is prolific on Hahajima.

Along the sheer cliffs of Chichijima and Hahajima, reef development is poor and coral communities are sparse. Small encrusting colonies inhabit the slopes and coral coverage is only 0–10 % (Nature Conservation Bureau, Environment Agency 1994). Most of the coral colonies are small encrusting mussids and faviids.

3. Water quality and physical environment

While the Ogasawara Archipelago are not directly influenced by the Kuroshio Current, the regional and local hydrodynamic patterns have received little attention and are largely unknown.

The surface water temperatures range from 19.0 to 28.8 °C (Futami Bay) and average of salinity is 34.8 PSU (according to Tokyo Metropolitan Government Ogasawara Fisheries Research Center) – the amount of nutrient is equivalent to other subtropics seas (Ogasawara Village of Tokyo 2002).

There are a few rivers that have steady discharge on these islands, but the Yatsuse and Otaki rivers of Chichijima have comparatively large amount of flow.

4. Notable species and ecosystems

About 1,000 fish species have been reported for the Ogasawara Archipelago, which originate both from the north and south (Randall *et al.* 1988). Several researchers have been compiled species checklists of marine invertebrates, especially on shellfish, crustaceans, sea urchins, and polychaetes (for example, Fukuda 1995), but information on other taxa is unknown, therefore the concept of introduced species is problematic.

There are no mangrove forests on the Ogasawara Archipelago, and macroalgae coverage is extremely low. In recent years, however, macroalgae have increased especially *Sargassum duplicatum* and *Dictyota spinulosa*. *Hydroclatharus clathratus* are now found year round with coral assemblages, which used to disappear in summer.

The Volcanic Islands, and Okinotorishima and Minamitorishima (Marcus)

1. Geographical features

The Volcanic Islands (Kitaiwojima, Iwojima and Minamiiwojima) were formed by submarine volcano activities in the Quaternary Era. Kitaiwojima has a fringing-like reef, which is on a wave-cut platform made of bedrock, supporting only sparse coral communities (Kikuchi *et al.* 1980). Around Iwojima and Minamiiwojima, there are wave-eroded platforms at 10-15 m, but no coral reef features (Kaizuka *et al.* 1981).

Okinotorishima (Is.) is a platform reef (9.44 km^2) formed in the last interglacial period. While the reef does not emerge at low-spring tides, there are two rocks that Minamitorishima (Is.) (1.51 km^2) is composed of karst that formed prior to the last interglacial period and a emerged table reef that formed in the last interglacial period. Modern fringing reefs develop around the island.

2. Coral distribution

The coral community on Kitaiwojima is extremely sparse, only supporting small massive colonies, except along the east coast where some massive *Porites* spp. communities are evident (Nishimura *et al.* 1988). On Iwojima the corals are mainly *Pocillopora* colonies along on the cliff slopes and rocky promontories, which is also the case in eastern Kangokuiwa. In contrast, the southwestern and northwestern coasts of Minamiiwojima support more diverse communities (Tokyo Fisheries Experiment Station 1994).

Kurata (1997) suggested that the steady influence of high waves reduces coral community diversity and coverage in Okinotorishima, but these speculations are not verified. Minamitorishima appears to support well developed fringing reefs but there is no detailed information available (Ogasawara Marine Station, Tokyo Metropolitan Goverment 1995).

3. Others

Except for some data from fisheries resources, information is extremely limited with regard to the physical environmental characteristics of these islands (Tokyo Metropolitan Fisheries Experiment Station 1994).

2 Situation of usages

1. Tourisum

There are 30 tourism businesses on Chichijima and 3 on Hahajima. Activities include scuba diving, swimming with dolphins, and whale-watching tours. In popular areas, mooring buoys have recently increased to reduce damage to corals from boat anchors. Snorkeling from beaches, sea kayaking tours and water skiing are also popular.

2. Fishery

The Fishery Cooperatives at Chichijima and Hahajima are mandatory for all fishers. These same fishers also undertake fishing expeditions (with tourists):

- Fisheries: Bottom line fishing (ruby snapper and groupers), Long line fishing (swordfish and bigeye tuna), trolling (saury pike and Spanish mackerel), stick-held dip net fishing (mackerel scad), gill net fishing (flying fish), spiny lobsters fishing, and green sea turtle fishing.
- Mariculture: Small cultivation (striped jack, red sea breams, amberjacks, groupers, and tunas).

3. Others

Recently, the salt industry, which dries out coastal seawater, is gaining local prominence as a viable business.

3 Threats and disturbances

1. Crown-of-thorns starfish

Crown-of-thorns starfish (*Acanthaster planci*) have been found on Chichijima (Kurata 1984), but not since 1994 (Tachikawa, personal communication). There have been no records of outbreaks in the past and it appears that their density is low in the region.

2. Bleaching

Minimal bleaching and mortality was reported in 1998 on Chichijima and Hahajima. Yet, in September 2003, a mass coral bleaching event was evident at Hahajima and remained evident until November 2003 (at the time of this reporting). Many *A. donei*, one of the dominant coral species, died in 2003 – while *Porites* colonies recovered. In other regions, bleaching has been minimal (Inaba, in prep.).

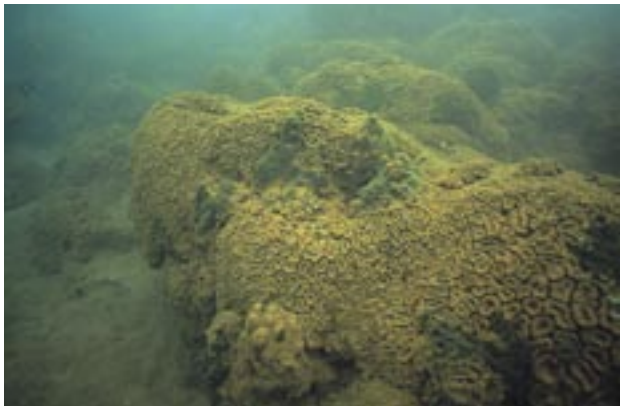


Photo. 1. Dead colonies of *Lobophylla hemprichii* by red soil influx in Fukuro Bay, Nakodojima (Is.).

3. Sedimentation

Because of the open nature of most reefs, red soil that runs of the land rarely accumulates and is rapidly diluted, except in Futami Bay, Kopepe Beach (Chichijima), and Fukuro Bay (Nakodojima), which has led to some reef destruction. In Fukuro Bay, which supported well developed reefs up until the 1970s, has accumulated some 3 m of red soil. Red soil runoff has supposedly led to the death of many *Lobophyllia hemprichii* colonies that were prolific in the bay (Photo. 1) (Inaba and Horikoshi 2002). Red soil runoff stems from cleared lands, primarily farmland and road construction. Red soil runoff on Nakodojima is thought to stem from goats clearing native vegetation.

4. Development

Higashi Port, on Hahajima, is thought to have once supported well developed coral communities that have disappeared through harbor development. But there have been no studies associated with this development project.

5. Others

There is recent evidence of coral mortality on Chichijima, but the cause is uncertain. At the same time, the macroalgae *Hydroclatharus* and *Sargassum* have increased. This tendency may be related to the thermal stress anomalies in 1998 and 2003, but cause-and-effect relationships are unclear. The current status of the Volcanic Islands, Minamitorishima and Okinotorishima remain mostly uncertain.

4 Monitoring

Monitoring on the Ogasawara Islands has been fragmen-

tary using a diverse array of techniques (e.g., Kurata *et al.* 1969; Nature Conservation Bureau Environment Agency 1999b; Inaba 2003). Moreover, monitoring for *A. planci* and bleaching of corals has not been systematic. Clearly a monitoring program is necessary using a rigorous method. 'Reefcheck' has been conducted on Hahajima since 1999 and on Chichijima since 2002.

5 Conservation

The Tokyo Metropolitan Government has conducted a vegetation recovery project since 1994, including wild goat extermination (completed in 1999), soil detainment, and vegetation recovery. However, the conditions in the abovementioned bays have not changed (Ogawara Branch Office, Tokyo Metropolitan Government 2003). There has been no preventive action against red soil run-off on Chichijima and Hahajima.

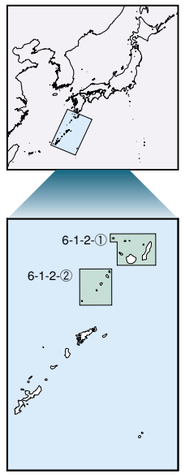
6 Necessary measures

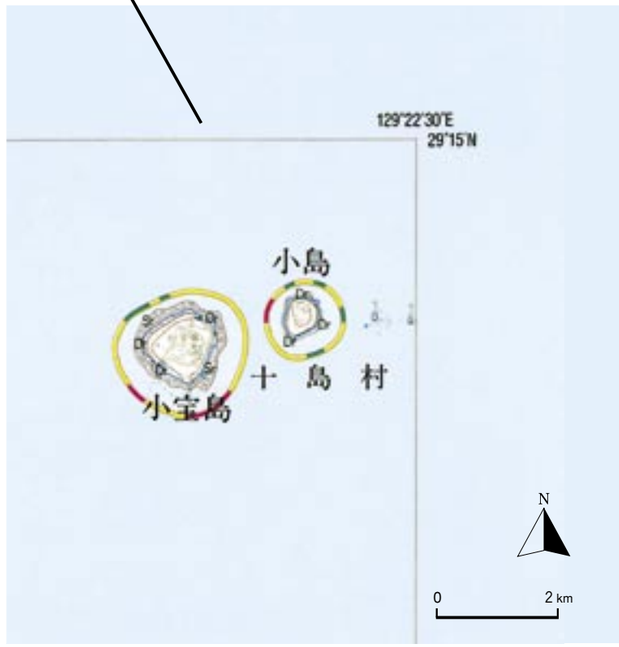
The Ogasawara Islands are isolated from other coral reef regions of Japan. Ecological research on these islands has just begun. Some serious bleaching damage has been reported regarding on Hahajima in 2003, and red soil erosion is common on Nakodojima. The decline in corals and concomitant increase in macroalgae due to unknown reasons are abserved.

6-1-2 Osumi Islands and Tokara Archipelago
(Map 6-1-2)

Province: Kagoshima Prefecture **Location:** Osumi Islands: ca. 100 km south off Kagoshima City, including Tanegashima (Is.), Yakushima (Is.), Kuchinoerabujima (Is.) and Magejima (Is.); Tokara Archipelago: Island chain of 12 islands stretching for ca. 160 km between Yakushima and Amami Oshima (Is.) **Air temperature:** 19.2˚C (annual average, at Yakushima) **Seawater temperature:** 24.3˚C (annual average, north off Yakushima **Precipitation:** 4,358.8 mm (annual average, at Yakushima) **Total area of coral communities:** 118.0 ha **Total length of reef edge:** 19km (around Takarajima, Kodakarajima, and Koshima) **Protected areas:** Kirishima-Yaku National Park: 44% of Yakushima (20,989 ha); Yakushima Wildness Area: 1,219 ha on Yakushima; World Natural Heritage site: 10,747 ha (designated in 1993) on Yakushima; Kurio Marine Park Zone in Yakushima.

＊“号” on this map means “site”.





Osumi Islands and Tokara Archipelago

(Maps 6-1-2-①, ②)

Tatsuo Nakai, Satoshi Nojima

1 Corals and coral reefs

1. Geographical features

The most outstanding feature of the region that includes the Osumi Islands and the Tokara Archipelago is that it is located near the northern limits of coral reef distribution. Figure 1 shows the distribution of coral reefs in this region.

The Osumi Islands comprise Tanegashima, Yakushima, Kuchinoerabujima, and Mageshima, and sometimes include Takeshima, Iwojima, and Kuroshima. Iwojima and Kuchinoerabujima are volcanic islands along the Kirishima volcanic belt, and there is an evidence of current volcanic activity. Saito *et al.* (1980) reported that the line along Tanegashima, Mageshima, and Takeshima represents the northern limit of coral reef development, and Nakai (1990) suggested that the northern limit lies near Tanegashima. Yamano *et al*. (2001) identified a coral reef at Iki Island (33°48' N) to be located in 350 km north from Tanegashima/Yakushima area. However, for reasons of the following, it is thought that there is some limiting line on coral reef distribution in this area. One of the reason is that there is no coral reefs between Iki Island and Tanegashima/Yakushima area, and there is discontinuity in distribution. Another reason is that main coral species forming reefs are different between Iki Island and the areas of south of Tanegashima/Yakushima.

The coral reefs in this region are composed of reef limestone covering flat shore platforms; this reef limestone layer can be up to several meters thick. The reef flat south of Tanegashima appears to be about 1 km wide, which is a result of the wide shore platform. Moreover, speaking two-dimensionally, coral reefs tend to develop in indented areas or on the lee side of islands rather than in high-energy, wave-exposed areas (Fig. 2). Such characteristics can be observed in the northern Tokara Archipelago, In addition, reef development on Tanegashima is limited to the eastern coast, and continuous development of reefs is not readily observable. On Yakushima, hermatypic coral communities can be observed in a few places around the island, and coral reefs with well-defined reef flats and reef slopes are limited to the north of the island (Nakai and Wada 1983). Nakata (1978) reported the existence of Holocene coral reefs in Anbou in southeastern Yakushima.

The Tokara Archipelago consists of 12 small islands (the largest of which, Nakanoshima, is only 34 km^2) that are scattered over some 160 km between Tanegashima, Yakushima, and Amami Oshima. Modern coral reefs can be seen on six of these islands (Kuchinoshima, Nakanoshima, Hirashima, Kogajyajima, Kodakarajima, and Takarajima). Reefs are underdeveloped on the other islands as a result of volcanic activity; these new volcanic islands have been active from the late Pleistocene of the Quaternary to the present. Half of Kuchinoshima and half of Nakanoshima belong in this category. Coral reefs in the Tokara Archipelago are well developed in terms of reef continuity as compared to both northern and southern islands, including Tanegashima and Yakushima to the north and Amami Oshima to the south. For example, 80–90 % of the coastlines of Hirashima, Kodakarajima, and Takarajima are surrounded by coral reefs. This is thought to be a result of the flow route of the warm Kuroshio Current.

Figure 2 depicts a model illustrating the latitudinal transition of coral reefs near the geographical limits of reef development, based on an analysis of the two-dimensional developmental state of the reefs from Tanegashima and Yakushima through the Tokara Archipelago down to Yoron Island (Nakai 1990). Changes in sea level and reef development are discussed based on the fact that some uplifted coral reefs of the late Holocene were discovered at Kuchinoshima and Nakanoshima, and late Pleistocene and late Holocene uplifted reefs were found at Kodakarajima and Takarajima (e.g., Koba *et al.* 1979). Moreover, the foraminiferan *Baculogypsina sphaerulea* was found in Kuchinoshima, Nakanoshima, Hirashima, Suwanosejima, Kodakarajima, and Takarajima; and, the composition of the sediment layer has also been examined with respect to reef development (Saito *et al.* 1980).

2. Coral distribution

One-hundred-and-fifty-one hermatypic coral (hereafter, coral) species have been confirmed in the sea around

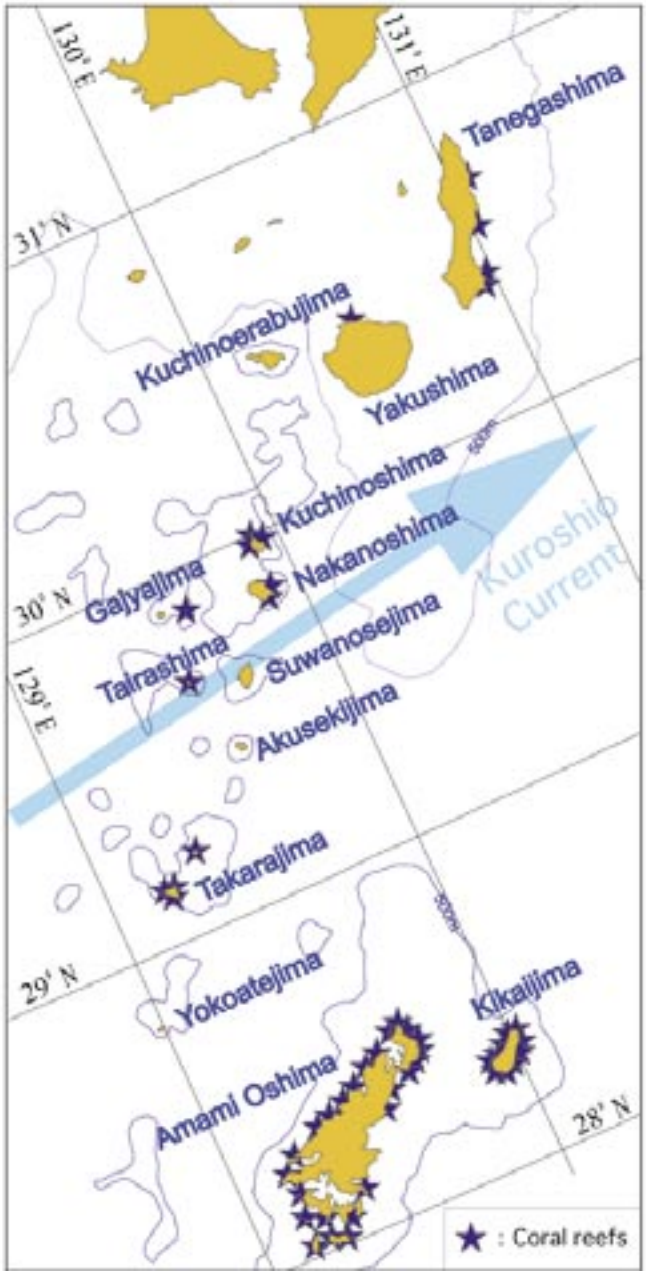


Fig. 1. Distribution of coral reefs from the Osumi Islands to Amami Oshima.

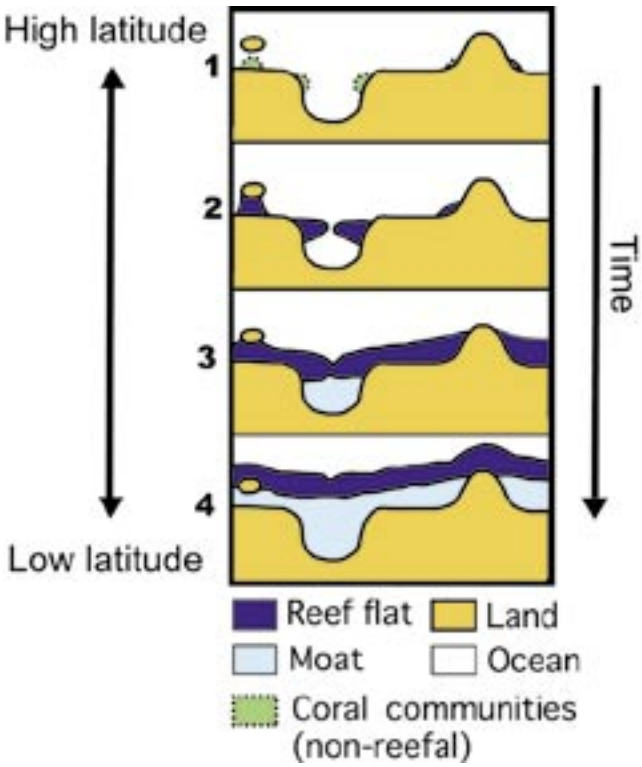


Fig. 2. Latitudinal transition model of coral reef development (partially modified from Nakai 1990).

Photo. 1. Underwater view at 20 m depth in Kurio, Tsukazaki, Yakushima (Is.).

Tanegashima (Veron 1992a, c; Nishihira and Veron 1995). 100 species from Yakushima (Investigation Group on Marine Organisms in the Coast of Yaku Island 1992; Nojima *et al.* 1992) and 68 species from Kuchinoerabujima have also been reported. The composition of coral species in Tanegashima and Yakushima is significantly different from that in Amami Oshima (Nishinira and Veron 1995). Southward along the Tokara Strait, the number of species greatly increases; coral communities of the 'southern Japan coastal region type' and the 'Okinawan type' dominate in the north and south, respectively (Fukuda *et al.* 1991). Although both types occur on Yakushima, the former type is more extensive in terms of coral cover (Investigation Group on Marine Organisms in the Coast of Yaku Island 1992; Nojima *et al.* 1992; Nojima and Yeemin 1999; Photo. 1).

In the Tokara Archipelago, the distribution of coral has been confirmed along the coastline, including an investigation of deposition (Saito *et al.* 1980). However, the identified species have not yet been organized into a comprehensive list. Tokioka (1953) identified ten coral spe-

cies (1 *Goniastrea*, 1 *Porites*, 4 *Acropora*, 1 *Psammocora*, 1 *Coeloseris*, and 2 *Pocillopora*) in Takarajima and two species (1 *Goniastrea* and 1 *Acropora*) in Nakanoshima. Hirata (1967) collected 21 major species (5 *Acropora*, 1 *Favia*, 1 *Favites*, 1 *Goniastrea*, 3 *Platygyra*, 1 *Hydnophora*, 3 *Pocillopora*, 1 *Porites*, 1 *Montipora*, 1 *Turbinaria*, 1 *Heliopora*, and 2 *Millepora*) around Takarajima and Kodakarajima. However, both surveys were fragmentary as the researchers did not use SCUBA equipment, and so systematic surveys have not been conducted in the Tokara Archipelago.

3. Water quality and physical environment

The main stream of the Kuroshio Current runs almost through the center of the Tokara Archipelago (28°–30° N latitude), from the East China Sea toward the Pacific. The mean surface water temperature during the coldest month is 18°C, which is generally considered to be the temperature limit of coral reef distribution, and the 18°C isothermal line occurs at the northern end of the Tokara Archipelago.

4. Notable species and ecosystems

Yakushima boasts one of the richest and most abundant fish fauna in Japan. In addition, sandy beaches on Yakushima represent important spawning grounds for loggerhead turtles (*Caretta caretta*).

Clear differences are evident in the distribution of terrestrial organisms between Tanegashima/Yakushima, located in the temperate zone, and Amami Oshima, located in the subtropics. The Tokara Archipelago, which is located in between, is considered the transition zone between temperate and subtropical regions. Saito *et al.* (1980) identified a discontinuous line of terrestrial organism distribution, which was termed 'Watase's Line'.

2 Situation of usages

1. Tourism

Tanegashima and Yakushima can be accessed by ferry and jetfoil from Kagoshima and by air from Kagoshima and Osaka. Yakushima is famous for its virgin forest, which has been classified as a World Heritage site; thus, many tourists visit the island. Two round trips connecting seven populated Tokara Islands and Kagoshima are offered regularly. Hundreds of people visit these islands each year, although the local population totals only 711 (each island supports 50–200 residents), and there are two to five hotels on each island. SCUBA diving and fishing (including trolling) are popular marine leisure activities.

2. Fishery

Fishing for *Haliotis diversicolor aquatilis* by skin diving and for *Spratelloides gracilis* by drift netting are common in Tanegashima, whereas fishing for *Scomber australasicus* by pole-and-line is popular in Yakushima. Yakushima boasts the top catch of *Cypselurus agoo agoo* by drift gill netting; *Renina renina* is also caught.

In the Tokara Archipelago, a handful of fishermen on each island catch *C. agoo agoo*, *Scomberomorus niphonius*, and *Katsuwonus pelamis* along the coast, and skin dive for *Panulirus japonicus*, cuttlefish, and *Turbo marmoratus*. The sea around the Tokara Archipelago is an excellent fishing ground because it intersects the path of the Kuroshio Current; thus, many fishermen, even those from remote islands, gather on these islands (e.g., Yakushima and Tanegashima).

3 Monitoring and conservation

The Yakushima Marine Organism Research Workshop, a local society, conducts surveys to monitor populations of fishes and corals. The entire Tokara Archipelago was designated a prefectural natural park for Kagoshima Prefecture in 1992. In addition, Kurio on Yakushima was designated a marine park zone. These areas are currently under active conservation and management programs.

According to a questionnaire targeted at local municipalities in Tanegashima and Yakushima concerning the 1998 coral bleaching event, the ratio of bleached to live corals was 60 % or greater off the Nishinoomote City in northern Yakushima and 20–60 % in other areas (Nature Conservation Bureau, Environment Agency 2000c). The crown-of-thorns starfish (*Acanthaster planci*) has not yet been recorded in Yakushima (Nature Conservation Bureau, Ministry of the Environment 2003d), and only one individual has been observed to date in Kuchinoerabujima (Nojima unpublished data).

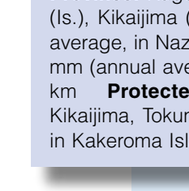
4 Necessary measures

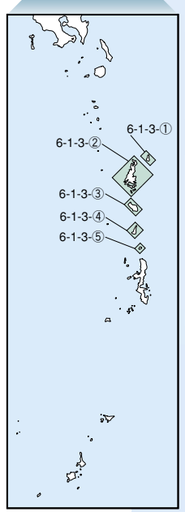
An outbreak of *A. planci* has not yet occurred in this

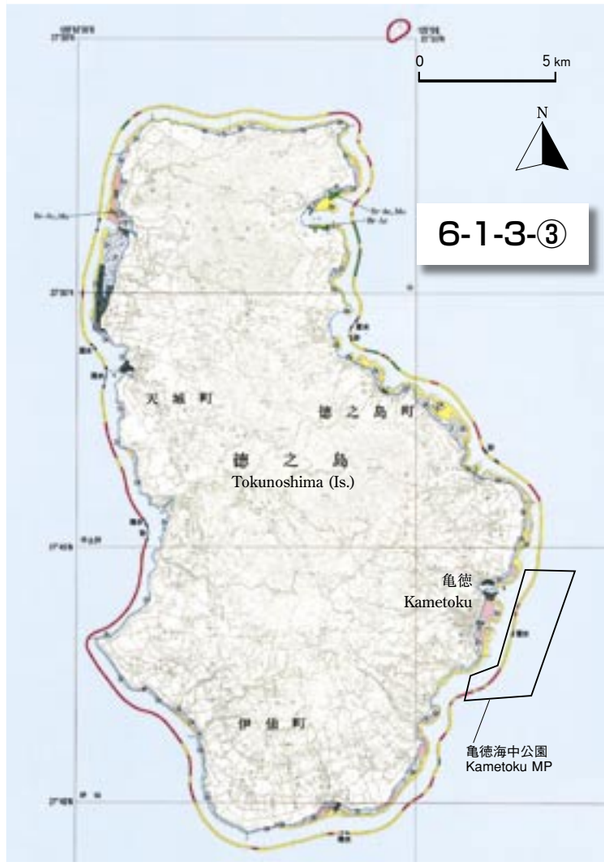
area, but *A. planci* has been recorded in the Amami Archipelago to the south. Therefore it is necessary to strengthen current monitoring efforts. Information on corals and coral reefs is lacking for the Tokara Archipelago. It may be difficult to conduct frequent monitoring considering the difficult access, but systematic surveys and monitoring on a regular basis are necessary.

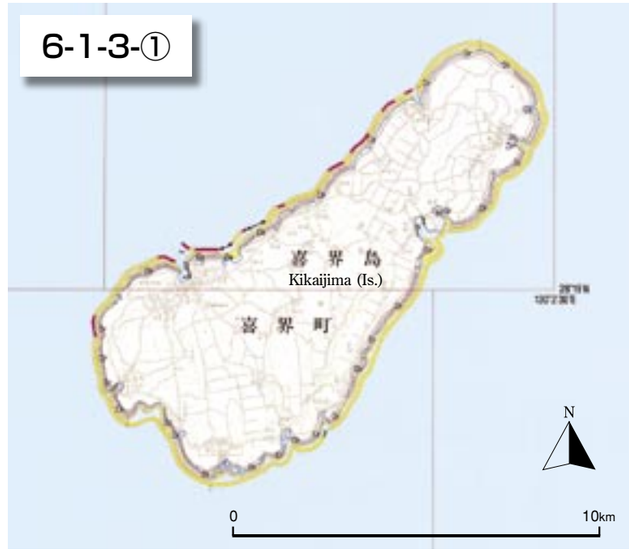
6-1-3 Amami Archipelago
(Map 6-1-3)

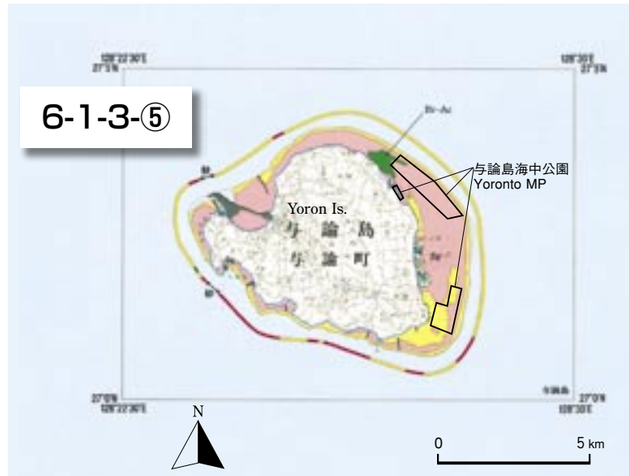
Province: Kagoshima Prefecture **Location:** ca. 400 km southwest off Kagoshima City, including Amami Oshima (Is.), Kikaijima (Is.), Tokunoshima (Is.) and Okinoerabujima (Is.) and Yoron Is. **Air temperature:** 21.5˚C (annual average, in Naze City) **Seawater temperature:** 24.5˚C (annual average, at north off Naze) **Precipitation:** 2,913.5 mm (annual average, in Naze) **Total area of coral communities:** 5951.2 ha **Total length of reef edge:** 420.3 km **Protected areas:** Amami Gunto Quasi-National Park: centering on coastal areas of Amami Oshima, Kikaijima, Tokunoshima and Okinoerabujima and Yoron Is.; Marine Park Zone: 2 zones in Amami Oshima, 1 zone in Kakeroma Island, 1 zone in Tokunoshima, and 1 zone in Yoron Island.











Amami Archipelago

(Maps 6-1-3-①～⑤)

Tatsuo Nakai, Katsuki Oki

1 Corals and coral reefs

1. Geographical features

The Amami Archipelago stretches between latitudes 27° 00' N and 28°30' N. Coral reefs at various stages of development are found throughout the islands. Reef development is extensive along the coast of the Kasari Peninsula, north of Amami Oshima Island, and off Kikaijima Island, but poor off southeastern Amami Oshima and in the Oshima Strait between Amami Oshima and Kakeroma Island (refer to Fig. 1 of 6-1-2). These differences are thought to be influenced by the Kuroshio warm current and tectonic movements. Reef development is also significant on the islands of Tokunoshima, Okinoerabu, and Yoron to the south of Amami Oshima. The reefs of Yoron Island are particularly well-developed structures with widths of over 1 km, distinct reef crests, and continuous backreef lagoons up to 3 m in depth; they representing the typical fringing reef formation that is also seen in the sowth of Okinawa Island.

This reef system is located on an uplift zone that lies along the Ryukyu Trench. On Kikaijima, Okinoerabu Island, and Yoron Island, most of the highest points are on a plateau that was originally formed under the sea. At Kikaijima, one of the world's primary regions of uplift, coral reefs that formed during the last interglacial period (ca. 130,000–120,000 years ago) have now been lifted to 200 m above sea level. This movement has been caused by plate-tectonic subduction under the Philippine Sea Plate, and the phenomenon characterizes the whole of the Ryukyu Islands. Several intensive geological surveys have been undertaken, including those of coral fossil depositions, beach rocks, and notches formed during the Quaternary (Nakta *et al*. 1978). Many drilling surveys on the Holocene coral reefs surrounding Kikaijima (Konishi *et al.* 1974; Ota *et al*. 1978) and Yoron Island (Yonekura *et al.* 1994) have also been conducted to better understand the geology and geography of the region. Consequently, sea-level change and crustal movement during the Quaternary and the developmental history of the coral reefs in this area are relatively well understood. The information gleaned from these surveys, together with data from other locations such as the Okinawa Islands, Miyako, the Yaeyama and Tokara Archipelagos, and Tanegashima Island, has also contributed to understanding the development of the Ryukyu Islands.

2. Coral distribution

Approximately 220 species of hermatypic corals (hereafter, corals) have been identified in the Amami sea area (Nishihira and Veron 1995). Well-developed communities dominated by *Acropora* were found throughout the islands until the 1998 mass-bleaching event, after which the dominant corals of the lagoon and reef crest communities shifted to *Porites* and *Favia*.

A survey commissioned by Kagoshima Prefecture and undertaken by the Kagoshima Prefecture Nature Association (1980) described the coral communities that were affected by crown-of-thorns starfish (*Acanthaster planci*) predation during the 1970s. The survey data collected included the coral distribution, the status of *A. planci*, and the extent of coral damage; the surveys were conducted in all of the marine park zones. The numbers of coral species identified at each site were: inner bay of Kasari Peninsula's east coast, 37; Surikozaki, 96; Setouchi, 83; Amami Oshima and Kametoku, 84; and Tokunoshima and Yoron Island, 71. The survey report also recorded the *A. planci* density and coral recovery status, and highlighted human impacts such as terrestrial red-soil runoff and the collection of tropical fishes for the aquarium trade. The Nature Conservation Bureau, Environment Agensy (1994) also conducted coral coverage surveys throughout all of the coral reef regions in Japan, including Kikaijima and Okinoerabu Island; however, the report of these surveys did not contain systematic survey data such as lists of the species identified.

3. Water quality and physical environment

Most of the reefs that fringe the islands are seaward facing and thus located in water that is largely oceanic. In the inner bays and straits, however, turbidity and sedimentation from the land can be observed.

4. Notable species and ecosystems

Seventy-one hectares of mangrove forests at Sumiyo in Amami Oshima have been designated as Special Protection Zones of Amami Gunto Quasi-National Park.

On Katoku Beach in Setouchi, the leatherback turtle (*Dermochelys coriacea*), an extremely rare species in Japan, was first recorded coming ashore to nest in 2002 (Kamezaki *et al*. 2003).

2 Situation of usages

1. Tourism

In the Amami Archipelago, there are about 50 dive operators around Amami Oshima, and the area is heavily used by SCUBA divers. A semi-submersible boat is operated in Naze Bay and the Oshima Strait. Sea-kayaking among the bays and straits and canoe tours among the mangroves are also popular. In addition, the coral reefs are used for shellfish harvesting and leisure fishing by local residents.

2. Fishery

The main fishery in this region is pole-and-line fishing for skipjack, tuna, grouper, and sea bream, but offshore longline fisheries and gill net, drive-in, and diving fisheries on the reefs are also important. The commercial aquaculture of kuruma prawn (*Penaeus japonicus*), ocellate puffer (*Takifugu rubripes*), red sea bream (*Chrysophrys major*), a brown algae (*Nemacystus decipiens*), and pearl oysters is also undertaken.

3 Threats and disturbances

1. Crown-of-thorns starfish

Between 1973 and 2002, a total of about 1.55 million *A. planci* were exterminated in the Amami Archipelago by the Amami Oshima Marine Park Marine Resource Conservation Association. In 1973, an *A. planci* outbreak occurred on Yoron Island, and 31 million *A. planci* were exterminated. Subsequently, the *A. planci* outbreak spread throughout the archipelago, and extermination projects extended into the marine park zones of Setouchi in 1974 and into Kasari, Surikozaki, and Kametoku in 1976. During the 1980s, nine million *A. planci* individuals were exterminated in Setouchi, after which the population was in decline until 2001, when the population again started to grow (Photo. 1).

Photo. 1. Crown-of-thorns starfish (*Acanthaster planci*) outbreak in 2002 in Amami Oshima.

2. Bleaching

A large-scale, mass-bleaching event caused by abnormally high water temperatures occurred at the end of August 1998 (Photo. 2). The *Acropora* colonies that were dominant in lagoons and on reef crests until this event almost died out. No subsequent major bleaching events have occurred, and new recruits of coral spats can now be seen, indicating that recovery of the coral communities is progressing. Coral damage from bleaching was relatively light along the southern coast of Amami Oshima, especially in the Oshima Strait, although these areas have been suffering from renewed outbreaks of *A. planci* predation since 2001.

Photo. 2. A mass-bleaching event occurred in August 1998 in Amami Oshima.

4 Monitoring

Extermination projects for *A. planci* have been conducted by the Amami Oshima Marine Park Marine Resource Conservation Association. The Association, formed in 1973, consists of the prefectural government

Photo. 3. Underwater monitoring survey on coral reefs by members of Amami Marine Museum in Naze City, Amami Oshima.

and local authorities. In addition to the extermination program, monitoring by visual census is also conducted. Reef Check surveys, using internationally standardized monitoring methods for coral reefs have been on-going at Yoron Island since 2000 and at Setouchi since 2001. Every few years since 2001, coral monitoring surveys have also been conducted by the Amami Marine Museum in Naze (Photo. 3). Six permanent survey sites, each consisting of 30 m ×50 cm belt transects, were established, and coral coverage to genus level has been monitored.

5 Conservation

1. Crown-of-thorns starfish

The countermeasures against the current outbreaks of *A. planci*, especially in Setouchi, have consisted of the establishment of two priority protection sites at Kurosaki and Ankyaba, east of the Oshima Strait. These sites have high coral coverage and are important scenic spots; intensive extermination of *A. planci* has taken place at these sites.

2. Sedimentation

Kagoshima Prefecture has established the 'Amami Region Red-clay Outflow Prevention Measures Promotion Conference', and has been offering lectures and fieldtrips. Efforts have been made to prevent red-soil runoff from public construction works, based on enterprise-specific guidelines, for example, the 'Oshima Branch Office Strategy for Soil Runoff Countermeasures' (Kagoshima Prefecture White Paper on the Environment in fiscal 2001).

3. Conservation measures in the tourism industry

Several practices have been implemented to conserve coral reefs at tourist sites. One example is the placement of mooring buoys at major dive sites by the dive operators; these alternate mooring sites prevent coral communities from anchor damage.

6 Necessary measures

In order to implement the measures necessary to prevent coral reef degradation in this district, up-to-date information on the status of regional reefs is required. It is therefore desirable that an archipelago-wide monitoring framework that extends beyond the national parks should be put into place in the near future.

Column

Living on coral reef atolls – Human induced vegetation changes

Masashi Chikamori

Natural vegetation

A coral cay, on an atoll, is rarely more than four meters above the high water line. It is always exposed to seawater spray and is occasionally inundated by seawater during storms. Plants that tolerate such conditions are few.

Rainwater rapidly infiltrates porous carbonate soil on coral reef islands and stays underground as a freshwater/brackish water lens because of the density differences of the two bodies of water, combined with hydrostatic pressure. This water is the 'water of life' for land dwelling organisms.

The plants that settle on the atoll through long distance dispersal are distributed in zones because of their differential tolerance to salinity, wind resistance, and geographical features of the ground, soil texture, and humus distribution. This article discusses plant life on a coral reef atoll, not in Japan but in the Cook Islands, to exemplify changes that may have taken place on atolls throughout the Pacific. Plants are generally distributed in concentric circles (Fig. 1).

Agroforestry

The plant landscape of an atoll changes remarkably after human settlement. When prehistoric Polynesians moved into the Pacific, they brought with them seeds and saplings of many plants, including taro, praca, and banana roots, breadfruit and coco trees, *Pandanus*, sugarcane, and other useful architectural timbers. Not all plants adjusted to the harsh atoll environment. Most introduced plants were of continental origin, and were unconditioned to high sodium, high pH, and low iron concentrations, as found on atolls. Therefore, humans implemented special protection and management strategies. At least 25 species, almost half of the 52 vascular plant species confirmed on Pukapuka Atoll, are introduced species. This shows how carefully humans worked at changing the vegetation.

People understood the micro-habits of the atoll, and cultivated plants accordingly. Residents dug up the central portion of the island, where the underground water layer was the thickest, built Taro paddy fields, and established concentrated production areas in the center. For example, breadfruit depends on underground water and is relatively intolerant to sea spray. Therefore, as in the natural situation, introduced plants are distributed in concentric circles (Fig. 1).

One of the largest features on the atoll is a sustainable agroforestry – namely coco, which tolerates a wide range of environmental conditions. Together with an active modification of the geographical features and a change in the landscaping, to fully utilize the underground water, people have elaborately managed 'useful' trees, and have attempted to protect the local wildlife – which includes many species of seabirds, sea turtles, and coconut crabs.

Having developed a system where land use and area is maximized, with highly seasonal yet productive crops, as has enabled relatively large populations of humans to dwell on Pacific atolls. The spectacle of today's atoll, where coco forests often cover the entire island, began after copra became an important monetary crop.

Copra and the canned food economy

A big change in atoll vegetation in the Pacific Ocean appeared after copra became an important industry. There was probably a gradual shift in land use and labor toward copra production, which lead, eventually, to copra monoculture. The expansion of coco forests lead to loss of other plant species, particularly beach vegetation that people had planted to protect the coastline and prevent erosion.

Decline of the copra economy

In the 1980s, the price of copra declined and transportation costs increased. As a result, copra production declined and the ill-maintained coco forests often became overcrowded. The high tree densities put further strains on the limited resources, which in turn resulted in reduced coconut (fruit) production. The collapse of the copra industry has lead to poor forest management. Young people, who in the past were actively involved in the copra industry searched for opportunities elsewhere, often leaving the atoll. Alternative income sources involve, remittance from workers that have left the atoll, international aid, and, or, support from an old suzerain. Authorities, or bureaucrats, engaged in aid generation have often replaced traditional leaders. Agroforestry management has become difficult because of the change in human population structure, progressive depopulation, and a change in the social politics. As a result the vegetation on many Pacific atolls is devastated. The plants that were carefully protected and managed for sustenance have withered, and diversity has been lost. Furthermore, the information and knowledge on agroforestry, accumulated and exchanged through culture over time, has being lost. The changes in vegetation, loss of diversity, and loss of coastlines, have changed in tandem with a loss of native languages.

(Partly rewroted from Chikamori (2001). Refer to the text for details.)

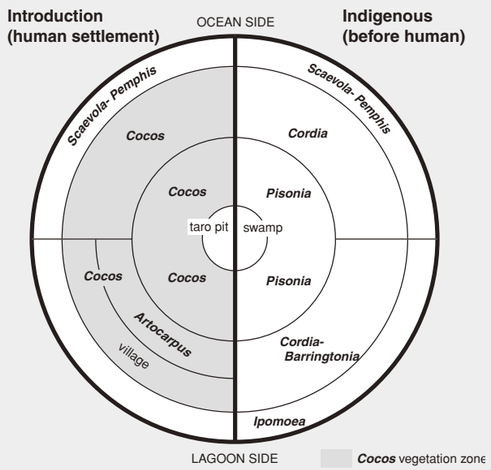
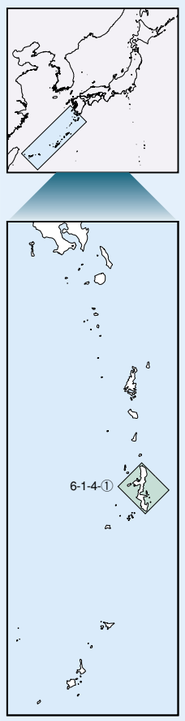


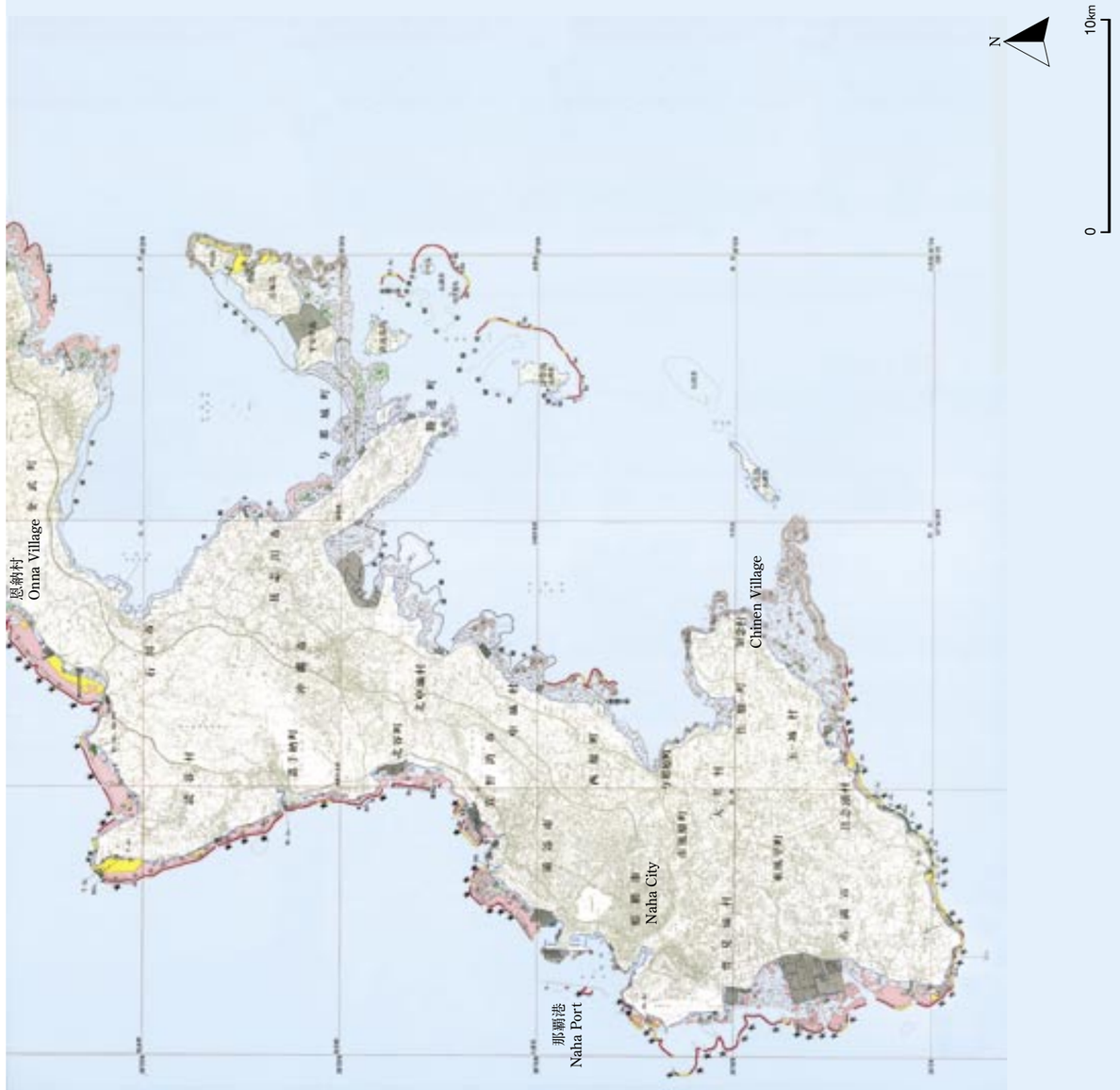
Fig. 1. Pattern of the vegetation distribution of a cay of Pukapuka Atoll. The upper portion of the figure represents the open sea, and the lower portion represents the lagoon. The horizontal axis shows the passage of time. The right portion shows the natural vegetation before human settlement, and the left portion shows present vegetation, artificially modified by human settlement. The half tones show the growing range of coco.

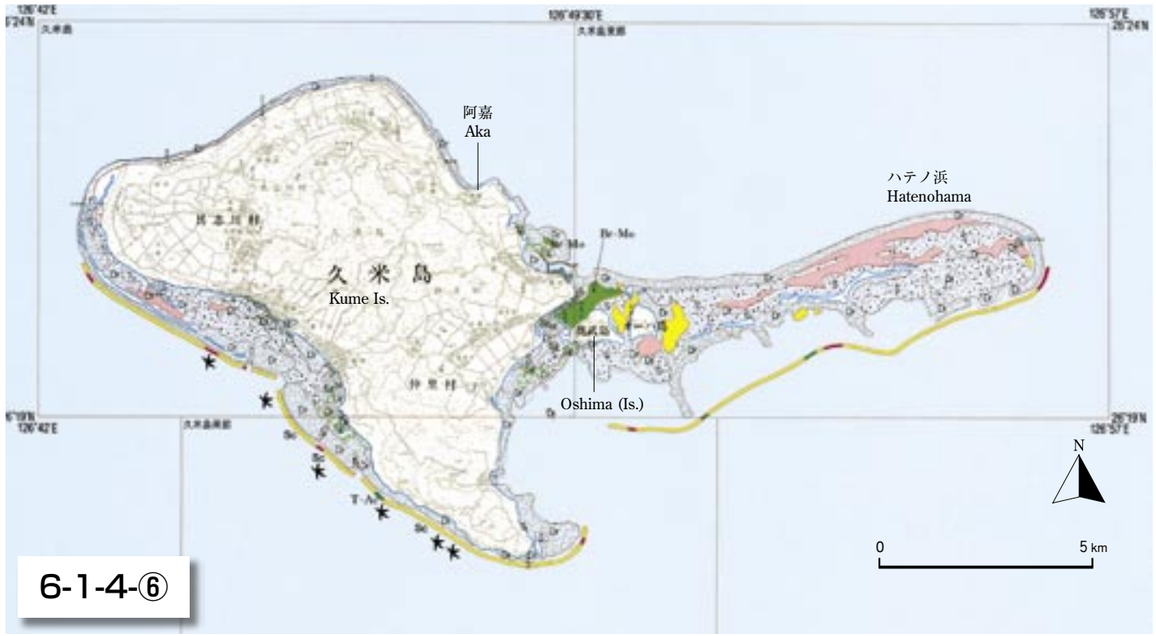
6-1-4 Okinawa Islands
(Map 6-1-4)

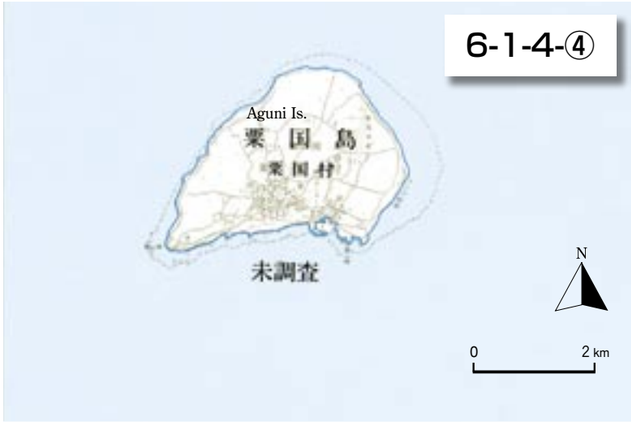
Province: Okinawa Prefecture **Location:** Okinawa Is. and neighboring islands, including; Iheya, Izena, Aguni, Tonaki, Kume Is., and Kerama Islands. **Air temperature:** 22.7˚C (annual average, in Naha City) **Seawater temperature:** 25.0˚C (annual average, at off Naha) **Precipitation:** 2,036.7 mm (annual average, in Naha) **Total area of coral communities:** 6,980 ha **Total length of reef edge:** 382.2 km **Protected areas:** Okinawa Kaigan Quasi-National Park: centering on west coast of Okinawa Is. and whole Kerama Islands; Marine Park Zones: 1 zone in Okinawa Island and 2 zones in Kerama Islands.

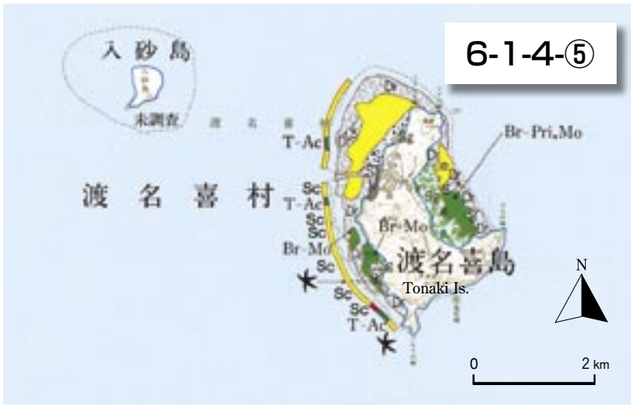
6-1-4-①



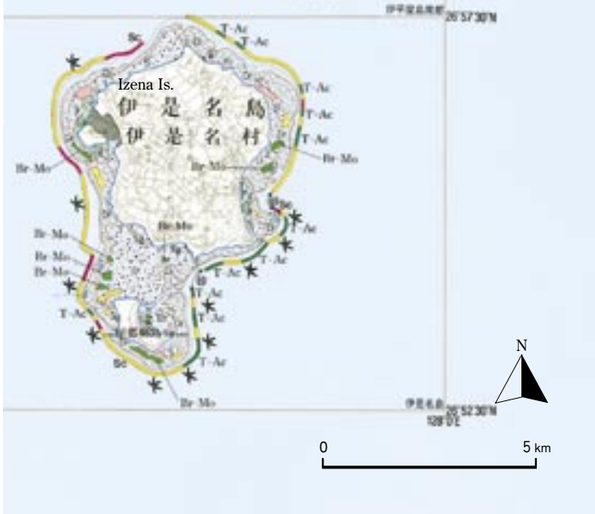


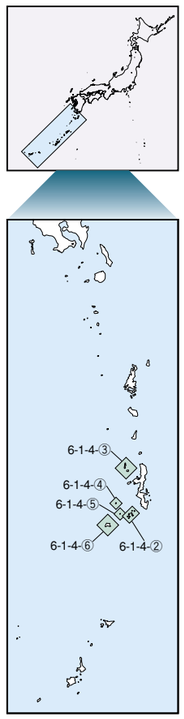

6-1-4-⑥
阿嘉
Aka
ハテノ浜
Hatenohama
久米島
Kume Is.
Oshima (Is.)
N
0
5 km

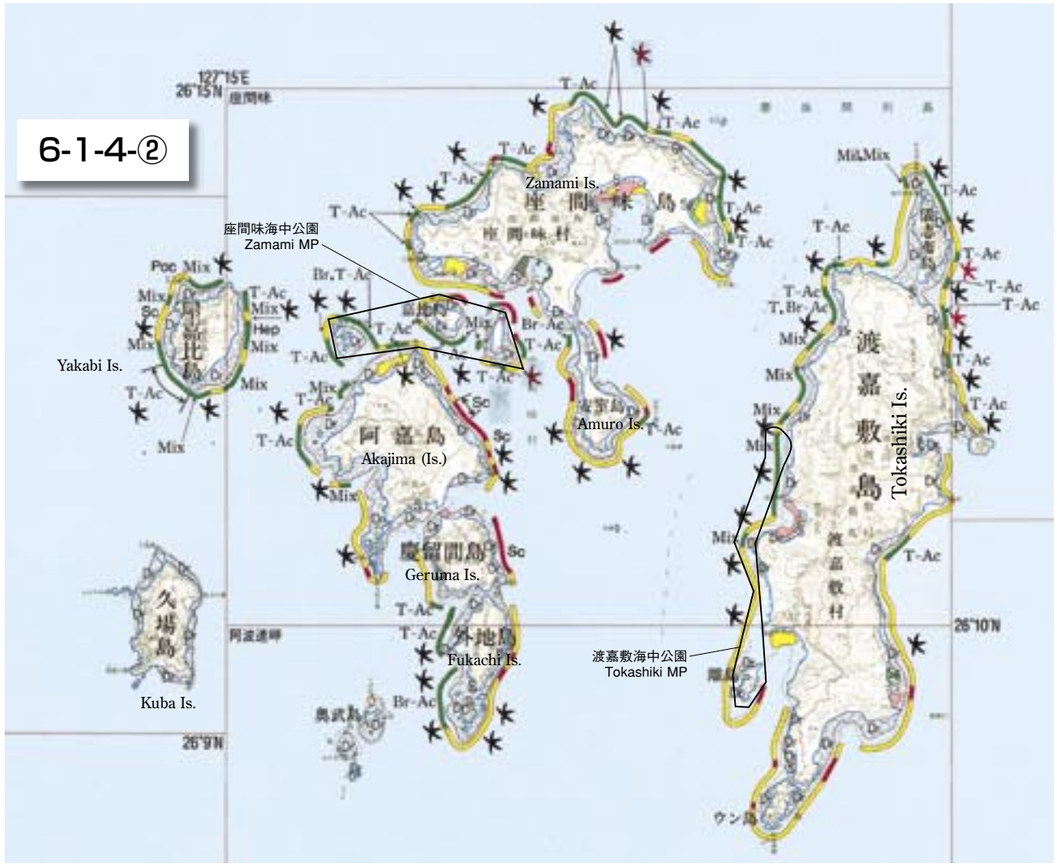

6-1-4-④
Aguni Is.
粟国島
粟国村
未調査
N
0
2 km

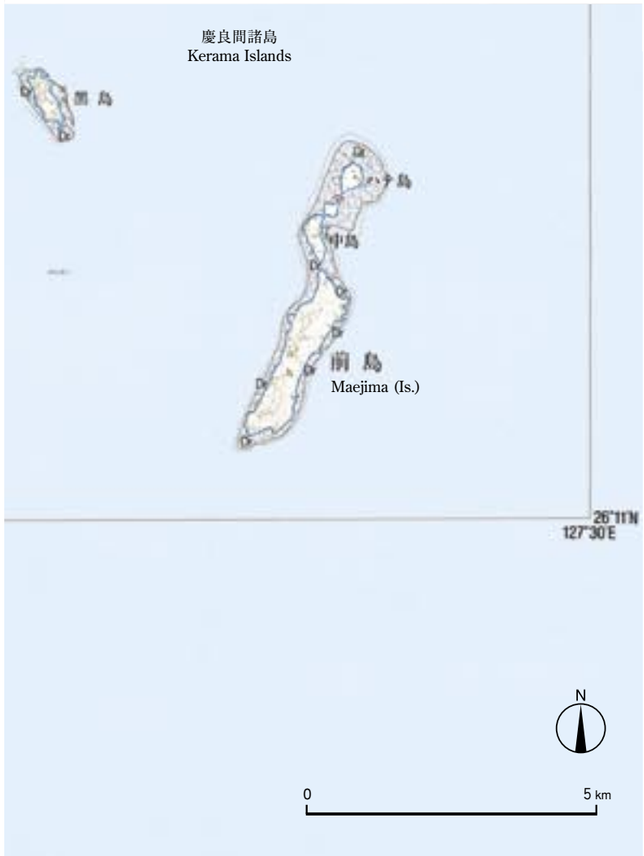

6-1-4-⑤
入砂島
未調査
渡名喜村
Br-Pri,Mo
Br-Mo
渡名喜島
Tonaki Is.
N
0
2 km

6-1-4-③
伊平屋島
Iheya Is.
伊平屋村
Gushikawa Is.


Izena Is.
伊是名島
伊是名村
N
0
5 km


6-1-4-③
6-1-4-④
6-1-4-⑤
6-1-4-⑥
6-1-4-②


6-1-4-②
127°15'E
26°15'N
座間味
Zamami Is.
座間味村
座間味海中公園
Zamami MP
Yakabi Is.
阿嘉島
Akajima (Is.)
Amuro Is.
慶留間島
Geruma Is.
外地島
Fukachi Is.
久場島
Kuba Is.
渡嘉敷島
Tokashiki Is.
渡嘉敷海中公園
Tokashiki MP
26°9'N
26°10'N


慶良間諸島
Kerama Islands
黒島
中島
前島
Maejima (Is.)
26°11'N
127°30'E
N
0
5 km

a. Okinawa Island

(Map 6-1-4-①)

Kazuhiko Sakai

1 Corals and coral reefs

1. Geographical features

Most of the coral reefs around Okinawa Island (hereafter Okinawa) are fringing and patch reefs, which have developed adjacent or close to the Okinawa. However, on the southeastern coast, patch reefs have developed several kilometers offshore. forming barrier reef like.

2. Coral distribution

Okinawa is in the direct path of the Kuroshio Current, which sustains more than 340 scleractinian corals, and eight non-scleractinian corals at a relatively high (26°N) latitude (Nishihira and Veron 1995). The number of the scleractinian coral species on Okinawa is three times more than that recorded at similar latitude on the Great Barrier Reef (Veron 1993; Nishihira and Veron 1995). To date there is only one unique coral species (an undescribed species of *Fungia*) reported on Okinawa (Nishihira and Veron 1995).

Corals have been gradually decreasing on Okinawa since the 1970s, mainly because of the crown-of-thorns starfish (*Acanthaster planci*) predation (Sakai and Nishihira 1986). Dramatic reductions in coral abundance also occurred in 1998 in association with the thermal stress event. For example, Loya *et al.* (2001) compared coral community structure between 1997 and 1999 on a fringing reef at southeast coast of Sesoko Island, northwestern Okinawa. They showed that coverage of coral communities (including hard and soft corals) decreased by 85 % because of the 1998 mass-bleaching event (Fig. 1). There was little apparent recover 5 years later (in 2003). A survey by the Conservation Division of Okinawa Prefecture (2003) revealed that only 2 of 80 surveyed sites (Minna-jima and Ie-jima Island) supported coral cover > 25 % (Fig. 2). A detailed examination of coral communities at 18 stations along the western coast of Okinawa in 2003 showed that percent cover of corals was less than 5 % at all the stations (Sakai, unpublished data). Although there were numerous *Acropora* recruits after 1998 mass-bleaching event, and exceeded 20 colonies per m^2 at some stations, survival was low and was reduced to less than 10 per m^2 in 2003. At these stations, *A. planci* was common and appeared responsible for the high mortality rates after bleaching (Photo. 1).

Coral species diversity was also reduced in 1998. Loya *et al.* (2001) showed that the number of coral species decreased by 61 % on the fringing reef of Sesoko Island because of the mass-bleaching event (Fig. 1). Mortality of branching corals was much higher than non-branching corals (Loya *et al.* 2001). Notably, the author has not found any colonies of *Seriatopora hystrix* and *S. caliendrum* around Okinawa since 1998, and fears a high probability of local extinction of these species.

3. Water quality and physical environment

Water quality is declining around Okinawa due to human activities. Terrestrial red soil run-off to coral reefs had been evident since at least the 1970s. Eutrophication, caused mainly by agricultural runoff and domestic sewage, has also recently increased. Low seawater transparency near Okinawan cities appears related, in part, to an increase in phytoplankton. Benayahu (1995) suggested that an increase in the percent cover of soft corals around Okinawa is due to a deterioration in water quality – the percent cover of soft corals is actually high near cities, for example Sunabe (central west coast).

4. Notable species and ecosystems

There have been some sightings of the endangered dugong species, *Dugong dugon*, on the northeastern coast of Okinawa (Photo. 2). An endemic species of fish, *Scartelaos histophorus*, is found on the tidal mud flats of Nakagusuku Bay (central east coast). It is highly probable that their habitats are threatened, as are the coral communities, considering prospective (rapid) development and land reclamation.

2 Situation of usages

1. Tourism

There are more than 130 dive shops on Okinawa. Some dive operators have changed their destination to the Kerama Islands, because coral reefs around Okinawa have degraded. For non-diving tourists, glass-bottomed

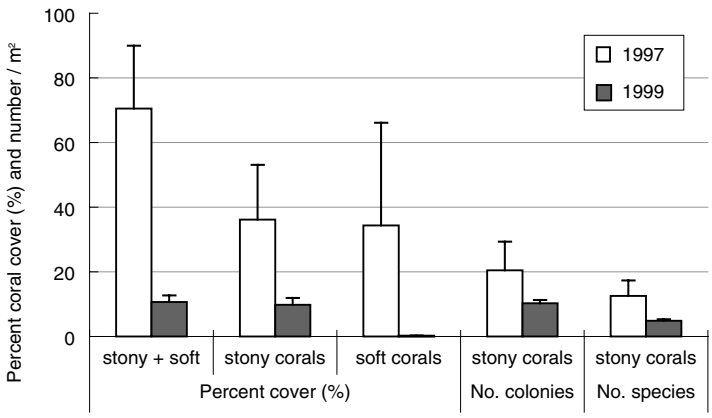


Fig. 1. Changes in coral coverage of stony and soft corals and the number of colonies and species between 1997 and 1999 on a fringing reef flat at southeast coast of Sesoko Island, northwestern Okinawa (from Loya *et al*. 2001). The error bar represents standard deviation.

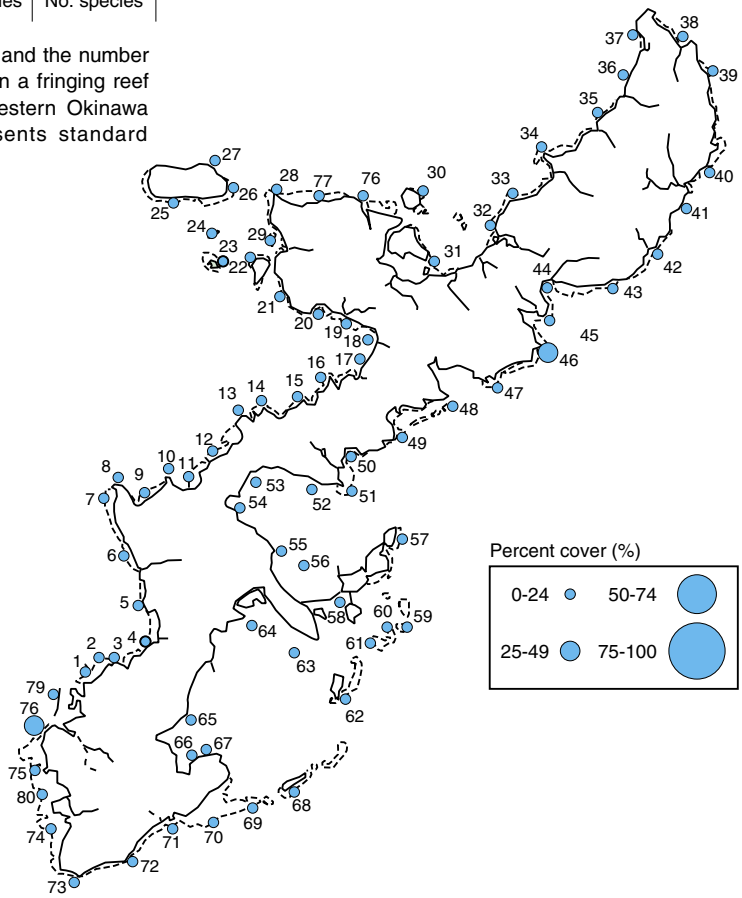


Fig. 2. Percent cover of hermatypic corals at 80 sites around Okinawa Island in a survey of 2003 (Conservation Division Department of Cultural & Environmental Affairs, Okinawa Prefectural Government).

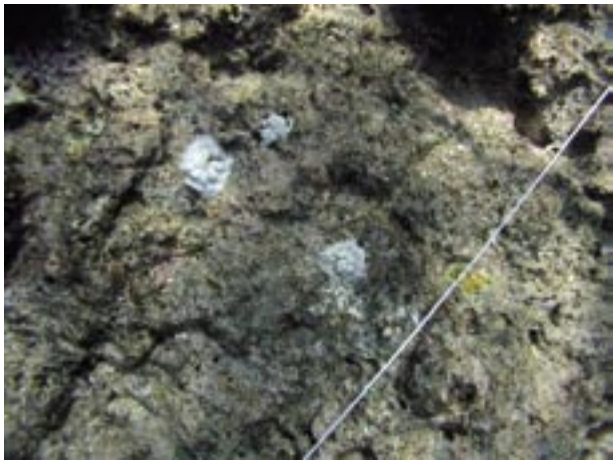


Photo. 1. Juvenile *Acropora* colonies recently (< 2–3 days) eaten by *Acanthaster planci* (3 white skeletons in the middle) on a reef off Onna Village in 2003 (an individual *A. planci* starfish was inside the burrow at the upper right), while one live juvenile *Acropora* colony can be seen at the center right of the photo.

Photo. 2. A Dugong (*Dugong dugon*) observed at off Abesaki, Kayo, Nago City (July 3, 2003). (photo provided by Ministry of the Environment, Government of Japan).

boats are available in Naha harbor, Chinen Village and Onna Village, and an underwater observatory is popular at Nago City. Recently, coral transplantation projects have attempted to restore the damaged reefs largely organized by local fisheries cooperatives and diving shop associations.

2. Fishery

There are 23 fisheries cooperatives on Okinawa. Coastal fisheries in coral reef areas were active in the past but have recently declined. Today, some traditional coastal fisheries are barely active. In contrast, aquaculture of fishes and macroalgae (seaweed) have recently increased.

3 Conservation

1. Crown-of-thorns starfish

Local fishermen and divers have been exterminating *A. planci* with support from the Okinawa Prefecture and the Ministry of the Environment. Notably, the Onna Village Fisheries Cooperative has been exterminating large numbers of *A. planci* for well over 10 years.

2. Sedimentation

Red soil run-off, from large construction works, has been recently reduced since the successful enforcement of the Okinawa Prefecture Red Soil Erosion Prevention Ordinance (http://www.c-okinawa.co.jp/eikanken/index.htm). However, run-off from agricultural fields remains a problem.

b. Kerama Islands

(Map 6-1-4-②)

Kenji Iwao

1 Corals and coral reefs

1. Geographical features

Some 30 islands make up the Kerama Islands, 20–40 km west of Okinawa (Fig. 1). There are two administrative districts divided by the Kerama Straits, Zamami Village in west and Tokashiki Village in east.

From the distribution of Japanese cedar and Japanese cypress fossils in the rock stratum, it is thought that the Kerama Islands were part of a mountain range that extended to (northern) Okinawa and exceeded 1500 m above sea level in the Pliocene (1.5 million years ago). Well developed coral reefs formed around Okinawa 600,000–200,000 years ago, and remain as uplifted Ryukyu limestone. This limestone layer in Kerama Islands, however, is about 80 m below sea level, because the Kerama Islands have subsided (via diastrophism). Subsidence resulted in a mountain range remaining above today's sea level – the tops of those mountains are the Kerama Islands (Kizaki 1992).

2. Climate and oceanography

Akajima, central Kerama Islands, shows air temperatures that do not fall below 10°C, even in winter, with highs around 37°C in summer (July–August), and a monthly average of 28.9–31.9°C. Seawater temperature is lowest in February–March, but does not fall below 20°C, and is highest in July-August at 27.1–29.6°C (note: the water temperature was exceptionally high in August 1998, when the monthly average was recorded at 30.4°C.) Typhoons are common, and are often experienced even in early summer. Summers have extreme oceanographic conditions with about five typhoons approaching every year, bringing high waves, wind and rain, followed by calm intermittent periods. From October to April, the northern monsoon brings strong north winds and large swells (Hayashibara 1995; Iwao 2001).

3. Coral distribution

There are approximately 248 hermatypic coral species found on Akajima and the surrounding Kerama Islands (59 genera and 14 families) (Hayashibara 1995)

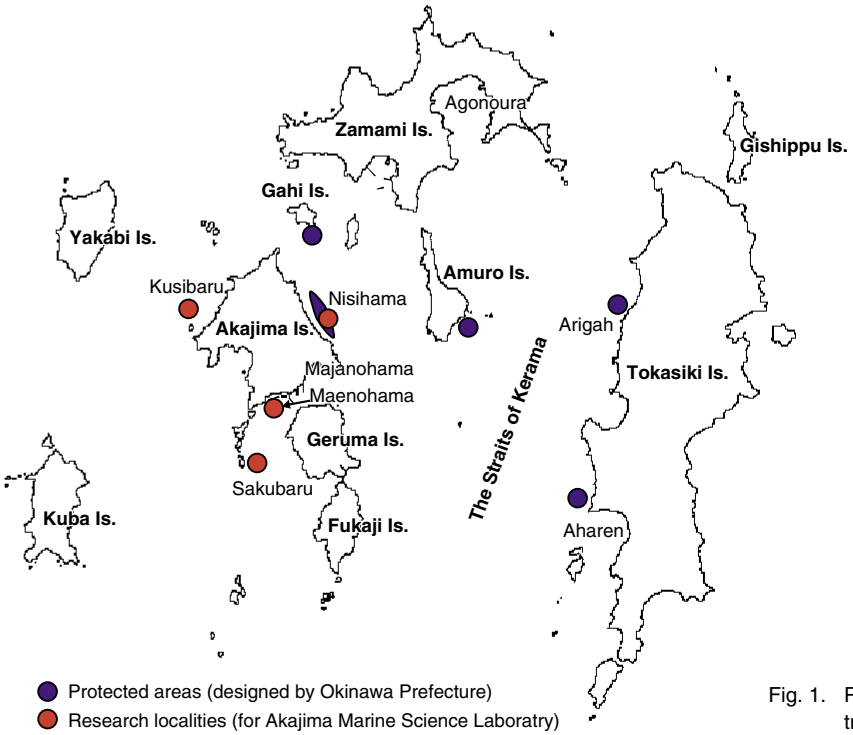


Fig. 1. Protected areas and survey localities using belt transects.

– or 62 % of the species recorded in Japan (Veron 1992). Considering their relatively small size the Kerama Islands are extremely rich in coral fauna (Hayashibara 1995).

The northern coast of Zamami Island supports spur and grooves and a tabular *Acropora* community, which used to be more extensive before the 1998 bleaching event and a more recent outbreak of the crown-of-thorns starfish (*Acanthaster planci*). The southwestern coast of the island supports high diversity, and Agonoura Bay, in the southeast island, is said to support unique coral communities but a satisfactory survey has not been conducted (Fig. 1).

Kushibaru, on the northwestern coast of Akajima, also has extensive spur and groove systems and large tabulate *Acropora* colonies from reef edge to 4–6 m down the reef slope (Photo. 1). Again, recent *A. planci* predation has reduced corals. Nishihama, on the eastern coast, supports diverse coral assemblages on a shallower slope. Maenohama, on the southern coast, supports artificial breakwaters about 100 m offshore; the sand bottom is scattered with sea grasses and rocks supporting massive faviids and branching *Montipora*.

Mass coral spawning has been observed annually on Akajima; spawning occurs in summer from May to September. Many *Acropora* (Photo. 2) and *Montipora* species spawn in May–June, *Merulina* in July, and some *Favia* in August–September.

'Healthy' coral communities are common on the west coast of Tokashiki Island. Especially in the two conservation areas where branching and tabular *Acropora* are dominant, showing in places more than 90 % coverage. The south coast receives most of the wave energy and supports few corals – mainly *Pocillopora* species. The east coast is also strongly affected by predominate wind and waves from the east, but branching and tabulate *Acropora* colonies are more typical in the bay area. The northeastern coast supports patches running perpendicular to the shore, with corymbose *Acropora* and alcyonaceans (soft corals and sea fans). The northwest coast supported the most diverse and luxuriant *Acropora* communities in the Kerama Islands, until 1998 coral bleaching and recent *A. planci* predation.

Photo. 1. Extensive spur and groove systems and large tabulate *Acropora* colonies form the reef slopes in Kerama Islands.

Photo. 2. Spawning of branching *Acropora* in Kerama Islands

The east coast of Gishippu Island, adjacent to Tokashiki Island, supports massive scleractinian corals and alcyonaceans. The west coast of Gishippu Island is comparatively shallow, supporting mainly *Porites cylindrica* and *Echinopora lamellosa* colonies, while the eastern and northwestern coast of Yakabi Island has many colonies of *Heliopora coerulea* (blue corals).

4. Notable species and ecosystems

Three hundred and sixty fish species, about 1,640 invertebrate species, including hermatypic corals, and about 220 seaweed species have been recorded in the Kerama Islands to date, but many groups of organisms have not yet been surveyed (Ohba 1995; Iwao 2003). Green turtles, loggerheads, and hawksbill turtles lay eggs on the beaches in summer, and are often encountered while diving. While the Kerama Islands are famous for their coral reefs, humpback whales (*Megaptera novaeangliae*) are very common in January to April, since they use the Kerama Islands as their breeding ground (Photo. 3).

On the land, 620 species of flora have been recorded, and the Kerama deer and other many animals inhabit. Kerama deer is a subspecies of the Japanese deer, and it lives only in the Kerama Islands. It is smaller and blacker than Japanese deer. The deer population on Akajima in 1970 was about 10, but has since increased to 130 in 1995. The deer are fully protected on some islands as a natural treasure of Japan (Editorial Board Zamami Village History 1989).

2 Situation of usages

1. Tourism

The diving industry flourishes here because of the rich marine life. There are 43 diving businesses in Zamami village and 14 in Tokashiki village, and even more for accommodation. Moreover, the number of tourists who enjoy sea kayaking has increased in recent years. While fishing was the main source of income in the past, now more than 80 % of the residents are engaged in tourism.

2. Fishery

From 1900 until the beginning of World War II, the skipjack fishery flourished, but declined during and after the war. Now, most skipjack catches are consumed locally. While swordfish, tuna, and skipjack are caught and consumed locally using lines, spinefoot (*suku*) are caught locally using gill nets in summer. In addition, local residents collect shellfish and octopus by scouring the reef flat at ebb spring tide.

3 Threats and disturbances

1. Change in coral communities

According to a coral survey using belt transects (explained later) at four localities on Akajima in October 1998, coral coverage was 35 % (219 colonies) at Kushibaru (northern cost), 34 % (565 colonies) at Sakubaru (southwestern coast), 29 % (275 colonies) at Maenohama (southern coast), and 37 % (316 colonies) at Nishihama (eastern coast). At all localities, except Nishihama, both coral coverage and number of colonies per unit area have decreased. At Nishihama, the number of colonies decreased over the next year but coral coverage increased. In 2000, both coverage and the number of colonies decreased in Maenohama, but were almost unchanged in Kushibaru and Sakubaru. Both coral coverage and colony abundance increased in Nishihama. In 2001, the state of the reef was as follows: 30 % (292 colonies) in Kushibaru, 31 % (450 colonies) in Sakubaru, 26 % (106 colonies) in Maenohama, and 53 % (324 colonies) in Nishihama. A survey in December 2003, found a decline in coral cover at all four localities – a consequence of *A. planci* predation (Taniguchi 2004).

Photo. 3. Humpback whales (*Megaptera novaeangliae*) are commonly seen in January to April in Kerama Islands, as their breeding ground.

2. Bleaching

In 1998 coral bleaching occurred on a worldwide scale. Bleached corals were first observed in the Kerama Islands at the end of July. By the end of August, *Seriatopora hystrix*, *Pocillopora damicornis*, and *Acropora* colonies were bleached at shallow area (< 3 m), as was *Acropora horrida* at 25 m. The result of September 1998 survey, at 15 localities, showed more than 90 % of the shallow colonies examined were bleached at 4 of 15 localities (in the inner bays or moats) (Taniguchi *et al.* 1999).

The belt transect results showed that 33 % of all the colonies examined were completely bleached, in September 1998 at Maenohama, and if partially bleached colonies were included, then 91 % of the colonies were bleached. By March 1999, only 64 % of the colonies remained (191 of 298 colonies surveyed). By November 1999, only 42 % remained), but the overpass of a typhoon was primarily responsible for the latter lose (Taniguchi and Iwao 2000). There were signs of recovery, based on re-growth from remnants and newly recruitment, but thermal stress and bleaching was again evident by the end of July 2001. In 1998, about 25 % of the corals died in Maenohama, which experienced the greatest lose, while mortality in 2001 was only 10 % (Taniguchi 2002).

3. Crown-of-thorns starfish

A well documented outbreak of *A. planci* in the 1970s changed the coral reefs of Okinawa considerably. A similar outbreak occurred on Chibishi reefs in 1997, between Okinawa and the Kerama Islands. In autumn 2001 an *A. planci* outbreak occurred on the Kerama Islands. Extermination was undertaken especially in the conservation areas; at three localities in the Zamami district (Nishihama on Akajima, southeast of Amuro Island, and on the south coast of Gahi Island), at two localities in the Tokashiki district (Arigah on Tokashiki Island and off Aharen Bay on Tokashiki Island). Local diving operators exterminated the starfish and these activities are continuing – some 120,000 *A. planci* individuals were exterminated in the last 2 years (to June 2003).

4 Monitoring

1. Belt transect survey

Monitoring was conducted by the Akajima Marine Science Laboratory (AMSL) at each of the four survey localities. At each locality a 30 × 0.5 m belt transect recorded coral communities. These surveys are repeated annually to determine the change in coral coverage, the number of coral colonies, and growth and death of each coral colony.

Photo. 4. Reef Check monitoring by volunteer divers in Kerama Islands.

2. Reef Check

At Zamami village, since 1998, local divers have followed 'Reef Check' protocol as part of the coral reef conservation efforts (Photo. 4). Since 1999, the year after Nishihama was closed, Reef Check surveys have been conducted. In 1999, coral coverage at Nishihama was 29 %, which appeared to increase to 41 % in 2000, and 48 % in 2001. Moreover, the number of fish and invertebrates have also increased.

3. Other surveys

In addition to the above-mentioned surveys, AMSL has been observing weather and oceanographic conditions, such as temperature, seawater temperature, and precipitation, every day since 1988. Moreover, plankton samples have been collected once a month off the southern coast of Akajima since 1989.

5 Conservation and research

1. Conservation activities

Considering reports of deterioration of coral reefs at several diving localities, Zamami Village Fishery Cooperative closed three diving sites for three and a half years, in July 1998. Mooring buoys were installed when the sites re-opened at Nishihama to prevent anchor damage and limit the number of boats to the area at any one time.

All the diving businesses on Akajima and Geruma Island in Zamami village participated in organizing the 'Aka & Geruma Diving Association' in November 2001, and coral reef conservation activities have been proactively implemented. For instance, the society led the transplantation of coral colonies from the east coast of Geruma Island to Nishihama and Majanohama (Akajima), before the colonies were damaged by road construction in January 2002. Most recently, a 'Zamami Diving Association' has been established (Hosaka and Taniguchi 2003).

2. Akajima Marine Science Laboratory (AMSL)

AMSL was established in July 1988 on Akajima, surrounded with rich coral reefs. Since then, in cooperation with local residents and many researchers both domestic and international, the laboratory has been actively researching coral reproduction, recruitment and coral settlement processes, which is highly applicable to conservation issues. Moreover, AMSL continues with education and awareness activities that involve local schools and the local community, by operating summer school and preparing pamphlets and newsletters.

6 Necessary measures

Recently, many research reports have highlighted the Kerama Islands as the main source of coral larvae for Okinawa and surrounding islands. Therefore, preserving the reef around the Kerama Islands is a regional issue. Although heavily damaged by an *A. planci* outbreak over the past two years, and showing some resilience to the 1998 and 2001 bleaching events, the reefs are still rich in biodiversity and aesthetically appealing. There is a general consensus in the Kerama Islands that human disturbances need to be kept low. There are no large rivers, and little pollution in the Kerama Islands. The fishery cooperative and diving association are now actively engaged in coral reef conservation, which gives hope for the Kerama Islands of the future.

c. Iheya, Izena, Aguni, Tonaki, and Kume Islands

(Maps 6-1-4-③～⑥)

Kazuyuki Shimoike

1 Corals and coral reefs

1. Geographical features

Iheya, Izena, Aguni, Tonaki, and Kume (ordered from north to south) are islands scattered between Okinawa Island and the Okinawa Trough (basin). The Okinawa Trough connects to the Kerama gap, south of Kume.

Iheya and Izena are located about 30 km north of Motobu Peninsula, Okinawa, and their highest points above sea level are 293.9 m and 119.9 m, respectively (Photo. 1). These hilly areas consist of alternating strata of chalk, sandstone, and shale (Kizaki 1985). On Iheya, two mountains run parallel to the long axis, and dunes of up to about 80 m above sea level develop at the northern tip (Mezaki 1988). On Izena, the hilly regions are located in the central and northeastern parts of the island, and strata of chalk can be observed (Mezaki 1988). These mountains are designated Nature Conservation Areas in Okinawa Prefecture.

Aguni (about 4 km east-west by 3 km south-north) is located approximately 60 km northwest of the city of Naha on Okinawa. To the west of this island, steep drop-offs of 1,500 m or more have developed, running north-northeast to south-southwest at the sea floor (Kizaki 1985). The island mainly consists of a terraced structure made of limestone, and the highest point is 97.3 m in the southeast, where the southeastern tip is fringed with abraded cliffs about 80 m high. Beach rock and dunes are well developed along the east coast.

Approximately 50 km west-northwest of Naha is the island of Tonaki (about 2.5 km east-west by 4 km south-north). Its highest point is Mount Otake (179 m). The foundation of the island is limestone, dolomite, phyllite, and volcanic rock of the Tertiary Cenozoic era (Kizaki 1985). The low ground at the center of the island is formed of tronbo structures (islands that are joined with the cay; Kan *et al.* 1997). A conglomerate of beach rock and Holocene coral reefs protected by the beach rock is distributed on the shores (Kawana 1996).

The island of Kume is located about 90 km west of Naha; its highest point reaches 326 m above sea level. The foundation of this island consists of Pretertiary layers and volcanic rock of the Tertiary Period (Kizaki 1985). A beach (Hatenohama) of Holocene coral reef deposits and sand-gravel extends nearly 8 km along the east coast (Machida 2001).

2. Coral distribution

According to the 4th National Survey on The Natural Environment (Nature Conservation Bureau, Environment Agency 1994), coral communities are well developed in this area as compared to those in the region around Okinawa. However, Aguni was not included as a targeted survey site. Of the 272.5 ha covered by coral on Iheya, areas with coverage of 50 % or more accounted for 68.3

Photo. 1. Aerial photograph of Iheya and Izena (September 2003). At left is Iheya Island, on the right is Izena Island; the island in the center is Gushikawa Island. These islands are surrounded by well-developed fringing reefs. Okinawa Island can be seen in the background.

% of the total while areas with coverage of 5 % or less accounted for only 14.2 %. High coverage by *Acropora* and *Montipora* communities could be seen throughout the fringe of the island. Hermatypic corals (hereafter, corals) were also abundant along the reef crest, on which areas with coverage of 50 % or more accounted for 45.7 % of the total length surveyed (39.2 km).

While branching *Montipora* were dominant (50 % or more) in the moat, tabulate *Acropora* were dominant (50 % or more) on the reef crest along the southeast coast of Izena. Of the 105 ha area covered by coral on Tonaki, areas with 5–50 % coverage accounted for 71.4 % of the total area, and areas with coverage of 50 % or more accounted for 28.6 %. Coral communities dominated by branching *Porites* and *Montipora* were distributed in the moat. On Kume, however, frequently exposed reef flats are widely distributed, and the moat is seldom visible. Branching *Montipora*-dominated communities (50 % or more) extend for 41 ha around Oojima, located on the east coast. The results of a survey conducted by Narure Conservation Division, Okinawa Prefecture (1999) revealed that large tabulate *Acropora* covered the patch reefs off Hatenohama and that the coral fauna (dominated by branching *Acropora formosa* and large colonies of *Favia*, *Pocillopora*, *Merulina ampliata*, and *Diploastrea heliopora*) was in good condition on the reef slopes.

According to a survey conducted by the Nature Conservation Bureau, Environment Agency (1994), the coral fauna was relatively impoverished, i.e., had low coverage, on Gushikawa, which lies between Iheya and Izena. However, a survey conducted in 2001 (Irikawa 2002) reported tabulate and branching *Acropora* communities with 64 % and 92 % coverage at depths of 2–3 m and 9–10 m, respectively, along the northern coast of the island.

3. Water quality and physical environment

The Kuroshio Current flows from southwest to northeast along the Okinawa Trough on the northwestern side of these islands, making water temperatures and clarity high throughout the year. However, inflow of terrestrial red clay is evident in some coastal areas of the islands.

4. Notable species and ecosystems

The fringing reefs of Tonaki have been designated as one of the 500 Important Wetlands of Japan (Nature Conservation Bureau, Ministry of the Environment 2002a). Mangrove trees, such as *Bruguiera gymnorrhiza* and *Kandelia obovata* (see Chapter 1–3), are distributed at the mouth of the Gima River in Kume Island and provide habitat for birds such as *Anas poecilorhyncha*, various ardeids, and *Phalacrocorax filamentosus* (Nature Conservation Division, Okinawa Prefecture 1999).

2 Situation of usages

1. Tourism

Leisure fishing is very active throughout these islands. A national fishing rally is held annually in June on Kume. SCUBA diving is also popular, and there are 14 dive shops on Kume. The coastal areas are also often used for camping and swimming. The natural stone pavement called 'Tatamiishi', with large pentangular and sextangular shaped rocks that resemble tortoise shell, has been designated a Prefectural Natural Treasure and is a popular tourist spot.

2. Fishery

The most commonly caught fish around these islands are tuna offshore, *Sthenoteuthis oulaniensis* by coastal fisheries, and snapper and grouper by towing net fisheries, pole and line fisheries, and gill net fisheries; shellfishes and seaweeds are also harvested from the surrounding sea. The cultivation of the brown algae (*Tinocladia crassa*) is common on Iheya and Izena, and the prawn (*Penaeus japonicus*) is raised on Kume.

3. Deep-sea waters

Taking advantage of its geographical location close to the Okinawa Trough, Kume has developed a new industry, which uses deep-sea waters pumped up from a depth of 600 m or more. These deep-sea waters are virtually aseptic and replete with nutrient salts; thus, they can be used in the manufacture of health foods and cosmetics, capitalizing on the recent boom in this field.

3 Monitoring and conservation

1. Sedimentation

As a result of the enforcement of the Okinawa Prefecture Red Soil Erosion Prevention Ordinance of 1995, red soil run-off has been controlled. The rate at which run-off increases the suspended particles in sea sediment (SPSS; see also Chapter 2–5) in coastal areas of Kume has

decreased somewhat, although run-off still occurs at a relatively high rate. Moreover, the rate of SPSS in Iheya and Izena is increasing even after the enforcement of the ordinance (website of the Okinawa Prefectural Institute of Health and Environment *1). Many sugarcane fields on these islands do not comply with the ordinance; this is considered a major obstacle to improvement and thus requires countermeasures.

2. Bleaching

The results of a questionnaire intended for city, town, and village officials showed that the ratio of bleached to live coral exceeded 60 % on Iheya, Izena, and Kume. The ratios of corals that died after bleaching were 20–80 % in Hatenohama and 80 % throughout Kume (Nature Conservation Bureau, Environment Agency 2000c). Bleaching occurred again in 2001, and *Acropora* communities on Gushikawa (located between Iheya and Izena) and *Porites* and *Montipora* communities on Kume, which survived the bleaching event in 1998, have since died out (Photo. 2). However, 50 % or greater of the communities survived the bleaching event in some areas, including the mixed species communities in the northern part of Ie as well as tabulate and branching *Acropora*-dominated communities in northern Gushikawa (Irikawa 2002). These survivors are expected to play an important role as sources of larvae for the neighboring coral reefs, including the west coast of Okinawa.

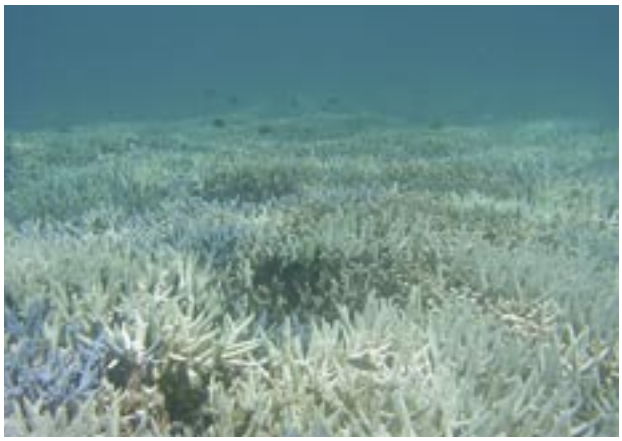


Photo. 2. Coral community on southern Iheya Island (1 August 2001, 3 m depth). (photo by A. Irikawa)
This community was once dominated by *Acropora* (e.g., *Acropora formosa*, *A. nobilis*, *A. microphthalma*, and *A. valenciennesi*), but many corals died after the bleaching event in 2001.

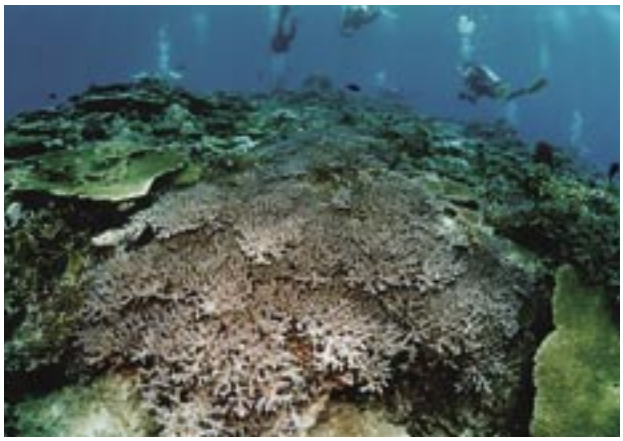


Photo. 3. Seascape of Akashita, Kume Island (June 1998, 3 m depth). (photo by N. Watanabe)

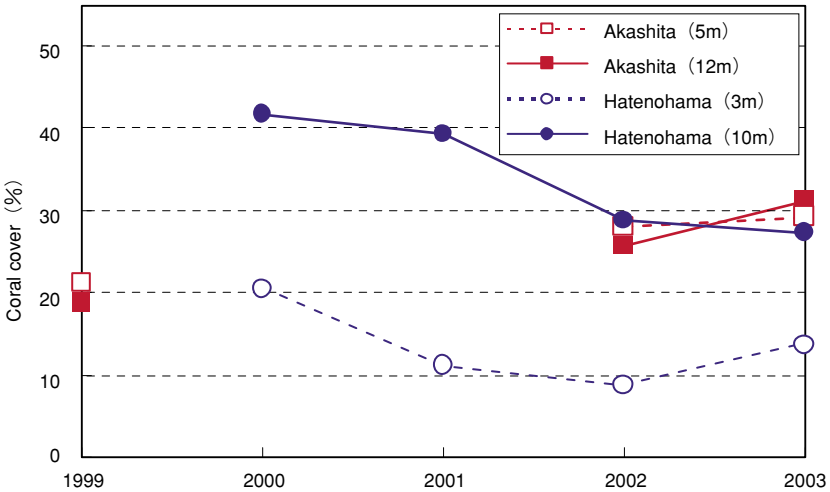


Fig. 1. Transition of hermatypic coral cover in Kume Island from the Reef Check monitoring.

3. Reef Check

Reef Check, an international standardized method of monitoring by volunteer divers (see also Column: 'Reef Check in Japan'), has been conducted on Kume since 1999. The result of the Reef Check monitoring survey is shown in Fig. 1. The state of coral communities at both surveyed sites (Akashita, on the north shore of Kume (Photo. 3), and Hatenohama) remains good at present. But, outbreak is worried because two crown-of-thorns starfishes (*Acanthaster planci*) were found on Akashita in 2003. (website of Reef Check Japan *2).

4. Zoning

Okinawa Prefecture has formulated an indicator system to evaluate the conservation needs of natural environments. As part of this process, the coastal areas of Kume have been classified into four priority rankings according to their conservation requirements (Nature Conservation Division, Okinawa Prefecture 1999). This act aims to advance the protection and conservation of natural areas, based on the indicator system.

4 Necessary measures

Little research has been conducted on these islands since the 4th National Survey of the Natural Environment (Nature Conservation Bureau, Environment Agency 1994), with the exception of a few sites. Thus, even the status of *A. planci* is currently unknown. However, a trend toward increasing numbers of *A. planci* was observed in Gushikawa from 2003 to 2004 (Irikawa personal communication); therefore, immediate measures, including monitoring surveys for coral reef conservation, are required to determine the current status of *A. planci*.

Cited websites:

*1: http://www.c-okinawa.co.jp/eikanken/akatuti/umi/umi.htm

*2: http://hs.st41.arena.ne.jp/reefcheckjapan/

Column

Coral reef development near cities

Makoto Tsuchiya

More than one million people live on Okinawa Island, mostly in cities, such as Naha, Ginowan, Urasoe, Tomigusuku and Itoman, situated in the southern part of the island. Many tourists utilize these urban areas year-round as their base for further tours to the northern areas and neighboring islands, such as Kerama Island. Current intensive bleaching events have apparently spared the coral reefs around Kerama Island (e.g., in 1998) and relatively healthy reefs are still found there.

Owing to intensive development activities following Okinawa's return to Japan in 1972, extensive coral reef areas around Okinawa Island disappeared and/or suffered various disturbances (e.g., bleaching events, crown-of-thorns starfish outbreaks, and terrestrial soil inflows). However, it is also true that healthy coral reef communities can still be seen in some places; such sites are utilized for activities such as environmental education and diving. These coral reefs may be unique in Japan, or even the world, in that they are so strongly connected to intensive human activities.

A coral reef near Naha Harbor has been protected from disturbance by human activities because of its location, in front of the American military base, which has meant that admission has been restricted for a long time. If intensive bleaching events have not occurred here, intrinsic coral reef communities will probably be found in this area. It is likely that species richness and abundance are greater here than in more disturbed areas and that larger sized reef organisms would be seen.

Rich *Acropora* communities were reportedly developing along the coast of Naha Airport until the 1998 bleaching event. On the breakwaters of Naha Harbor, located adjacent to the airport, it has been observed that many coral colonies are proliferating (Photo. 1). These areas have the potential to foster the healthy growth of coral communities, despite their seemingly unfavorable locations, and thus

Photo. 1. A coral community developing on the breakwater of Naha Harbor, Okinawa (photo by K. Shimoike).

may serve as appropriate sites for research into the conservation and management of coral reefs, with reference to the human activities. Recently, the coexistence of coral communities with the activities of Naha Harbor has been discussed (Ports and Harbors Bureau, Ministry of Land, Infrastructure and Transport 2003).

Since such urban-adjacent reefs are easily accessed from neighboring cities, and relatively rich flora and fauna exist, they are frequently used as sites for environmental education. The Nature Conservation Section of Okinawa Prefecture holds an event for the public to observe marine life on these reefs every year.

Changes in the size of fish catches off Okinawa have also been affected by human activities related to the history of Okinawa. During the 1970s, sea urchins, octopus, and giant clams were caught in relatively large numbers, but the catches have decreased since that time (Fig. 1). Although data before 1973 are unfortunately not available, we can assume, from information on fish catches off Okinawa, that these organisms were not caught in great numbers before that time (Tsuchiya 1999; Tsuchiya in preparation). It has been speculated that the cause for this change relates to changes in the dietary habits of the Okinawan people. Their food choices have been affected by mainland Japan's habit of eating these organisms. The resulting increase in demand has resulted in fishermen over-catching these particular resources. Similar information has been obtained from many fishermen on Okinawa Island and from the Yaeyama region.

On the other hand, other possible reasons for the sudden decrease in the size of fish catches should also be considered, because catches of other preferred fishes, such as lobsters and parrotfish, have remained relatively stable. The effect of terrestrial soils derived from land development projects may be one cause. Fishes that can swim freely, and lobsters living mostly at reef edges, may not be directly affected by soil accumulation, while benthic organisms living mainly on reef flats are more susceptible.

As more people inhabit the area, more food resources will be required, and this means that more fishing will occur. Needless to say, resources are limited. Therefore it is necessary to understand the carrying capacity of coral reefs, both with respect to food and recreational resources, in order to avoid their degradation. For the future sustainable use of coral reefs, more precise information and further detailed discussion are required.

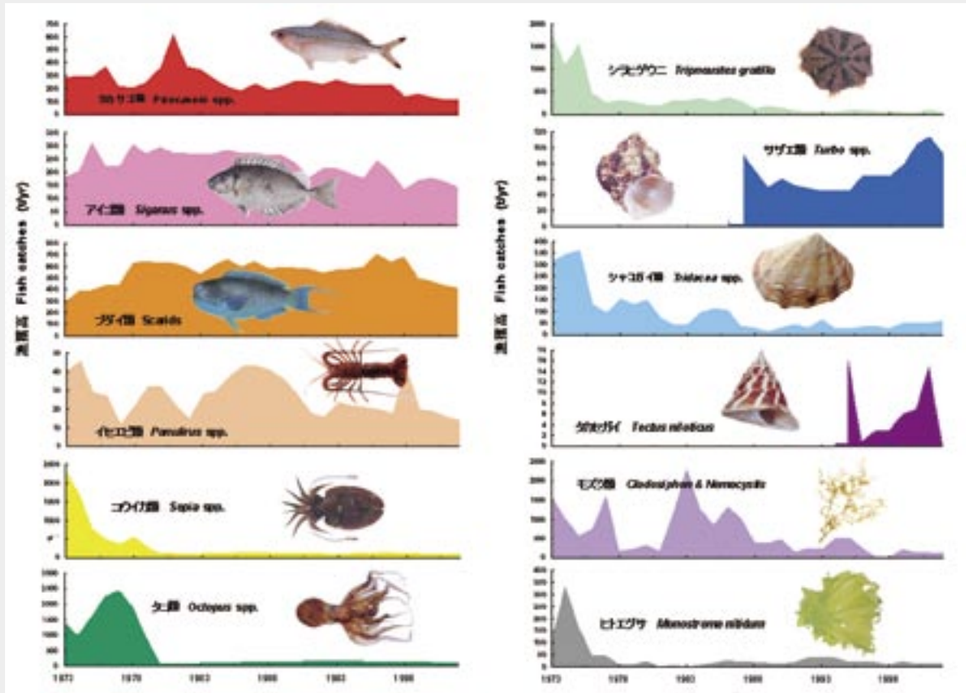


Fig. 1. Changes in fish catches on Okinawan coral reefs (Tsuchiya 1999, modified).

Column

Folkcraft of Okinawan coral reefs

Moritaka Nishihira

The people of the Ryukyu Islands have developed a deep cultural relationship with coral reefs; from ancient times, they have enjoyed and exploited coral reef environments. Animals and plants found in different reef habitats have been used in various ways, which have included their use as materials for construction, dwellings, cooking, eating and drinking, food storage, and the making of amulets, accessories and toys (Uezu 1973, 1982; Nishihira 1988, 1990).

Traditional uses of coral and coral rubble

Ryukyu limestone was used as a construction material for the castle walls of Shurijo Castle, a World Cultural Heritage site, as well as for many other buildings. Limestone and coral rubble were used for stone pavements, and piled up to form the walls of private houses. In old times, house walls were constructed using huge roughly processed skeletons of massive *Porites* corals, the fine skeletal structure of which makes it easy to process. Tabular corals were also used for walls. Maintenance or repair of these walls was difficult and cavities within them were often used as refuges by venomous habu snakes. Consequently, concrete is now used in village construction. Domed massive colonies, including poritids and faviids were used as pillar bases for wooden houses.

Massive *Porites* colonies were also used for making domestic burial urns. These also exploited the fine skeletal character of this coral. Millet-cake-like rocks of consolidated foram tests, called "*Awaishi*", were quarried and used as a construction material. Corals were also used for many other purposes. Wheat threshers ("*Mujishiriishi*") incorporated roughly processed skeletons of faviid corals, making good use of the ruggedness of the skeletal surface. Tabular low-relief acroporids were also used as wheat threshers.

"*Sangozome*" is a recently invented form of material printing that seems to be peculiar to Okinawa. Structural patterns within massive coral skeletons, such as those of faviids, are printed in color onto the cloth of T-shirts and handkerchiefs. Patterns change with coral species, direction of growth, and the cutting plane.

Handicrafts, tools, and toys made of shellfish and other reef animals

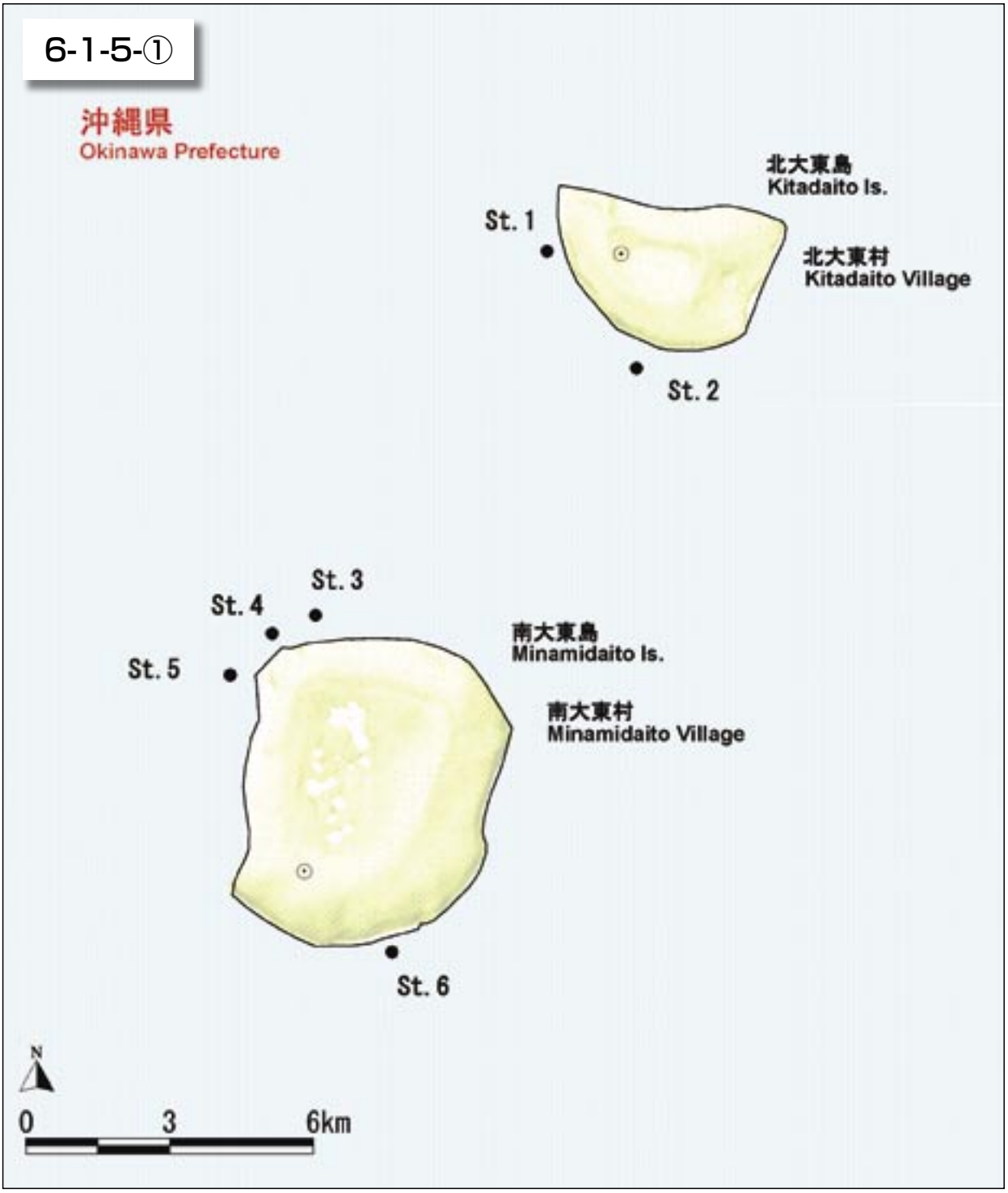
Souvenir shops sell key rings composed of foraminifer tests embedded in plastic resin, wind chimes made using spines and cleaned tests of sea urchins, and various ornaments made by cutting and polishing sea shells. Traditionally, children used various gastropod shells as toys; for example, tiger cowries (*Cypraea tigris*) on strings represented cows, while smaller cowries (gold ring cowries, *C. annulus*, and money cowries, *C. moneta*) and opercula of turban shells (*Turbo argyrostomus*) were used as marbles, and strawberry conches (*Strombus luhuanus*) were used as tops, sometimes after the upper half of the shell had been cut off.

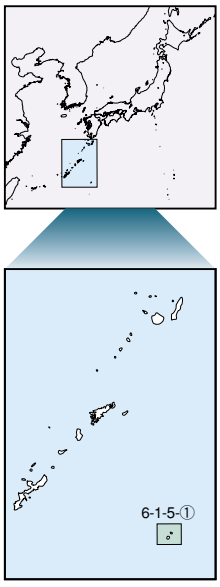
Shellfish were used for various purposes. Tools and accessories such as "*Kaiwa*", a wristband, and "*Kaifu*", a chopper, have been excavated from many ruins; in addition, cowries were used for currency. Large cowries (such as *C. tigris* and the serpent's head cowrie *C. caputserpentis*) with the dorsal parts of the shell removed were tied to the bottom of fishnets where they functioned as weights. Valves of the crocus giant clam, *Tridacna crocea*, were also used for this purpose. Valves of giant clams (*T. squamosa*) were placed facing outwards on gateposts or walls as talismans against evil influences; for similar reasons, chiragra spider shells (*Lambis chiragra*) were hung at the entrance to the pigpen. These shells were also used as hanging hooks. Modified trumpet triton shells (*Charonia tritonis*) were used as kettles. They were hung on the burner by a wooden handle screwed into a hole drilled in the center of the shell. Valves of the large mangrove clam (*Geloina coaxans*) and the common turtle limpet (*Cellana testudinaria*) were used as ladles. Besides these examples, gastropod shells were used for many other kinds of tools. As island lifestyles have become more modern, however, simple customs and cultural details that helped to maintain deep relationships with coral reefs are gradually being lost.

Left-upper: Wall constructed with limestone blocks and coral rubble (Ikei Island, Okinawa).
Left-middle: A giant clam talisman set on a gatepost (Ikei Island, Okinawa).
Left-lower: Kettle made of a triton shell (Okinawa Prefectural Museum).
Mid-upper: "Sangozome", a coral dyeing and printing technique (Shuri Ryusen Co.).
Mid-lower: "Mujishiriishi", a wheat thresher (Okinawa Prefectural Museum).
Right-upper: A spider shell talisman, unusually set in a palm tree (Ikei Island, Okinawa).
Right-middle: Fishnet with weights made of tiger cowries (Okinawa Prefectural Museum).
Right-lower: Domestic burial urns made of the skeletons of massive *Porites* colonies (Okinawa Prefectural Museum).

6-1-5 Daito Islands
(Map 6-1-5)

Province: Okinawa Prefecture **Location:** ca. 360 km east off Okinawa Is., including Kitadaito, Minamidaito, and Okidaito Is. **Features:** Kitadaito and Minamidaito Is. are manned island **Population:** ca. 2,100 **Air temperature:** 23.1˚C (annual average, at Minamidaito Is.) **Seawater temperature:** 25.1˚C (annual average, at south off Daito Islands) **Precipitation:** 1,649.8 mm (annual average, at Minamidaito Is.) **Information on coral communities:** not available **Protected areas:** none





Daito Islands

(Map 6-1-5-①)

Masanori Nonaka

1 Corals and coral reefs

1. Geographical features

While the Daito Islands belong to the Ryukyu Islands archipelago (Okinawa Prefecture), they are located approximately 360 km east of Okinawa Island and are geographically isolated from the Ryukyu Islands (which consists primarily of the Amami Islands, Okinawa and associated islands, Miyako Islands, and the Yaeyama Islands). The Daito islands did not appear on any map until they were discovered by finding on discovery by the Russians in 1820 onboard the vessel 'Borodino", and were named the 'Borodino Islands' after the Russian vessel. The first Japanese pioneers to set foot land on the islands was in 1899.

The Daito Islands primarily consist of three major islands: Kitadaito Island, Minamidaito Island and Okidaito Island; the last of which is uninhabited. Kitadaito Island and Minamidaito Island are located in close proximity, about 7 km apart, while Okidaito Island is about 150 km to the south, and is much smaller. Minamidaito Island is the largest island in the group. It is oval shaped. Its long axis extends 6.5 km, covering approximately 30.6 km^2, and supports a human population of about 1,400. Kitadaito Island is somewhat smaller covering 12.7 km^2, and supports about 600 people. These islands are basically raised atolls that lack rivers, but support many freshwater ponds distributed around the islands' center.

2. Coral distribution

During October 2–4 in 2001, visual census of corals and fishes was conducted at 6 sites (sites are described on the previous page). The islands support poorly-developed fringing reefs and coastline is mostly precipitous cliffs (Photo. 1). A gradual slope continues to about 20 m, and then suddenly drops steeply to approximately 2,000 m. Benthic organisms and seaweeds were sparse from the shoreline to 10 m depth (Photo. 2). However, 62 spe-

Photo. 1. The east coast of the Minamidaito Island. Coastline is mostly precipitous cliffs; fringing reefs surrounding the islands are poorly developed.

Photo. 2. Benthic organisms and seaweeds were sparse from the shoreline to 10 m depth.

Photo. 3. *Pocillopora eydouxi.*

Photo. 4. Large sponges.

Photo. 6. *Chaetodon daedalma.*

Photo. 5. *Chaetodon quadrimaculatus.*

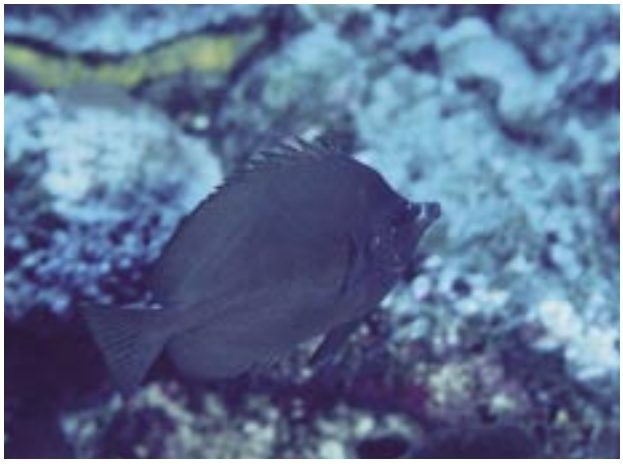


Photo. 7. *Hamitaurichthys thompsoni.*

cies of hermatypic corals (hereafter, corals) were recorded at 10–20 m (Appendix 1-7-Table 1). Most of the confirmed coral species were the same as species reported on Okinawa Island. Dominant coral genera were *Porites* and *Pocillopora* (Photo. 3), while *Acropora* and faviids, which are very common on Okinawa, were not common on the Daito Islands. In contrast, *Astreopora* colonies, which are not commonly seen on Okinawa Island, were rather abundant. Mean coral coverage throughout the observed area was approximately 10 %.

3. Notable species and ecosystem

There was a remarkable contrast in invertebrate fauna compared with Okinawa and adjacent islands. Sponges, especially large colonies (more than 40 cm tall) (Photo. 4), were prolific. Fish fauna was also different than recorded on the more western Ryukyu Islands. Sixty species of coral reef fishes were recorded (Appendix 1-7-Table 2). *Chaetodon quadrimaculatus* (Photo. 5), *C. punctatofasciatus* and *C. reticulates*, very rare in the western Ryukyu Islands' were common on the Daito Islands. Also, *C. daedalma* (Photo. 6), *Centropyge flavissima* and *C. interrupta* have not been recorded in the Ryukyu Islands but were observed on Izu and Ogasawara Islands (Nakabo 2000). *Hamitaurichthys thompsoni* (Photo. 7), especially, has only once been recorded in Japan in Muko-jima in the Ogasawara Islands (Senou *et al.* 1997), but this species was common in Minamidaito Island.

2 Situation of usages

1. Tourism

Tourists are rare and the majority of visitors are fishers (100–120 people/year) and SCUBA divers (ca. 200 people/year). Recently, a cruise boat operation to the Daito Islands has commenced, transporting about 100 visitors annually.

2. Fishery

There are about 30 fishermen on Minamidaito Island, however only four are devoted to fishing full time. Others have side businesses, and attend agricultural plots or provide service industries. Most fishers target offshore tuna and mackerel using rods, harpoons, or by trolling. There is only one fisherman engaged in catching coral reef fishes, including parrotfish and grouper, using SCUBA. Sometimes fishers gather on the shallow coral reef to catch blue sprat using a net (and snorkel).

3 Threats and disturbances

The coral communities of the Daito Islands suffered severe damage during the 1998 coral-bleaching event, similar to other areas in the Ryukyu Islands. High coral coverage was observed all around Minamidaito Island before the 1998 bleaching event. The north sides of the islands, especially, were dominated by branching species (probably *Acropora*) that, according to local information, covered in places nearly 100 % of the substrate. In 2001, many *Acropora* spats (i.e., recruits) were observed and the communities appear to be recovering (Kohama personal communication). Mr. Hisao Kohama who has been a professional diver for more than 20 years, has seldom seen crown-of-thorns starfish (*Acanthaster planci*) in the Daito Islands. Therefore, it can be assumed that there have been no *A. planci* outbreaks in recent years.

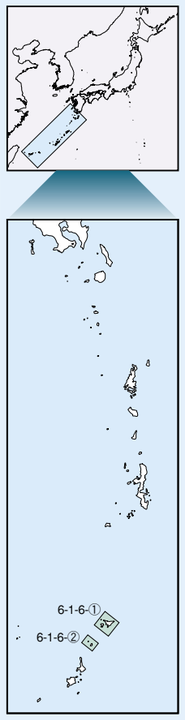
Major anthropogenic threats to coral reefs in the Daito Islands are the development of ports, roads and shoreline protection structures. A common result is high sediment discharge, including red soil, on the coral communities. Other known sources of damage include (long) fishing nets that cover corals, often stemming from offshore fishing boats (Kohama, personal communication).

4 Necessary measures

The fisheries cooperative association of Minamidaito Island has prohibited waste deposal at sea. But so far there have been no coordinated conservative efforts among the island's residents. Therefore, it is necessary to develop an educational program on environmental problems particularly on marine and coral reef issues (Kohama, personal communication).

6-1-6 Miyako Archipelago
(Map 6-1-6)

Province: Okinawa Prefecture **Location:** ca. 300 km southwest off Okinawa Island, including Miyako, Irabu, Ikema, Oogami, Kurima, Minna and Tarama Island. **Features:** Yaebishi (Yabiji) Reef lies at north of Miyako Island, which consists of ~100 table and platform reefs scattered in a 10 × 6.5 km area **Air temperature:** 23.3˚C (annual average, at Miyako Is.) **Seawater temperature:** 25.8˚C (annual average, at south off Miyako Is.) **Precipitation:** 2,019.3 mm (annual average, at Miyako Is.) **Total area of coral communities:** 1,957.1 ha **Total length of reef edge:** 121.6 km **Protected areas:** none



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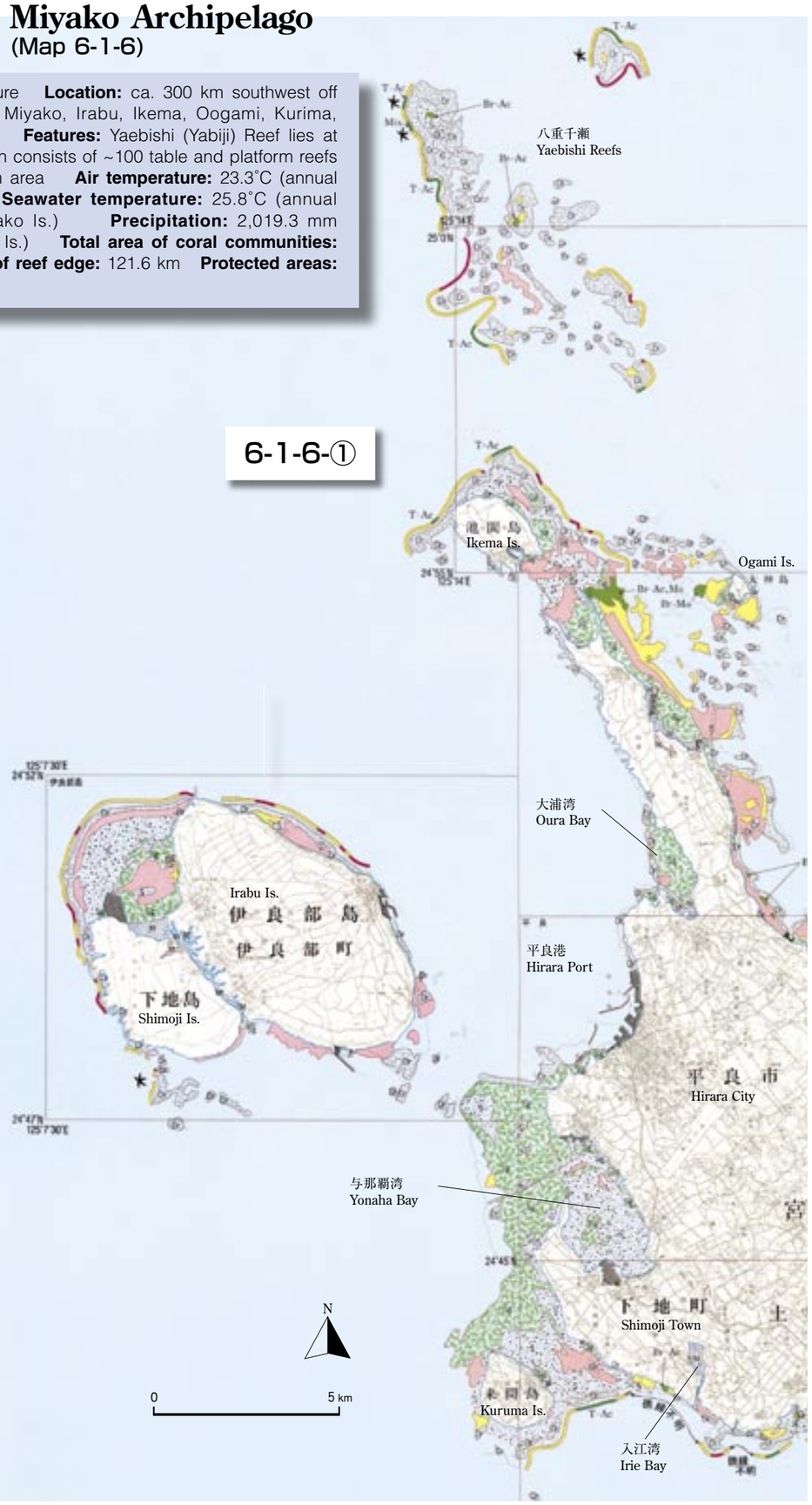

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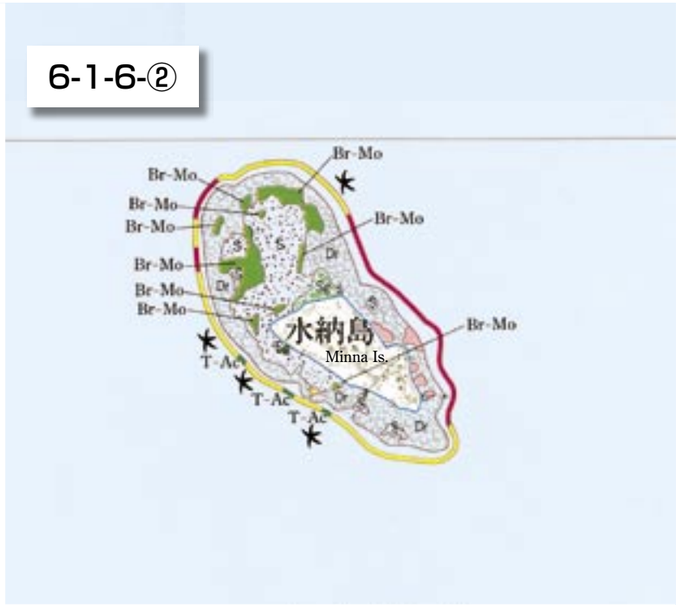
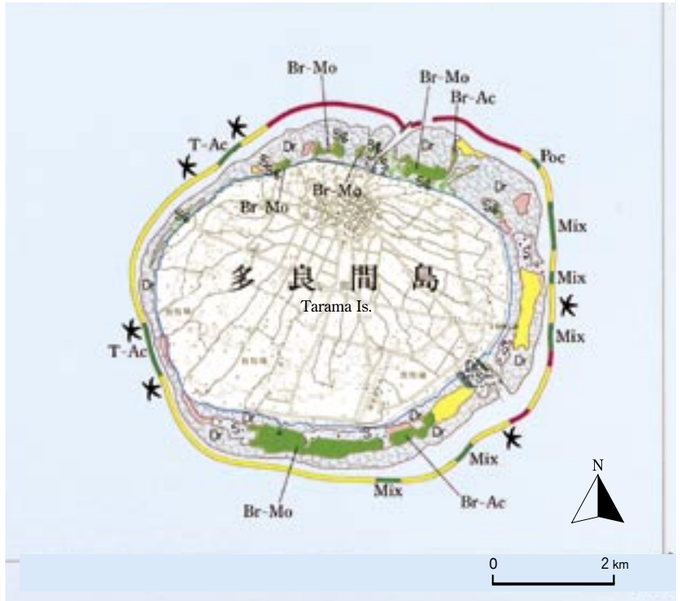




Miyako Archipelago

(Maps 6-1-6-①, ②)

Kenji Kajiwara, Hisashi Matsumoto

1 Corals and coral reefs

1. Geographic features

The Miyako Archipelago is comprised of coral reef limestone (the Pleistocene Ryukyu Group), based on lower stratigraphic divisions of mudstone and sandstone (the Pliocene Shimajiri Group; Nakamori 1982).

Miyako Island is the largest in the archipelago. To the west are the major islands of Irabu and Shimoji, which are surrounded by small islands such as Kurima, Ikema and Ogami. Reefs in the Miyako Archipelago consist mainly of fringing reefs around these islands, although many patch reefs occur between islands.

Miyako Island is triangle-shaped with western, southern and northeastern coasts. Coral reefs have developed along the northeastern coast (Photo. 1). Tsufutsuwa Reef is a 2.5-km-long patch reef that is located centrally along this coast, off Pisseokanzaki. Towards the northern end of this coast is a group of patch reefs around Ikema and Ogami Islands. North off of Ikema Island is Yabiji Reef, which consists of ~100 table and platform reefs scattered in a ~10×6.5-km^2 area (Photo. 2). The southern coast of Miyako Island has sheer cliffs, and the reefs here are comparatively narrow. Relatively shallow (20–50 m depth) and calm water lies between the western coast of Miyako Island and Irabu Island. However, reefs are not well developed here; instead, the sea bottom is a gradual slope that is covered with coral sand and rubble. The sandy or muddy bottom of Yonaha Bay, in the southwest of Miyako Island, is only a maximum of 5 m deep, and sandy stretches are home to the largest seagrass bed in Okinawa (902 ha; Nature Conservation Division, Okinawa Prefecture 1999).

Photo. 1. Landscape of coral reef at Agari-hennazaki, Miyako Island

Irabu and Shimoji islands are surrounded by weakly developed reefs, with sandy bottoms and flat bare rocks also present. Many submerged patch reefs occur to the south and around Kurima Island. Tarama and Minna islands are surrounded by relatively simple fringing reefs, and the sea bottom is mostly covered with flat bare rocks. Sandy bottoms are found to the north of Minna Island.

2. Coral distribution

Coral fauna of the Miyako Archipelago is not well described. In terms of hermatypic corals, 302 species from 61 genera and 17 families have so far been reported or recognized (Matsumoto 1992; Nishihira and Veron 1995; Hirara City 2003; Matsumoto personal communication) in this area. Although this number of species constitutes at least 50 species less than that is known to occur in the Yaeyama Archipelago or Okinawa Islands, this is probably reflective of the fact that relatively few studies have been carried out in the Miyako Archipelago. Owing to the structurally complex and relatively pristine nature of the area's coral reef habitats, it is expected that future investigations will uncover coral species biodiversity similar to that of other Okinawan reefs.

The percentage of coastal sea bottom within the Miyako Archipelago that is covered by coral communities is 18.2 % (3703.4 ha), which is relatively low (34.4 % (3707.4 ha) is bare rock, 25.5 % (2749.8 ha) is sandy, and 20.2 % (2180.5 ha) is covered by seagrass or algae; Nature Conservation Burean, Environment Agency 1994). Coral coverages of generally < 5 % occur on the western coast of Miyako Island and around Irabu and Shimoji islands. By contrast, branching *Porites* colonies cover more than 50 % of the southern reef flat of Tarama Island and the northern reef flat of Minna Island. Off the southern coast of Kurima Island, the northeastern coast of Miyako

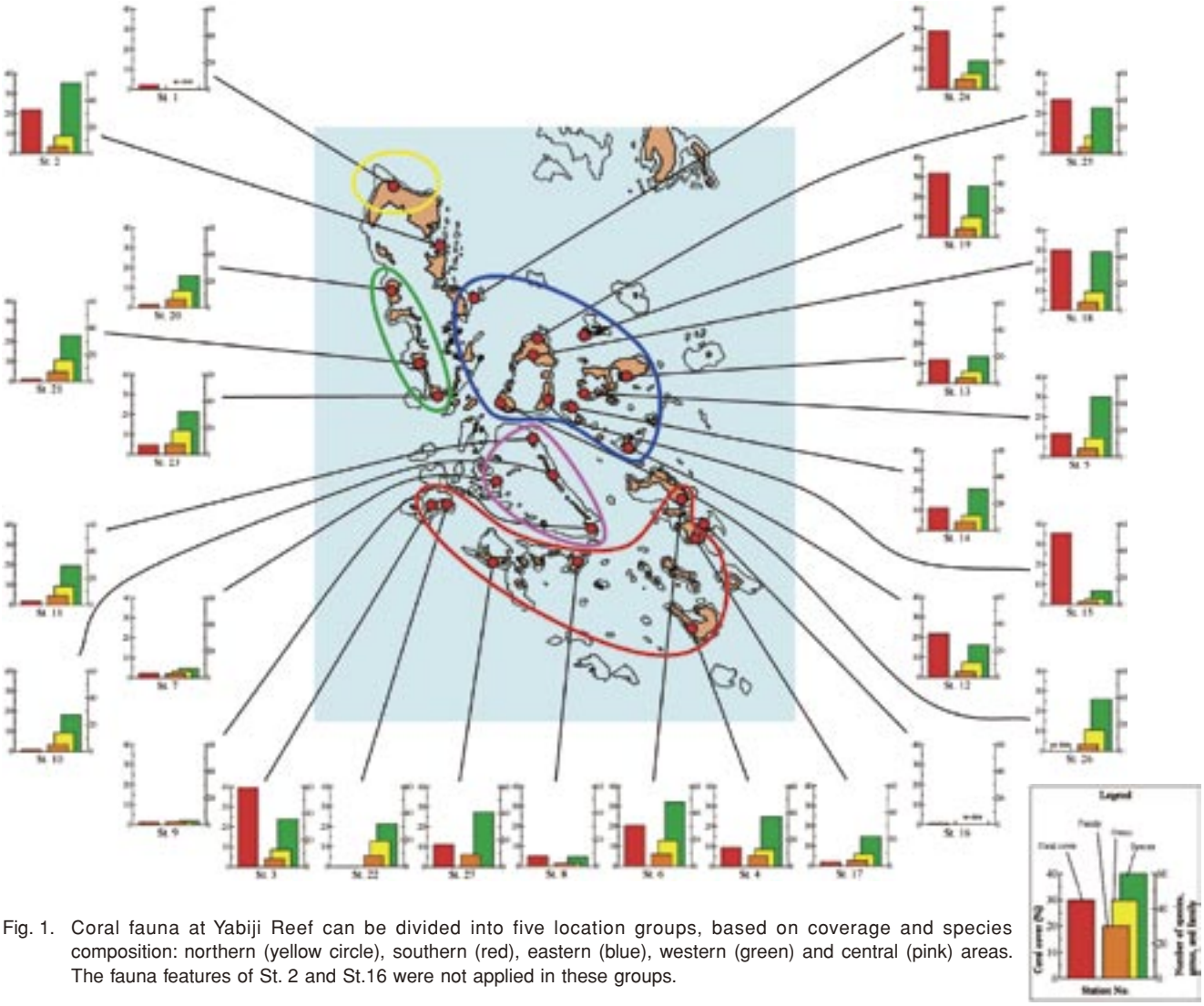


Fig. 1. Coral fauna at Yabiji Reef can be divided into five location groups, based on coverage and species composition: northern (yellow circle), southern (red), eastern (blue), western (green) and central (pink) areas. The fauna features of St. 2 and St.16 were not applied in these groups.

Island, and around Yabiji Reef and Ikema and Ogami islands, coral cover is also > 50 %. These areas are mostly dominated by branching and tabulate *Acropora* and/or branching *Porites*. Branching *Montipora* dominates in some locations along the southern coast of Miyako Island.

The coral fauna of the reef edge and reef flat of Yabiji Reef has been investigated, and it has been suggested that the coral communities of this area can be classified into five categories, on the basis of location (Hirara City 2003; Fig. 1). In northern communities, only encrusting corals were found at reef edges. Heavy winter sea conditions, generated by seasonal winds from the north, probably render this habitat unsuitable for branching or tabulate corals. Southern communities were dominated by many small colonies of branching *Acropora*, many of which appeared to have died quite recently, as their skeletal structures were still easily distinguishable. The reason for their death remains unclear. Eastern coral communities were characterized by large colonies of branching *Acropora* and *Montipora*; this is probably due to the prevailingly calm sea conditions that result from the protective influence of numerous patch reefs. Many massive Faviidae and encrusting *Montipora* spp. have been found amongst western coral communities. These reefs face the open sea, and consequently wave action is probably a strong influence. Central coral communities were dominated by small colonies of branching *Acropora*, and by relatively low coverage. The sea bottom was found to be mostly covered with sand and/or rubble, and sedimentation is probably a major influence on this habitat. Since the reef slope fauna has yet to be investigated, it is likely that the coral species biodiversity of Yabiji Reef is higher than that has been reported thus far; it is probably similar to that of other Okinawan reefs. Yabiji

Photo. 2. Low tide at Kijaka, part of Yabiji Reef in the Miyako Archipelago.

Reef is also important because of its healthy state; its isolation means that anthropogenic disturbances are kept to a minimum, and its proximity to the sea means that water temperatures remain below those that cause mass bleaching events.

3. Water quality and physical environment

The Miyako Archipelago is mostly flat, with a single river of sufficient size to be visible on a 1/25,000 scale topographical map (published by Geographical Survey Institute of Japan). The Urai River is ~500 m in length and is located near the northwestern coast of Miyako Island. Complex groundwater veins are a characteristic feature of Miyako Island, and groundwater exudes at some points both terrestrially (mainly around the southern cliffs) and from the sea bottom in coastal waters (little is known of these locations).

4. Notable species and ecosystems

Okinawa's largest seagrass bed (902 ha) is in Yonaha Bay. Plant species mainly consist of turtle grasses' *Thalassia hemprichii*, *Cymodocea rotundata* and *Syringodium isoetifolium*. In 1999 this was designated a strict nature reserve, according to guidelines for natural environment conservation (Nature Conservation Division, Okinawa Prefecture 1999).

There are almost no long rivers on Miyako Island, and therefore suitable habitats for mangroves are scarce. Even the largest mangrove swamp zone, on the northern coast at Shimajiri, is only ~2 ha in area. *Rhizophora stylosa* mangroves dominate, although *Bruguiera gymnorrhiza*, *Kandelia candel* and *Avicennia marina* also occur here. These Miyako Island *A. marina* are at the northern limit of their natural distribution (Hatushima 1975). This mangrove swamp has been designated a geographically valuable Japanese wetland (Nature Conservation Bureau, Ministry of the Environment 2002a).

Fudeiwa Island, a small rocky island northeast of Ikema Island, is an important breeding ground for sea birds such as terns and gannets.

2 Situation usages

1. Tourism

SCUBA diving is popular, and there are more than 50 dive operators, mainly based on Miyako Island. Dive sites are established not only at places where corals are abundant, such as Yabiji Reef, but also in areas where there are underwater caves and where coral distribution is limited, such as around Shimoji Island. Snorkeling is popular at Aragusuku, Yoshino, and Bora on the southeastern coast of Miyako Island. Fish-feeding (especially damselfish and butterfly fish) is common in these areas. Coastal or offshore gamefishing is also popular around the archipelago.

For around three days, each April, 2000–3000 tourists use large ferries to land on Yabiji Reef (see Section 4-2). During ebbing spring tides, tourists take part in reef walking.

2. Fishery

Three fishery cooperatives have fishing rights in the waters of the Miyako Archipelago. Approximately 50 demarcated areas of sandy reef flats and sea grass beds around Miyako and Irabu islands have been specifically designated for aquafarming of 'mozuku' (*Nemacystus decipiens* and *Tinocladia crassa*).

From 1981–2001, 52 steel or concrete artificial fish breeding reefs were installed throughout the archipelago. Hatchery-raised juveniles of desirable species (e.g., swimming crab, sea urchin, emperor fish, button shell and giant clam) have been released into the coastal waters of the archipelago to supplement natural stocks. These juveniles were produced at the Sea-Farming Center of Hirara City, Miyako Island, the Okinawa Prefectural Sea Farming Center on Okinawa Island, the Fishery Experiment Stations of Okinawa Prefecture on Okinawa and Ishigaki islands, and the General Fishery Research Center (the former Japan Sea Farming Association) on

Ishigaki Island.

The major fisheries in the archipelago include longline and trawl fishing (for swordfish and tuna), pole and line fishing (for snappers, groupers and skipjack), dive fishing (for groupers, parrotfish, lobsters, giant clams, top shells, octopus and sea urchins), crab trapping (for swimming crabs), "drive-in" fishing (diving fishermen drive fish such as fusiliers into a net), and single hook fishing (using fist-sized stones as disposable weights for deep sea fishing, targeting species such as snappers and sea bream). Giant clams, top shells, octopus, sea urchins and seaweeds are collected from reefs at low tide by gleaners. Aquaculture for mozuku and prawns (*Penaeus japonicus*) also occurs. "Drive-in", gleaning, and fishing with single hooks are the traditional methods.

3. Others

Since 1997, the Sea-Farming Center of Hirara City has run work-study classes for high grade elementary school students, which involve the release of cultured juvenile fish (Photo. 3). These classes aim to raise environmental awareness of the need for the conservation of fishery resources. Training for voluntary coral reef guides has been available since 2001 in Hirara, with the objective of decreasing the destructive impact of the annual Yabiji Reef landing tour. Program participants have established an NGO called the "Reef Interpretation Society, Miyako Islands" and, since 2002, have conducted reef observation events and exhibitions for residents that emphasise the importance of the natural and cultural aspects of coral reefs. Other relevant work-study classes are available at some schools. For example, students at Karimata Junior High School can experience traditional drive-in-fishing methods.

Photo. 3. Elementary school children releasing juvenile sea urchins (*Tripneustes gratilla*) as part of a work-study class. This program aims to educate the public about environmental conservation issues, including the need for management of fishery resources in the Miyako Archipelago.

3 Threats and disturbances

1. Crown-of-thorns starfish (*Acanthaster planci*)

Outbreaks of crown-of-thorns starfish (COTS) in the archipelago were reported from 1957–1959 (Nature Conservation Burean, Environment Agency 1973), and also through the 1970s and 1980s, when outbreaks occurred all around Okinawa Island. However, there are almost no detailed records regarding the scale or the progression of the outbreaks, or regarding the status of coral communities before and after the outbreaks. No outbreaks have been observed since these events.

2. Bleaching

During the world-wide beaching event in 1998, mass coral bleaching occurred in the Miyako Archipelago. Intense bleaching and subsequent colony death was observed, predominantly affecting *Acropora* species. Although detailed data from before and after the event do not exist, a comparison of coral coverage in 1992 and 1999 suggests degradation of coral communities (Fujiwara and Kondo 2000). Studies of subsequent recovery patterns have not been conducted. In 2001, a warm water mass developed near Okinawa and another bleaching event was observed. However, this did not seem to lead to mass mortality.

3. Sedimentation

Although terrestrial soil run-off from various stretches of the coast of Miyako Island does occur after heavy rainfall, the amount of sedimentation is generally low. Omija *et al.* (1993) evaluated that the average suspended particles in sea sediment (SPSS - an index of the amount of soil run-off) was 9.5 kg/m^3, observed over nine stations around Miyako and Irabu islands. This is quite low compared to the 40.1 kg/m^3 evaluated from 233 stations throughout the rest of Okinawa. Probable reasons for the low SPSS in the Miyako Archipelago, where most of the land area has been developed, include the highly water-permeable soil (called Shimajiri-maaji) and the general flatness of the island, together with the absence of large rivers.

4. Others

According to the Marine Biotic Environment Surveys, 69.7 ha of coral reef area were reclaimed for port construction in the period 1987–1991 (Nature Conservation Burean, Environment Agency 1994). Another 69 ha were reclaimed up until 2002, mainly at Hirara and the town of Shimoji. The largest single reclamation project of recent years involved 32 ha for a resort facilities site, undertaken by the city of Hirara, from 1995 to 2002.

4 Monitoring and conservation

1. Current state of research

Hirara has monitored coral community coverage changes (with species identification to genus level) at four stations on Yabiji Reef since 1999. Since 2000, a Japanese NGO, Coral Network, has promoted Reef Check (a world-standardized-method survey of coral reefs) in the Miyako Archipelago.

In October 2003, the COTS Table of Miyako Marine Dangerous Organisms Consortium developed a framework for monitoring COTS outbreaks. The monitoring methods follow those of the Rapid Survey Manual (Nature Conservation Division, Okinawa Prefecture 2002).

2. Current conservation measures

The city of Hirara is promoting environmental conservation, fishery protection, and tourism as part of a project monitoring the impacts of the annual Yabiji Reef landing tour. The project includes observations of coral community status, investigation of actual impacts of tourism, and a test introduction of volunteer reef guides. Guidelines regulating tourism on this reef will shortly be developed (see Chapter 4–5 for details).

The COTS Table includes the Miyako Branch Office of Okinawa Prefecture, six municipalities, three fishey cooperatives, diving services, and other organizations. Members discuss the monitoring framework, selection of protective zones, extermination methods, and other COTS countermeasures.

5 Notes

There is no research organization based in the Miyako Archipelago, and consequently very little coral reef status information is available, as compared to other locations in the Okinawa Islands or Yaeyama Archipelago. No marine protected areas (or similar reserve sites) have been designated in the Miyako Archipelago.

Column

Geographical features and use of Ryukyu limestone

Shigekazu Mezaki

Coral reef islands in the Ryukyu Islands can be roughly divided into 'High Islands' or 'Low Islands', based on their geomorphology; where the former supports mountains while the later are low-land plateaus. While High Islands are either composed of ancient metamorphic or volcanic rocks, of the Palaeozoic and Mesozoic era, most of Low Islands are composed of Ryukyu limestone (Pleistocene limestone) (Fig. 1). About one third of the Okinawa Prefecture is covered by Ryukyu limestone.

Karst topography, shaped by solvent etching processes, exists at the surface and underneath the Ryukyu limestone. In some parts of the Amami Island group, there are karst plateaus with shallow geographic depressions, or dolines (sinkholes). However, most of the islands are composed of convex geographical features that resisted solvent etching, for example, Okinawa Island. Okinawa was named 'limestone wall' by the U.S. military geological survey in postwar days, because of its peculiar bank-like topography that parallels fault or terrace ledges. They are well developed in central and southern parts of Okinawa Island and on Miyako Island. The 'upheaval atoll' of Kitadaito Island and Minamidaito Island are rare geographical features, since there are only about 10 examples in the world of such low island karst topography.

Ryukyu limestone areas support few surface running rivers, and the soils are difficult to dig. Therefore, the location of traditional villages was closely related to spring water or underground rivers. Spring water is easily obtained at the bottom of faults and terrace ledges because the limestone layer plays a role of aquifer. Many villages were built at the south and southwest side of faults and ledges. This premeditated 'geomancy' village protects houses from the northeast monsoon in winter, but faces the sunny south. Since the limestone banks are elevated, many were also used to support castle walls (*Gusuku*) or for places of worship (*Utaki*). The negative aspect was the residual soil of weathered limestone (called the *Shimajiri maagi*) is sparse on terrace flat lands, therefore, only potatoes and sugarcane grow well on these soils.

Ryukyu limestone is associated with innumerable limestone caves. However, because the Ryukyu limestone layer is thin, short-horizontal caves are most common. 'Gyokusendo', the caves in southern part of the Okinawa Island, are famous for sightseeing. The caves were originally used as grave yards and places of ancestral worship. However, some of them are now historic war sites, because they were used for shelters during World War II.

Thus, Ryukyu limestone is used in multiform and in people's living on Okinawa.

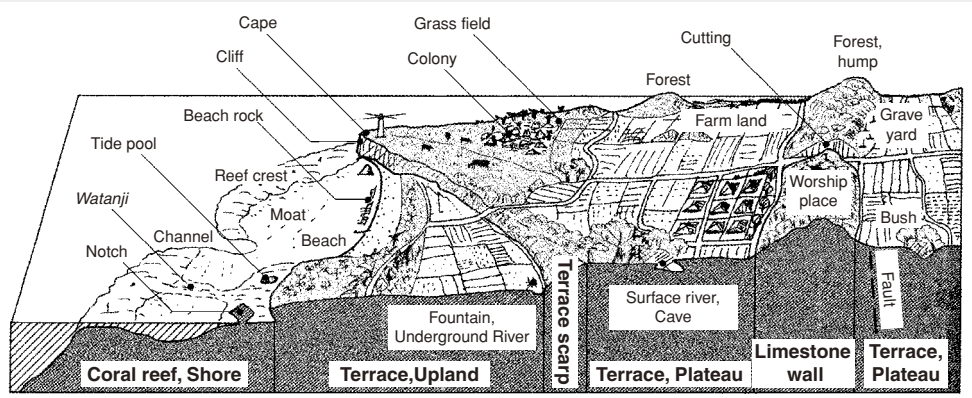
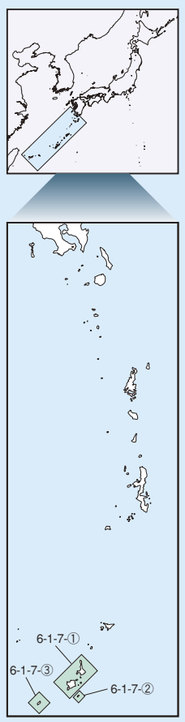
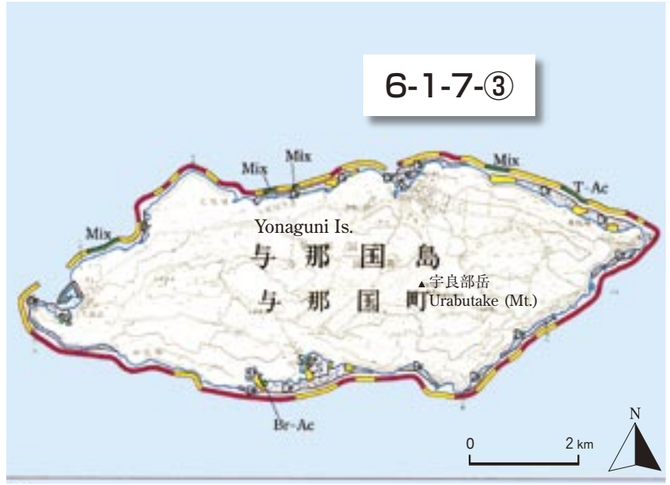


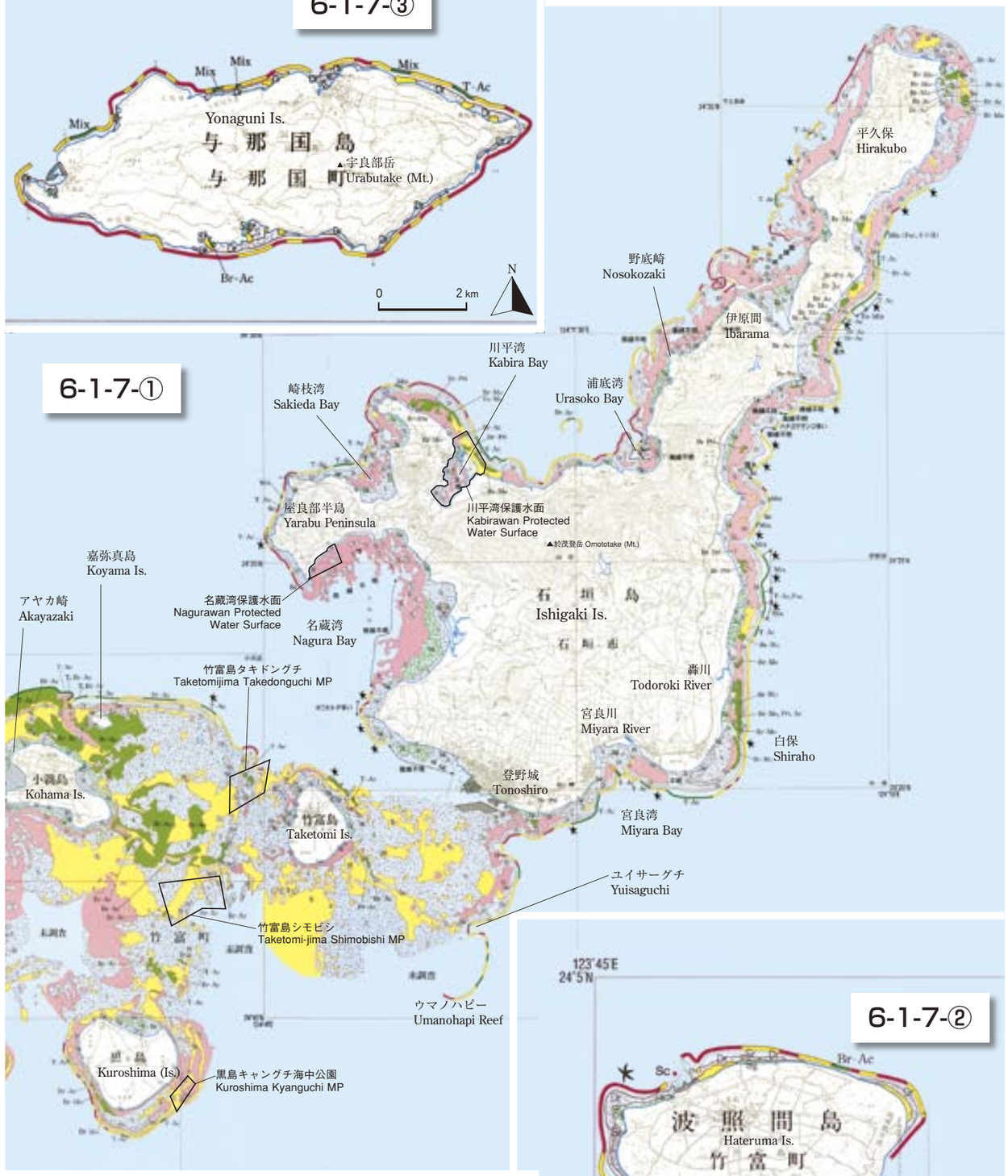
Fig. 1. A model map of the geographical features, their names, and the land use of 'Low island' composed of the Ryukyu limestone (from Mezaki and Toguchi 2002). *Watanji*: infilled moat that provides people's pathway to the reef during low tides.

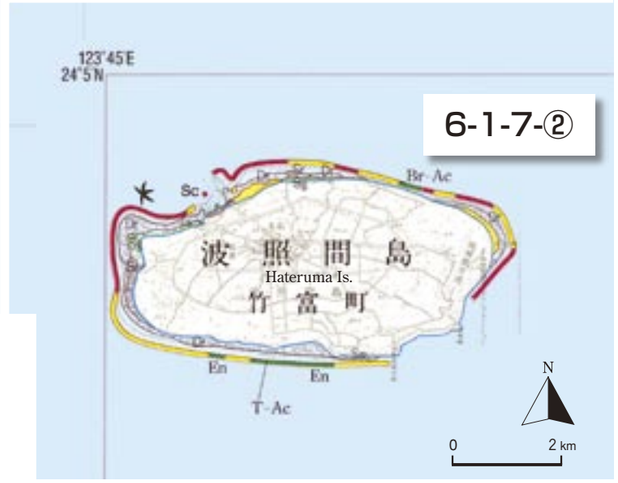
6-1-7 Yaeyama Archipelago
(Map 6-1-7)

Province: Okinawa Prefecture **Location:** ca. 430 km southwest off Okinawa Island, including Ishigaki, Iriomote, Kohama, Taketomi, Yonaguni and Hateruma Island, and Kuroshima (Is.). **Features:** Sekisei Lagoon, the only barrier reef in Japan lies between the southwestern coast of Ishigaki Island and the southeastern coast of Taketomi Island **Air temperature:** 24.0˚C (annual average, at Ishigaki Is.) **Seawater temperature:** 25.2˚C (annual average, at east off Ishigaki Is.) **Precipitation:** 2,061.1 mm (annual average, at Ishigaki Is.) **Total area of coral communities:** 19,231.5 ha **Total length of reef edge:** 268.4 km **Protected areas:** Iriomote National Park: at 37 % of the Iriomote Is. and part of Sekisei Lagoon; Marine park zones: 4 zones in Sekisei Lagoon; Nature Conservation Areas: Sakiyama Bay (whole area is designated as marine special zones as well); Protected Water Surface: Kabira and Nagura Bay in Ishigaki Is.









a. Ishigaki Island

(Map 6-1-7-①)

Hitoshi Hasegawa, Hiroya Yamano

1 Corals and coral reefs

1. Geographic features

Ishigaki Island is composed of Paleozoic to Mesozoic Yaeyama metamorphic rocks, along with Tertiary Miyara Group and plutonic rocks, surrounded by terraces of the Ryukyu Group (Kawana *et al.* 2001). The islands face the Ryukyu Trench and the Holocene has seen significant uplift and tilting (Fig. 1, Photo. 1), as revealed by the heights of the notches (Kawana 1987). Ishigaki Island is surrounded by fringing reefs of several hundred meters to 1 km in width (Photo. 1). Well-developed reefs with distinct topographical zonation are found along the Pacific or windward (northern) coasts, while poorly developed reefs are found in more protected leeward areas. Differences in wave energy have been suggested as the cause of this contrast (Mezaki 1991; Yamano *et al.* 2003).

Ishigaki Island's modern coral reefs began accumulating around 9400 years BP (Hori and Kayanne 2000). The reef crest reached present sea levels around 4700 years BP on windward reefs. Since that time, reefs have expanded both oceanward and landward (Yamano *et al.* 2001b, 2003). The pattern and speed at which reef development occurs depends on wave energy. For example, 1000-year delays in reef development have been confirmed in a moderate-energy reef, as compared to that of a high-energy windward reef (Yamano *et al.* 2001a, 2003).

Ishigaki Island is hit by typhoons every year (Yamano *et al.* 2000), and occasionally by tsunamis (once every 500–1000 years; Kawana 1989; Kawana and Nakata 1994). Typhoons move coarse coral fragments to backreef sand areas (Yamano *et al.* 2001b). Tsunamis carry coral rubble to backreef areas, and deposit big carbonate rocks on the island (Kawana *et al.* 1987; Kawana and Nakata 1994).

2. Coral distribution

Nishihira and Veron (1995) reported 363 species of hermatypic corals around Ishigaki Island. As with topographical zonation, there is a clear zonation in coral distribution. Massive *Porites* and *Goniastrea aspera* colonies occur near the shore, and branching *Montipora* and arborescent *Acropora* are found behind the reef crest, where wave motion is limited owing to wave protection at the reef edge. In Shiraho, backreef areas are densely populated by colonies of *Heliopora coerulea* (Photo. 2) along with *Montipora* species. Tabular or corymbose *Acropora* and *Pocillopora* occur at reef edges exposed to wave action (Takahashi *et al.* 1985; Nakamori 1986; Nakamori *et al.* 1992; Iryu *et al.* 1995; Satoh *et al.* 2000; Yamano *et al.* 2000; Sugihara *et al.* 2003). While colonies are few on well-developed reef crests that are exposed to wave action during low tides, tabular or arborescent *Acropora* are found on less-developed reef crests that are sheltered

Photo. 1. Shiraho reef. (photo by H. Kan)

Photo. 2. *Heliopora coerulea* colonies in Shiraho reef. (photo by S. Harii)

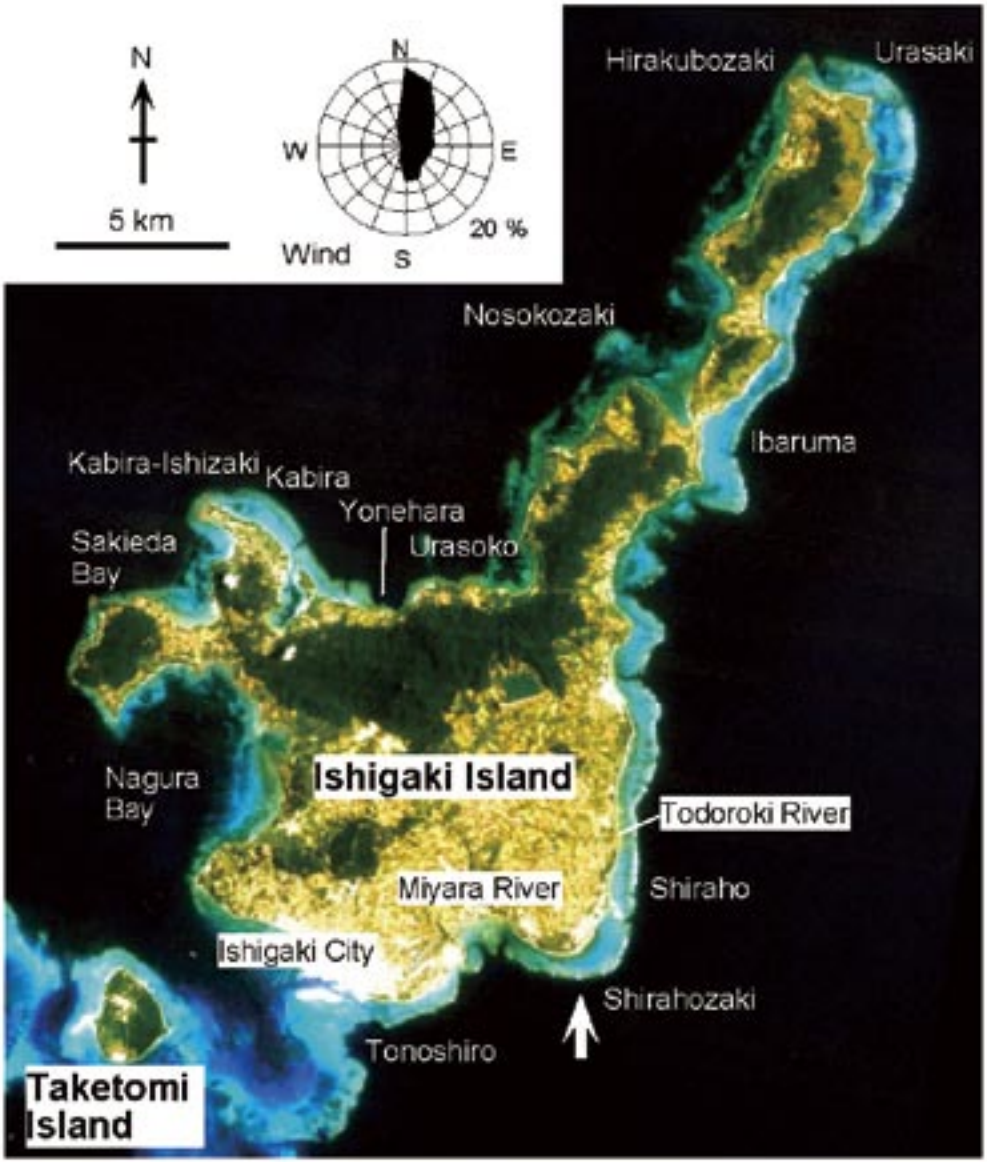


Fig. 1. Landsat TM image of Ishigaki Island (16 May 1994) including wind rose. The arrow indicates the direction in which Photo. 1 was taken.

from waves (Yamano *et al.* 2001a). Massive poritid and faviid colonies are found on a coral reef affected by red soil runoffs (Omija *et al.* 1998). Other organisms such as algae, forams, and sea urchins also show zones of distribution in association with topography (Matsuda 1987; Iryu *et al.* 1995; Ohba *et al.* 2003; Suzuki and Kan 2004).

3. Water quality and physical environment

Water circulation around reefs is mainly driven by tidal current, wind, and radiation stresses induced by waves breaking on the reef crest. The basic pattern of water circulation involves an inflow of ocean waters over the reef crest, water movement into the backreef moat, and subsequent outflows through channels towards the open sea (Yamano *et al.* 1998). The Ryukyu Islands are situated in a monsoon area where the dominant winds change direction seasonally: towards the north in summer, and towards the south in winter. Water flow patterns in coral reefs show a marked wind influence. Flow patterns resulting from north wind conditions are considered dominant, as northern winds dominate throughout the year (Yamano *et al.* 1998). In semi-enclosed Shiraho Reef, there is a slackwater period when the moat is separated from open sea during low tides (Nakamori

et al. 1992; Kayanne *et al.* 1995). Typhoons enhance the exchange of ocean and moat waters (Nadaoka *et al.* 2001).

While turbidity of coral reef water is generally low, groundwater discharge from adjacent terrestrial areas can be observed near the shore (Umezawa *et al.* 2002a, 2002b; Hasegawa 2001). Significant red soil inflow is observed around the mouth of the Todoroki River (Ohgaki and Noike 1992; Omija *et al.* 1998; Mitsumoto *et al.* 2000).

4. Notable species and ecosystems

Shiraho Reef features one of the largest *H. coerulea* communities known in the world (Photo. 2). Larval supply from nearby adult communities, along with characteristics of the larvae and the reef itself, are important factors in the formation and maintenance of these communities (Harii and Kayanne 2003). *H. coerulea* planulae tend to settle near their parents, because the competency period is short, swimming activity is low, and the lipid content (thus buoyancy) is low (Harii *et al.* 2002). Furthermore, calm waters during the slackwater period at low tides (Nakamori *et al.* 1992; Kayanne *et al.* 1995) probably foster locally successful settlement of *H. coerulea* larvae (Harii and Kayanne 2002).

2 Situation of usages

1. Tourism

a) Regional economics and tourism

Approximately 500,000–600,000 tourists are estimated as visiting Ishigaki Island annually. Most tourists come from the more northern parts of Japan, although the number of tourists from Taiwan has recently increased. In 2002, 31,262 people came to the island by sea, of which 19,209 were on cruise ships, mostly from Taiwan.

Photo. 3. Glass-bottomed boat tours of coral reefs around Shiraho. (photo by H. Hasegawa)

In the Yaeyama region, including Ishigaki Island, tourism is worth approximately 40.9 billion yen a year (18 % of the region's total income). This percentage is far greater than that for Okinawa Prefecture overall (7 %). On Ishigaki Island itself, tourism is estimated to be worth 26 billion yen annually; the contribution of tourism to regional economies is significant, as the net production of Ishigaki City was about 90 billion yen in 2003 (Tourism Promotion and General Affairs Division, Yaeyama Branch Office, Okinawa Prefecture 2003).

b) Tourist use of coral reefs

The main tourism activities are SCUBA diving, snorkeling, and coral observation tours using small glass-bottomed boats (Photo. 3). A "*Sabani*" cruise on a traditional Okinawan fishing boat, during which traditional fishing methods can be observed and participated in, has been available to tourists since 2000.

SCUBA diving for tourists has been available since the 1980s. At present, ~60 dive shops on Ishigaki Island cater for 8,000–100,000 divers per year. Most divers visit the island between May and September. Seventy percent of the shops are in the city of Ishigaki and surrounding areas, while the rest are in Kabira and the northern areas.

Many dive sites are in the Sekisei Lagoon area, as well as around the western parts of Ishigaki Island, off the Yarabu Peninsula to Kabira-Ishizaki, and at Yonehara. When winds from the north predominate (in winter), more protected dive sites around Nagura Bay to Shirahozaki are used. Recently, the range of dive sites has expanded to include areas around Nosokozaki, and the area from Ibaruma to Hirakubozaki.

Divers mostly visit reef slopes or patch reefs to watch manta rays and other fishes. Schools of manta rays come to the island between September and November, and up to 40 individual mantas can be observed daily. The large numbers may be attributed to the good relationship between mantas and divers; these dive sites offer good examples of this. Diver behavior resulting in distress or injury to the mantas has occurred in other regions.

Coral observation from glass-bottomed boats is popular at Kabira and Shiraho, where there are thirteen and six such boats, respectively. Approximately 300,000 tourists use glass-bottomed boats each year in Kabira, along with 5,000-5,500 in Shiraho.

Reclamation of the Shiraho reefs for construction of a new airstrip was planned in 1979. Although coastal construction did commence, the reclamation project was abandoned thanks to campaigns against the destruction of the reefs. Owing to the success of these campaigns, Shiraho became very popular with tourists, and the local provision of tourism services, such as hotels, increased. During this period, local hotels commenced their operation of glass-bottomed boat and snorkel tours around Shiraho. The operation of glass-bottomed boats began in 1975 in Kabira.

Overuse of coral reefs has become very apparent at Shiraho. Inside Shiraho Reef, where tour boats often take visitors for snorkeling, there are some depressions with a diameter of 200–300 m. No rules regulate glass-bottomed boat or snorkel tours in Shiraho, and damage to the reef from snorkelers and boat anchors is increasing. The fact that no snorkeling is permitted during glass-bottomed boat tours around Kabira may be contributing to the observed differences in reef health.

2. Fishery

For general information about fishing activities in the Yaeyama region, please refer to Section 6-1-7b, Sekisei Lagoon. Here we specifically describe fishing activities around Ishigaki Island.

Fishery production off Ishigaki Island is derived from three main types of operation: fishing on coral reefs, offshore fishing, and mariculture (e.g., *Nemacystus decipiens*). It is not possible to use large boats in the shallow coral reef areas of Ishigaki Island, so it is remarkable that these fisheries achieve such high catch rates; these rates are achieved through effort-intensive methods such as small fixed-net fishing, single-line fishing and SCUBA fishery. Among these three, 225 tonnes (13.5 % of the total annual catch) is obtained by fishermen using SCUBA gear (Ishigaki City 2003; Department of Agriculture, Forest and Fisheries, Okinawa Prefecture 2003*[1]). Of the 327 communities involved in fisheries, 322 are privately managed companies, and 100 are full-time fishermen. Recent decreases in fish stocks and the resultant lowered income probably account for the small number of full-time fishermen.

3 Threats and disturbances

1. Crown-of-thorns starfish (*Acanthaster planci*)

Crown-of-thorns starfish (COTS) outbreaks were reported in the 1970s and 1980s (Yamaguchi 1986), but control and extermination efforts terminated the outbreak in the early 1990s. Re-occurrence of COTS was recently reported in the area (Nature Conservation Bureau, Ministry of the Environment 2002c).

2. Bleaching

A significant bleaching event occurred at Ishigaki Island in the summer of 1998 (Fujioka 1999; Hasegawa *et al.* 1999; Kayanne *et al.* 1999, 2002). The degree of coral damage appeared to be species-dependent. *H. coerulea* suffered only slight damage from bleaching, while *Montipora* and *Acropora* communities in backreef moat habitats suffered significant damage. In Urasoko, all bleached *Acropora* colonies subsequently died out (Fujioka 2002). Seaweed was found overgrowing dead coral skeletons (Ohba *et al.* 2003). Another bleaching event occurred in 2001, but the affected area was smaller than in 1998 (Strong *et al.* 2002; Nature Conservation Bureau, Ministry of the Environment 2001). Since 1998 bleaching has frequently been observed in the summer in the backreef moat off Ishigaki Island.

3. Sedimentation

Red soil inflow occurs around the mouth of the Todoroki River (Ohgaki and Noike 1992; Omija *et al.* 1998; Mitsumoto *et al.* 2000). A significant amount of red soil was discharged following heavy precipitation on 31 May 2001, which caused a decline in the adjacent coral communities (Nature Conservation Bureau, Ministry of the Environment 2001).

Management of farmland significantly affects the amount of red soil runoff. Rainfall at more than 30 mm/h (which occurs 20–30 times a year in this area) can induce red soil runoff from poorly managed farmland.

Overall, the coral reefs of Ishigaki Island suffer disturbances at both local and global scales, and large shifts in community structure (e.g., from corals to algae) have been reported (Ohba *et al.* 2003; Hasegawa 2001).

4 Monitoring

1. *In situ* monitoring of coral reefs at Ishigaki Island

WWF Japan conducted monitoring at 26 sites on the Ishigaki reefs in 1989, 1994 and 1999 (Mezaki 1991; WWFJ 1995). Their procedure was similar to that adopted by the Environment Agency (now the Ministry of the Environment) described below.

Monitoring has been conducted annually at 75 sites since 1998 by the Environment Agency (Nature Conservation Bureau, Environment Agency 1999a, 2000a, b; Nature Conservation Bureau, Ministry of the Environment 2001, 2002a). Visual estimates were made of the following parameters: water depth, substrate characteristics, water transparency, percent cover of live corals, coral morphs, maximum diameter of tabular *Acropora*, density of juvenile *Acropora* colonies, density of *A. planci*, molluskan tracks, degree of bleaching, and other disturbance status (Fig. 2).

Since 1997 Reef Check surveys have been conducted at several sites, including Sakieda Bay, Tonoshiro and Yonehara.

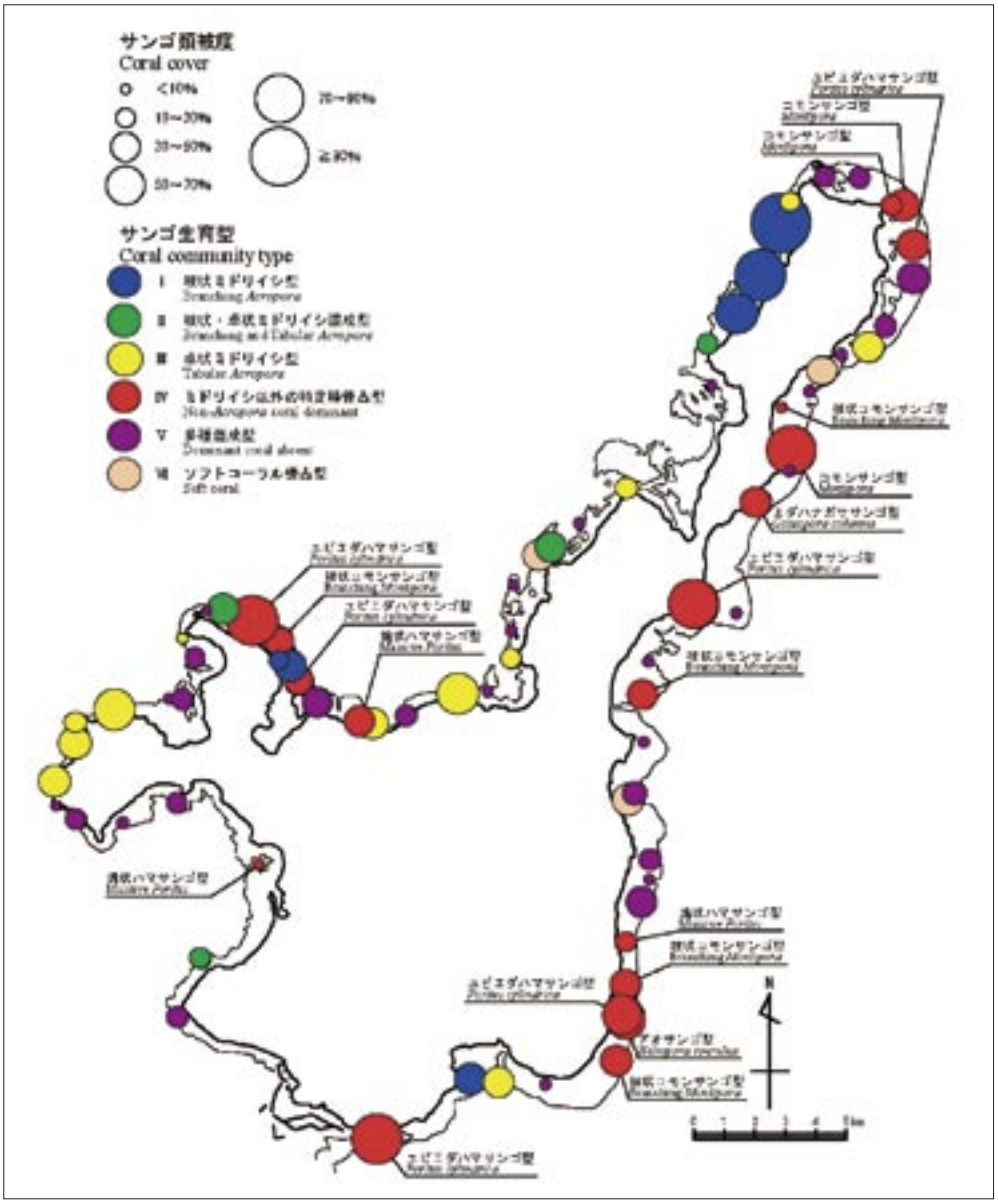


Fig. 2. Area coverage and lifeform of hermatypic corals and soft corals in Ishigaki Island in 2002 (from Nature Conservation Bureau, Ministry of the Environment 2002).

Reef-scale monitoring occurs at Shiraho and Urasoko. At Shiraho Reef, coral status along five shore-reef crest transects has been monitored since 1998 (Kayanne *et al.* 2002). This study has shown that susceptibility to bleaching is coral-dependent: *H. coerulea* has high tolerance, while *Porites*, *Montipora*, and *Acropora* populations have low tolerance to bleaching. Furthermore, post-bleaching recovery of *Montipora* is affected by the colony size; large populations recover more quickly than small populations. At Shiraho, observations using quadrats or transects have been conducted by Tohoku University and WWF Japan, respectively. At Urasoko, quadrat-based monitoring aims to document changes in coral communities (Fujioka 1999, 2002).

2. Remote sensing

Monitoring of reef status is also possible using satellite images or aerial photographs. For island-scale monitoring, Landsat TM has been used to reveal changes since the 1980s (Matsunaga *et al.* 2000); the severe bleaching event in 1998 was detected using this method (Yamano and Tamura 2004). At Shiraho, sedimentation of red soil from the Todoroki River was monitored by Landsat ETM+ (Paringit 2003). Historical aerial photographs have demonstrated that the seagrass area has increased, which is probably due to increasing inflow of red soil (Hasegawa 2001). At Kabira, historical aerial photographs of backreef areas reveal that coral colonies have changed significantly over time. This has been attributed to typhoon-related disturbances (Yamano *et al.* 2000).

3. Water temperature

In addition to the monitoring of coral reef status, water temperatures have been monitored both *in situ* (Nature Conservation Bureau, Ministry of the Environment 2001, 2002) and remotely by NOAA AVHRR (Strong *et al.* 1997, 2002c). At Shiraho, water temperatures have been monitored at four locations by WWF Japan and Kokushikan University, since 1999. Additionally, in 1999 the Environment Agency began monitoring at ten locations around Ishigaki Island. These data are published by each organization. SST monitoring by NOAA (Strong *et al.* 1997) contributed to the detection and monitoring of the bleaching event in 2001 (Strong *et al.* 2002).

5 Conservation

For general information on the Yaeyama region, please refer to Section 6-1-7b Sekisei Lagoon. In this section, we describe management and conservation activities that are specific to the reefs of Ishigaki Island.

Significant amounts of red soil runoff have been observed in the Miyara and Todoroki rivers. Red soil deposition has been observed near the river mouths, on the southeastern coast of Ishigaki Island. The annual amount of soil discharge has been estimated to be 32,880 tonnes (Department of Health and Environment, Okinawa Prefectural Government 1994). Red soil runoff is considered a product of land development, from projects that commenced in the 1970s (Ohgaki and Noike 1992). Irrigation and drainage systems and agricultural fields were constructed around that time, and a stable yield of sugar cane has been achieved. However, over time, the fields have become wider (up to 200 m in width) and fields with gradients as steep as 5 % have been cleared. In addition, decreased soil permeability, owing to disturbance and the use of artificial materials, has resulted in soil runoff for more than 30 years.

Okinawa Prefecture and Ishigaki City have been attempting to control runoff by constructing grit chambers and by decreasing the gradient of the fields. Other good land management practices, including covering crops and mulching, planting sugar cane in spring, and developing green belts around the fields, have also been tried.

Despite these countermeasures, red soil runoff has continued. Over half of the farmers surveyed in 2001 were aware that red soil was running off from their fields, but 25 % and 16 % of the farmers were disinclined to introduce green belts and the covering of crops, respectively, even if the cost was subsidized by the government (Ishigaki City 2001). Thus, significant discrepancies in intent with respect to conservation exist between the administration, farmers, and fishermen.

6 Necessary measures

Although COTS outbreaks have not caused significant damage around Ishigaki Island, corals were severely damaged in the Sekisei Lagoon area. Frequent bleaching has been observed since 1998, probably due to climate change, but there is no effective management for bleaching events.

Multiple stressors are considered to contribute to bleaching events, the most important of which is abnormally

high water temperature. Stress due to sedimentation (red soil runoff) could also be a contributing factor. Various soil management activities have been attempted by administrative agencies, but, so far, they appear to have been unsuccessful. The effectiveness of these countermeasures is open to examination.

Another significant disturbance is that of excessive nitrogen input due to cattle sheds; this source of contamination is currently unregulated. Ishigaki Island has the highest rate of beef cattle production in Okinawa Prefecture (27,000 heads). Nutrients flowing into rivers directly from cattle sheds could constitute a significant input of nitrogen to coral reefs, potentially resulting in the decline of coral communities (Hasegawa 2001).

Tourism is important to the economy of Ishigaki Island. Increasing tourist numbers has been their first priority, and little consideration has been given to the overuse of coral reefs. Government administrative bodies should be responsible for the sustainable development (in terms of the "carrying capacity" of the limited coral reef resources) of tourism.

Cited website:

*1: http://www.pref.okinawa.jp/suisan/mokuji1.htm (as of Nov. 5, 2003)

b. Sekisei Lagoon

(Map 6-1-7-①)

Kazuyuki Shimoike

1 Corals and coral reefs

1. Geographic features

Most coral reefs in the Ryukyu Islands are fringing reefs. However, Sekisei Lagoon is somewhat deep, about 10-20 m in depth, and supports Japan's only well-developed barrier reefs. The lagoon is located in the sea, between the southwestern coast of Ishigaki Island and the southeastern coast of Taketomi Island, and between Taketomi Island and Kohama Island (Machida *et al.* 2001).

Holocene coral reefs in the eastern part of Sekisei Lagoon began growing about 7,600 years ago on comparatively smooth basic Ryukyu Group geographical features (about 20–25 m in depth). Active upheaval occurred to the southeast of Ishigaki Island, and the thin coral reefs that initially appeared about 7,000–6,000 years ago were subsequently formed by transgression. Approximately 5,600–5,000 years ago, patch reefs reached the sea surface in the eastern parts of Sekisei Lagoon, and fringing reefs formed around Taketomi Island at about the same time. Approximately 3,600 years ago, barrier reefs developed outside the fringing reefs (both eastern and southeastern lagoon areas). As a consequence, the present day coral reefs of Sekisei Lagoon are formed in three rows, including the uplifted region to the southeast of Ishigaki Island. The unique barrier reefs of Sekisei Lagoon have probably been caused by the smooth Ryukyu Group features of the substrate (Kawana *et al.* 1999; Kawana and Kan 2000).

2. Coral distribution

The Yaeyama district is on the orbit of the Kuroshio Current, close to The Philippine Sea, and has the largest diversity of coral reef species in Japan. Nishihira and Veron (1995) reported 363 species of hermatypic corals, of which 38 species are known only from this location in Japan. Sekisei Lagoon is shallow and calm and a very suitable area for coral growth. The whole area of the Sekisei Lagoon was included in the Iriomote National Park in 1972. Four especially beautiful areas of the Sekisei Lagoon were zoned as marine parks in 1977 (Photo. 1).

Photo. 1. Beautiful coral reef scenery at Taketomijima Shimobishi Marine Park Zone in Sekisei Lagoon (September 2003).

Coral communities on patch reefs around Kuroshima (Is.) and Yonara Waterway, between Kohama Island and Iriomote Island, feature > 60 % *Acropora* coverage. The sea area around the northeastern and southern coasts of Kohama Island has the lowest percentage of coral coverage in the lagoon (Fig. 1).

Big colonies of *Porites cylindrica* are seen in the area between Uechi and Shimoji Islands in the Aragusuku Islands. A moat occurs from the southeastern to the southwestern coasts of Kuroshima, and branching *Montipora* is the dominant species group here. Soft corals dominate communities on patch reefs between Aragusuku Island and Iriomote Island (Nature Conservation Bureau, Ministry of the Environment 2003b).

3. Water quality and physical environment

The complex geographical features of land and reefs create a highly variable flow field through Sekisei Lagoon. The current off the southeastern coast of Iriomote Island is somewhat weak and stagnates easily. However, the Yonara waterway has a strong current. As a whole, seawater in Sekisei Lagoon tends to flow in from the south and out to the north. The main stream of the Kuroshio Current flows north of the Yaeyama Islands, although a stream flows in south of Yaeyama to an

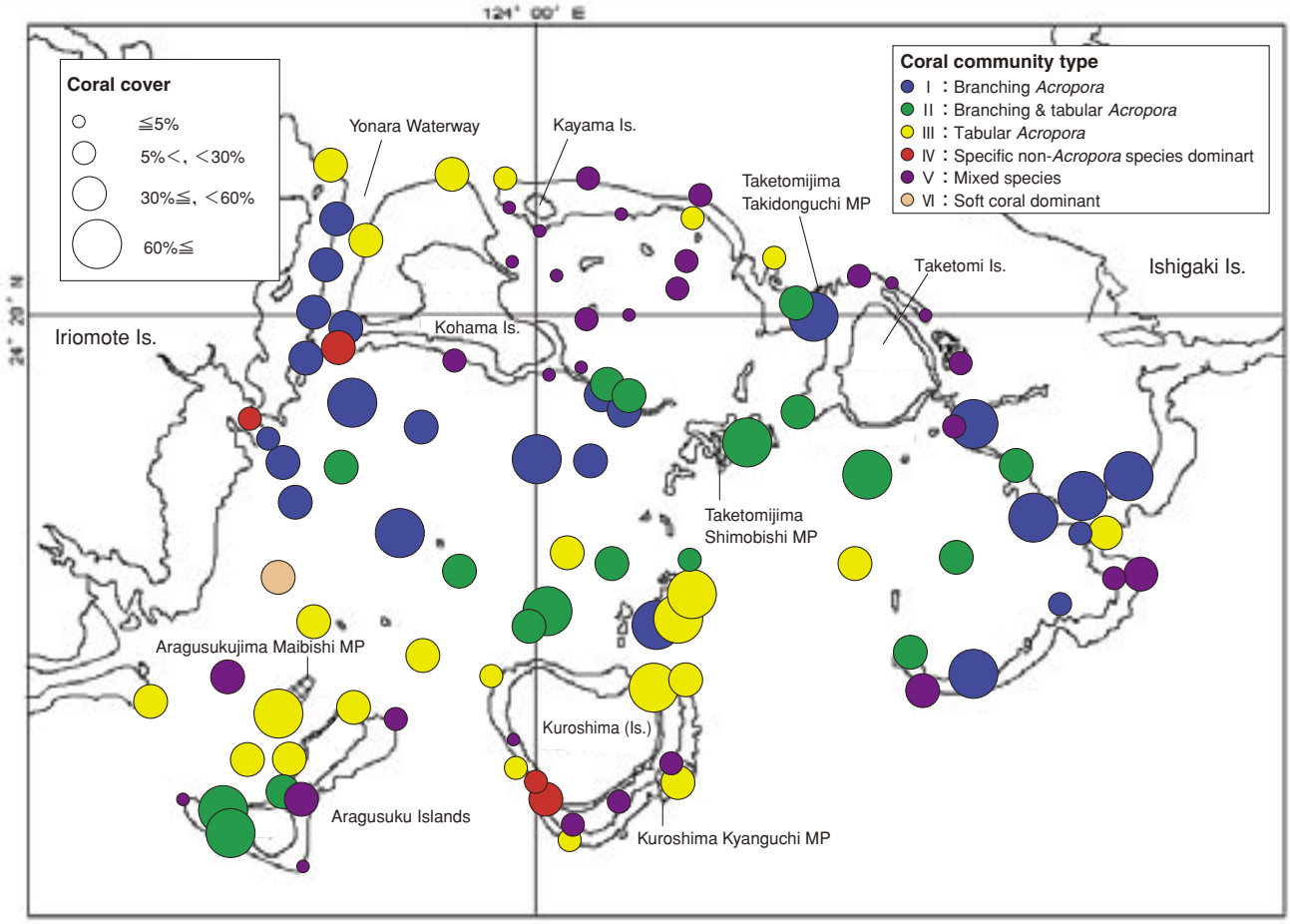


Fig. 1. Hermatypic corals in Sekisei Lagoon in 2002 (from Nature Conservation Bureau, Ministry of the Environment 2003b).

easterly direction, instead of flowing out to the west of Yonaguni Island. When a large anti-clockwise cold eddy approaches the Miyako Archipelago, currents in the southern sea area of the Yaeyama Islands begin to flow westward. This could possibly influence flow patterns within Sekisei Lagoon. The influence of inflow from rivers is limited to areas immediately around river mouths, except at Kohama Island. Following heavy rains, turbidity increases more around Ishigaki Island than it does around Iriomote Island because of red soil runoff from the former (Nature Conservation Bureau, Ministry of the Environment 2003a). Many typhoons approach during summer, and often disturb coral communities.

4. Notable species and ecosystems

Mangroves grow in the area between capes Hosozaki and Akayazaki on Kohama Island, out to the island of Yufu-jima (located between Iriomote and Kohama islands). This area has been designated one of '500 important wetlands in Japan' (Nature Conservation Bureau, Ministry of the Environment 2002a).

Marine algal communities (with 5 % or more coverage) occur off the eastern coast of Iriomote Island, around Kohama Island, and in the sea area off the northwest to the northeastern coasts of Taketomi Island. Gulfweeds and other seaweeds grow on reef edges north of Kohama and Kayama islands, off the southern coast of Aragusuku Island, off the northern and southern coasts of Kuroshima, and at Umanohapi (reef edge off the southern coast of Taketomi Island; Nature Conservation Bureau, Ministry of the Environment 2003a). These algal habitats, in close proximity to coral reefs, create the potential for diverse ecosystems, and are important nursery grounds for fishes and other organisms.

Green turtles, loggerheads, and hawksbill turtles lay eggs on beaches of these island in summer. Recearch on these sea turtles has been conducted in the Yaeyama Marine Park Research station since 1978.

2 Situation of usages

1. Tourism

SCUBA diving is the most popular marine leisure activity in Sekisei Lagoon. There are about 50 dive shops in the area of the city of Ishigaki, and about 20 around the town of Taketomi. Dive sites featuring beautiful coral reef communities, or locations that are frequently visited by fish such as manta rays (Photo. 2), are popular. In recent years there has been a rapid increase in the numbers of tourists participating in ecotourism activities involving canoes or kayaks. Sea bathing, snorkeling, glass-bottomed boat tours, and windsurfing are also popular in coastal areas.

2. Fishery

In Sekisei Lagoon, fishing activities are mainly undertaken by members of the Yaeyama Fishery Cooperative, based in the urban centers of Ishigaki and Taketomi. These fishermen are called 'Uminchu' (a sea person), and most use traditional Okinawan boats called '*Sabani*'. Sport-fishing and reef gleaning, especially for shellfish, are also popular activities. Major fishing methods used in the Yaeyama district include longline and trolled line fisheries (marlin and tuna), single-rod fishing (*Etelis* spp. and coral trout, etc.), diving fisheries (grouper, parrot fish, black sea bream, and cuttle fish, etc.), and drive-in fisheries (double-lined fusilier, etc.). Reef gleaners collect giant clam, button shell, and octopus at low tide. Aquaculture operations raise prawn (*panaeus japonicus*) (on Taketomi Island) and species such as *Nemacystus decipiens*.

The total fish catch of coastal fishing peaked at 2,943 tonnes in 1980, and in 2001 this had decreased to 1,251 t. It is feared that overfishing has reduced the stock size. Resource management is necessary if stocks are to be saved.

3. Others

Every summer since 1982, the Ministry of the Environment has conducted an outdoor school for marine nature observation, for tourists and the local residents of Kuroshima and Taketomi Islands. It aims to deepen the understanding of the need for coral reef conservation, through guided marine observation snorkeling trips and lectures by coral reef researchers.

Courses in coral reef conservation have been run every year since 1996 by the Japan International Cooperation Agency (JICA) in order to train administrative officials and technical experts from other nations with coral reefs in their waters. Field courses are conducted on Kuroshima and other islands.

Photo. 2. Manta ray (*Manta birostris*). They are seen around the Yaeyama Archipelago, and popular among the divers. (photo by T. Tani)

3 Threats and disturbances

1. Crown-of-thorns starfish (*Acanthaster planci*)

The greatest damage to coral communities in Sekisei Lagoon has been inflicted by outbreaks of the crown-of-thorns starfish (COTS; Photo. 3). A population increase of *A. planci* was first observed around Hatoma Island around 1970. COTS numbers increased in the south-eastern part of Sekisei Lagoon during 1972, and after 1976 a widespread outbreak occurred throughout the whole area. The damage extended to the western part of Iriomote Island. By 1983 live coral communities existed in only two sea areas: off the northeastern coasts of Kohama Island and the shore off Komi, on Iriomote Island. These reefs escaped annihilation because of intensive human intervention and extermination of *A. planci*. The Sekisei Lagoon outbreak finally died out in the 1990s.

Live coral coverage did not increase over the 1980s. However, coverage did start to increase after 1991, and

Photo. 3. Corwn-of-thorns starfish (*Acanthaster planci*) outbreak occurred in Yaeyama Archipelago in 1970s. (photo by K. Nomura)

Photo. 4. Mass bleaching event, Sekisei Lagoon, 2001.

by 1995 many locations appeared to have recovered to their previous state (Nomura *et al.* 2001).

COTS numbers were four or fewer during monitoring surveys from 1992 to 2000; however, 14 were observed in 2001 and 2002. Another outbreak is possible (Nature Conservation Bureau, Ministry of the Environment 2003b).

2. Bleaching

After the outbreak of *A. planci* had subsided, coral communities in Sekisei Lagoon appeared on track for recovery. However, they were further damaged during the mass bleaching event in the summer of 1998, caused by globally high water temperatures. Reef edges off the north-northwestern coasts of Taketomi Island were particularly severely damaged.

In Sekisei Lagoon, the death rate of *Acropora* and decrease in live coral cover was estimated to be 40 and 8 % respectively (Nomura *et al.* 2000). In addition, another mass mortality of intertidal zone *Acropora* also took place, owing to a record cold wave at the end of 1999 (Nature Conservation Bureau, Environment Agency 2000d). Coral bleaching occurred again in the summer of 2001 (Photo 4), when 29.1 % of corals were bleached in Sekisei Lagoon, and 3.5 % died. Damage was especially severe in the eastern moat of Kuroshima Island, where 95 % of corals were bleached (Nature Conservation Bureau, Ministry of the Environment 2002b).

3. Sedimentation

Red soil runoff from Kohama, Iriomote, and Ishigaki islands continues to aggravate the reef environment, and to disturb opportunities for the healthy recovery of the coral community. Deposition of silts is relatively high and coral coverage is low in the sea area from the northeastern to the southern coasts of Kohama Island. The proportion of sedimentation that seems to be of red soil origin is increasing every year. Silt is also piling up on the sea floor at Yonara Waterway, where coral communities featuring high coverage of *Acropora* occur (Nature Conservation Bureau, Ministry of the Environment 2002b).

4 Monitoring

The Yaeyama Marine Park Research Station was established in Kuroshima (Is.) by the Marine Park Center in 1973 for the management of the marine park of the Sekisei Lagoon, and since then the institute had led the coral reef monitoring of the Sekisei Lagoon and education of the coral reef conservation. However the Marine Park Center dissolved in 2002, the monitoring of the coral reef was succeeded to the Ministry of the Environment International Coral Reef Research and Monitoring Center which was established in Ishigaki Island in 2000, and the Yaeyama Marine Park Research Station was succeeded to the Sea Turtle Association of Japan, NPO. International Coral Reef Research and Monitoring Center is expected to play not only in our country but also the role in the east Asian sea as the base on Global Coral Reef Monitoring Network (GCRMN).

These monitoring programs are designed to quickly identify factors that threaten the healthy growth of coral communities, and to enable the best use of this information for conservation purposes.

1. Monitoring surveys in Sekisei lagoon, in Iriomote National Park, and in adjacent areas

The Yaeyama Marine Park Research Station began monitoring in 1983, partly on behalf of the town of Taketomi. The Environment Agency (now the Ministry of the Environment) took on the role of setting up these surveys in 1998. Monitoring was undertaken using the 'spot check' method for 15 minutes (3 × five-minute observation periods) per point, at about 110 fixed points in Sekisei Lagoon. Parameters included coverage and morphs of live corals, maximum diameter of tabulate *Acropora*, bottom features, depth, sedimentation, number of *A. planci*, coral bleaching, and other specific details (Nomura *et al.* 2001).

2. Proof region monitoring

Proof region monitoring has been proceeding, as part of a project set up by the Ministry of the Environment, since 2000. Data, including information on coral coverage, dominant species, benthic organisms, and coral disturbance phenomena, are recorded along a belt transect of 15 × 2 m. Six transects are set between the islands of Ishigaki and Iriomote, and two transects are set off the eastern coast of Kohama Island and off northern Kuroshima Island.

3. 'My point' survey

This research program aims to observe coral reefs over the entire Yaeyama district, through the eyes of members of the Yaeyama Coral Reef Conservation Council. Each member has a specific site ('my point'), which they visit regularly to observe and record survey data (such as coral growth form and coverage, numbers and sizes of COTS, and any unusual events).

4. Reef Check

Reef Check, a globally standardized technique for surveys of coral reefs by volunteers, has been conducted around the islands of Kuroshima and Kohama since 1998.

5 Crown-of-thorns starfish

1. Crown-of-thorn starfish

Between 1972 and 1985, 1.9 million *A. planci* were exterminated in Sekisei Lagoon and surrounding areas through operations conducted by the town of Taketomi, the city of Ishigaki, the Yaeyama Fishery Cooperative, and the Yaeyama Diving Society, among others (figure based on the exterminating budget of the Environment Agency). In addition to ongoing intensive extermination at priority conservation sites, a COTS monitoring network was set up, involving fishermen and other interested parties, as well as representatives of the diving industry (Nature Conservation Buren, Ministry of Environment 2003d).

2. Sedimentation (red soil runoff) countermeasures

The majority of the red soil (clay) that finds its way onto reefs originates in farmland. Since 1993, Okinawa Prefecture has been attempting to implement water quality control measures (by preventing outflow from cultivation) on Ishigaki Island. Methods employed include lessening the gradient of arable land, the construction of drainage channels to filter out the red clay, and the repair of sedimentation ponds. In 1999, a council for conservation measures for the sea around Ishigaki Island was set up by 38 groups; these groups included administrative bodies and private organizations. This council attempts to prevent red soil runoff by planting sunflowers and other crops during the sugar cane fallow period, as well as plants such as *Alpinia zerumbet* around farmlands.

3. Coral transplantation

As part of research into coral reef ecosystem restoration techniques by the Environment Agency, the Marine Parks Center of Japan has carried out transplantation projects in Sekisei Lagoon. Follow-up surveys have been conducted at six-month intervals over the period 1992-1994. The Yaeyama Coral Reef Conservation Council has cooperated with this work. Two and a half years after these projects began, the survival rates for transplanted *Pocillopora eydouxi*, *Acropora formosa*, and *Cyphastrea serailia* were 0–12 %, 0–36 %, and 8–78 % respectively. From these results, it is clear that the suitability of coral species for transplantation differs according to habitat (Nature Conservation Bureau, the Environment Agency 1995a). The Yaeyama Fishery Cooperative has been transplanting *Acropora* around Kuroshima Island, Taketomi Island, and the southwestern coast of Ishigaki Island since 1994.

4. Fishery resource management program

In 1998, in attempt to better conserve fishery resources, the Yaeyama Fishery Cooperative established an area in

which fishing was prohibited at certain times of the year. For five years at this location, fishing was prohibited during the two-month spawning period of *Lethrinus atkinsoni*. In the Sekisei lagoon, Yuisaguchi, a place off south of Ishigaki Island, and Kyanguchi, the southeastern coast of Kuroshima (Is.) have been designated conservation areas that are closed to fishing.

5. Nature restoration program

In 2002, Sekisei Lagoon was selected as a project site for the Ministry of the Environment's natural restoration program. This program aims to recover a healthy ecosystem through active restoration. The management method takes into consideration the future environmental conservation and sustainable use of the Sekisei Lagoon area; progress reports are awaited with interest.

6 Necessary measures

Since 2000, there have been signs of an incipient COTS outbreak. An extermination system has been organized and it is hoped that effective monitoring will enable rapid implementation of the extermination program, and that damage to the coral communities will be minimized.

As the numbers of SCUBA divers increase, destruction of coral colonies by dive boat anchors is becoming noticeable. Simple countermeasures, such as mooring buoys or insertion and retrieval of anchors by divers, are necessary.

As the global environment changes, coral bleaching events have begun to occur more frequently, preventing the healthy maintenance or recovery of coral communities. This constitutes a clear sign of global warming, and should be included in international discussions about the impacts of human activities. Less damage occurs in undisturbed environments, because coral bleaching seems to result from a combination of stressors, of which water temperature is just one. At local levels, all that can presently be attempted is the fostering of corals' regenerative abilities through reduction of human-induced marine disturbances, and the maintenance of good conditions in coral habitat. The development of new techniques (such as the transplantation of young corals cultivated from coral larvae) will be necessary to promote regeneration of degraded coral communities.

c. Iriomote Island and neighboring islands

(Maps 6-1-7-①～③)

Hiroyuki Yokochi

1 Corals and coral reefs

1. Geographic features

None of the Yaeyama Islands are volcanic. 'High islands' have mountains comprised of old boulders, while smooth 'low islands' are composed of Ryukyu limestone.

Iriomote Island is a 'high island', composed, mostly, of Yaeyama Group strata. The island appears to be a comparatively flat plateau when viewed from a distance, because its mountains are all about the same height (~400 m above sea level, including Komidake at 469.7 m). This geographical feature is called a peneplain, or a low-relief erosion surface (Kawana 1988). These mountains and hills are covered with subtropical laurel forest. Generally heavy rainfall feeds large and small rivers, including the Nakama River and Okinawa's largest river, the Urauchi River. Mangrove communities have developed in these estuaries. The southern coast of the island lacks large rivers; sea cliffs, 200–300 m high, are the prominent feature.

The island's surrounding fringing reefs are generally narrow in the south and wide in the north. Eastern shore reefs face Sekisei Lagoon and are less developed. The northwestern ria coast is more complex, with wide, deep bays. During the last glacial period, about 20,000 years ago, sea levels were 120–130 m lower than at present, and valleys were formed by erosion in this area. The valleys became submerged as sea levels rose, and the resulting bays are seen only in this region of Okinawa Prefecture. Iriomote Island displays a wide variety of environments in a relatively small area, from quiet estuarine tidelands in protected bays to well-developed coral reef areas facing large waves from the open sea.

Hateruma Island is a 'low island' composed of Ryukyu limestone. The highest point is about 60 m above sea level and there are no rivers. The coastline consists, mostly, of limestone rocks, with some sandy beaches. Coral reefs are small, and poorly developed off the southeastern shores, where a cliff 20–30 m high has been lifted up through faulting.

Yonaguni Island is a 'high island' with widely varied geographical features, including a range of mountains such as Urabudake (231.3 m). Based on Yaeyama Group strata, mainly limestone terraces are widely distributed in the northern and central parts of the island. The coastline is made up of cliffs and rocks, in the main, with few sandy beaches. The coral reef around the island is small, with a poorly formed moat.

2. Coral distribution

More than 360 species of reef-building corals, belonging to 70 genera, are found in the highly biodiverse seas surrounding the Yaeyama Islands, which include Iriomote Island (Veron 1993).

Except for some areas off the southern coast, Iriomote's hermatypic corals were catastrophically damaged by outbreak populations of crown-of-thorns starfish (COTS) (*Acanthaster planci*) in the early 1980s (Nature Conservation Bureau, Environment Agency 1984, 1988, 1989; Yokochi *et al.* 1991). Coral communities in different locations subsequently recovered at different rates. By 1997, live coral cover approached 70 % at a well-recovered location (Department of Planning and Development, Okinawa Prefecture 1994; Yokochi 1999a). However, shallow water coral coverage dramatically decreased following the mass bleaching event in 1998, and *Acropora* became extinct in some locations (Okinawa Development Agency 2000; Yokochi 2000).

The Ministry of the Environment began a monitoring survey in 1999, which involved observation at 21 locations around Iriomote Island (with the exception of the eastern coasts). *Acropora*-dominated regions (in which 60+ % of coverage was *Acropora*) were observed south of Hatoma Island in 2002. Some places with high coverage have been observed in inner bays of western Iriomote; this coverage has generally been because of domination by a single species such as *Goniopora columna* or *Galaxea fascicularis*. In reef-edge areas, there are many tabular *Acropora* colonies or coral communities composed of mixed species. Although coverage is generally less than 40 % in these places (Nature Conservation Bureau, Ministry of Environment 2003b) (Fig. 1), tabular *Acropora* colonies are growing, and the coverage as

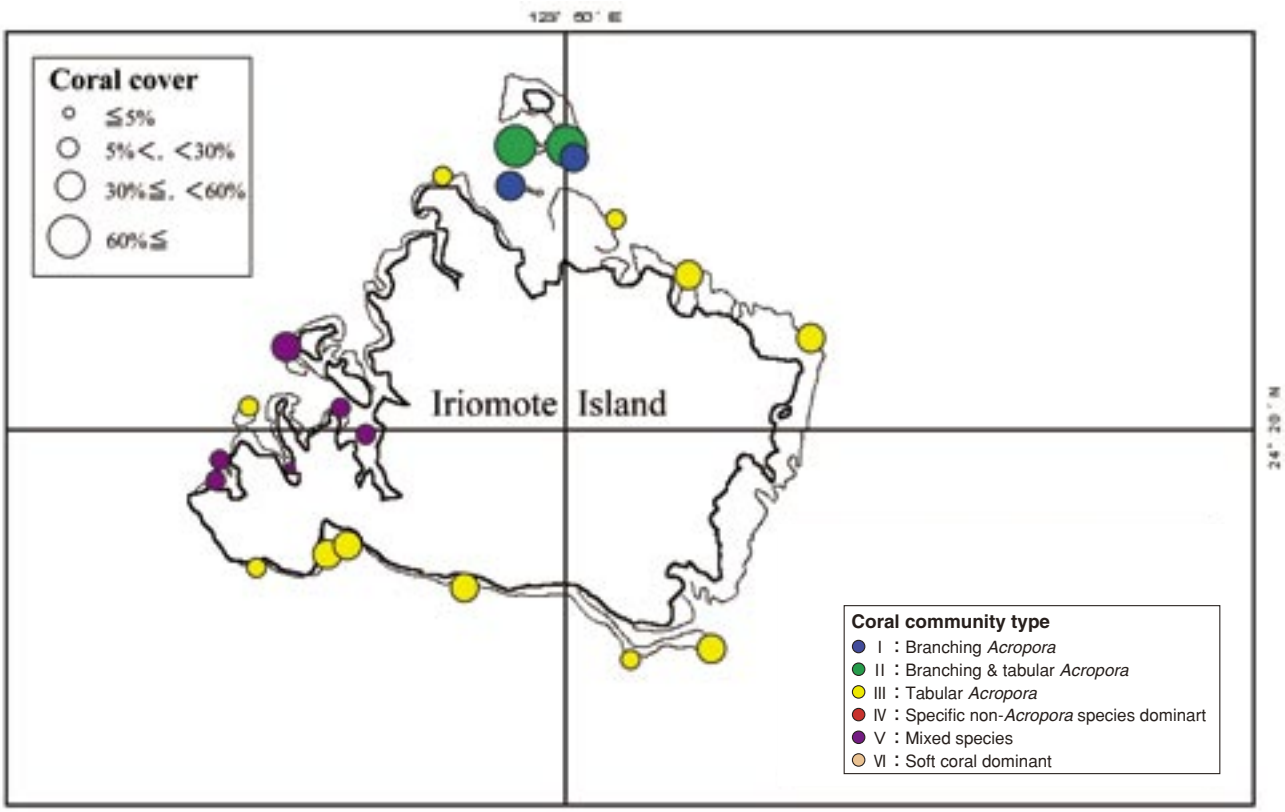


Fig. 1. Area coverage and lifeform of hermatypic corals and soft corals on Iriomote reefs in 2002 (from the Nature Conservation Bureau, Ministry of the Environment 2003b).

a whole is increasing. Coral communities, in general, appear to be recovering.

The complex geography of the western areas of Iriomote Island entails greater environmental diversity, and presumably fosters the observed high species biodiversity. Coral communities around Iriomote Island have repeatedly recovered from a series of near-catastrophic disturbances.

Off the northern coast of Hateruma Island, tabular and branching *Acropora* or *Montipora* dominate in the shallow areas, and mixed species coral communities grow below 5 m depth. Corals at these locations were catastrophically damaged by the COTS outbreak in the mid-1980s. However, starfish predation damage was minimal at a coral community off the eastern and southern coasts, where there was a low coverage mix of *Pocillopora*, *Favia* and *Millepora*, etc. (Nature Conservation Bureau, Environment Agency 1986, 1989). Patches of high-coverage tabular *Acropora* occur off the southern coast (Nature Conservation Bureau, Environment Agency 1996), but the coverage here is generally low (Nature Conservation Bureau, Environmental Agency 1986; Department of Planning and Development, Okinawa Prefecture Association 1994).

Coral cover is also generally low in the waters off Yonaguni Island. High mixed species coverage areas, with scattered tabular *Acropora*, occur at some places off the northern coast (Nature Conservation Bureau, Environmental Agency 1996).

3. Water quality and physical environment

This area is strongly influenced by the Kuroshio Current, which flows northward between the Yaeyama Islands and Taiwan. Countercurrents, eddies, tidal currents, and coastal currents make the hydrography of this area very complex.

Winter winds blow strongly from the north and northeast, while in summer the winds come from the south. Thus the northern coasts of Iriomote experience strong waves in winter and calm conditions in summer. The complex nature of the northwestern coastline means that wave height and direction are highly variable.

Inland waters have a big influence on environments

around Iriomote Island. Turbidity is generally high, and sedimentation is heavy, in estuaries at the mouths of big rivers (Shimoji *et al.* 1990; Nature Conservation Bureau, Ministry of the Environment 2003c). After heavy rainfall, a tongue of turbid, low salinity water temporarily extends to the surface in estuaries and bays.

4. Notable species and ecosystems

The river mouths of Iriomote Island are home to one of the greatest mangrove forests in the country. The Nakama River Conservation Area (designated as a Natural Monument of Japan), along with 12 other areas, are among the 500 Important Wetlands in Japan identified as representative mangrove areas with high diversity (Nature Conservation Bureau, Ministry of the Environment 2002a).

Tropical seagrass beds are widely distributed in the northwestern and eastern shallows off Iriomote Island. This is the only place in Japan where seagrass beds, thickly vegetated with large *Enhalus acoroides*, are to be found. Sakiyama Bay, which is the only sea area in the country that has been designated as a nature conservation area, has a large seagrass bed of about 39 ha, dominated by *E. acoroides* (Yokochi 1999b). Together with the seagrass bed of adjacent Amitori Bay, these areas have been included in the 500 Important Wetlands in Japan (Nature Conservation Bureau, Ministry of the Environment 2002a).

2 Situation of usages

1. Tourism

There are many famous dive sites among the coral reef areas around the islands. There are about a dozen diving shops on Iriomote Island, and many divers visit and use the services offered in this area.

The first ecotourism society in Japan was established on Iriomote Island in 1996. Ecotours using canoes and sea kayaks can be undertaken on rivers and the sea. Coastal areas are also used by tourists for bathing, snorkeling, glass-bottomed boat tours, and leisure fishing (including lure fishing). An international swordfish fishing tournament is held annually off Yonaguni Island.

2. Fisherys

The Yaeyama Fishery Cooperative controls fishing over the whole of Iriomote Island, including the city of Ishigaki City and the town of Taketomi. Various types of fishery occur around the islands of Iriomote and Hateruma, although there are not many full-time fishermen. Please refer to the section about Sekisei Lagoon at '6-1-7b' in this chapter for details about common fishing methods. Yonaguni Island boasts an active marlin fishery and produces the largest catch in Okinawa Prefecture. Mariculture of pearl oysters, including black pearl production, occurs off the western coast of Iriomote (Ryukyu Pearl Ltd.).

3. Others

There are several research facilities on the island of Iriomote, including the Iriomote Station of the Tropical Biosphere Research Center, University of the Ryukyus, and the Okinawa Regional Research Center of Tokai University. Domestic and foreign researchers are currently conducting active surveys and studies.

3 Threats and disturbances

1. Crown-of-thorns starfish (*Acanthaster planci*)

Shortly after a local COTS population increase was observed around the island of Hatoma, around 1970, an outbreak commenced in the Yaeyama region. Outbreak populations became obvious around Iriomote in the 1980s, following closely on the outbreak in Sekisei Lagoon. A rapid increase in the COTS population was confirmed around Amitori Bay off the northwestern coast of the island in the summer of 1980, and the outbreak extended to the northern coast soon after. Subsequently, predation damage became apparent off the southern coast, beyond Sakiyama Bay. By the mid-1980s this outbreak had caused almost catastrophic damage to corals all around Iriomote Island, except for some small areas. At this point, the COTS population decreased rapidly because their food supply had diminished, and the outbreak was considered over by the late 1980s (Nature Conservation Bureau, Environmental Agency 1984, 1989; Yokochi *et al.* 1991). Around Hateruma Island, COTS numbers increased explosively in 1984, causing extensive predation damage to corals from the northern to the western coasts, but the starfish had mostly disappeared by 1988 (Nature Conservation Bureau, Environmental Agency 1989).

COTS density has subsequently remained low in the Yaeyama Sea area, unlike the chronic situation around Okinawa Island. However, in recent years, signs of increasing numbers have been seen in Sekisei Lagoon and Nagura Bay, both of Ishigaki Island. Precautions, such as increasing monitoring surveys and further developing preparations for preventative extermination programs, are being taken (Natural Conservation Bureau, Ministry of the Environment 2002b; Okinawa Prefecture Department of Cultural and Environmental Affairs 2003).

2. Bleaching

Coral bleaching was observed around Iriomote Island in 1983, 1991, 1993, 1998 and 2001 (Research Institute for Subtropics 1999; Yokochi unpublished data). Among these events, the bleaching event of 1998 was the largest in scale, and especially heavy damage occurred to shallow water *Acropora* colonies. It has been estimated that about 60 % of *Acropora* colonies died, and the total abundance of coral colonies decreased by about 30 % (Nature Conservation Bureau, Environmental Agency 2000d).

3. Others

As occurs elsewhere in the Ryukyu Archipelago, typhoons often cause destruction and damage to coral reefs around Iriomote Island. However there have been no official surveys undertaken, offering detailed accounts of the damage. In October 1985, a typhoon off the western coast of Iriomote caused a lot of damage to south coast coral communities that had barely survived the COTS outbreak (Yano personal communications; Yokochi unpublished data). A subsequent survey (using the fixed survey points in Amitori Bay, in 1994) described partial destruction of the reef and a decrease in a coral coverage (Nature Conservation Bureau, Environment Agency 1995).

While the outflow of terrestrial soils to coral reef areas has become a social problem, anthropogenic influence in this respect has fortunately remained negligible around the island of Iriomote, except for some natural sedimentation at the head of a bay (Nature Conservation Bureau, Ministry of the Environment 2003c).

4 Monitoring

1. Coral reef monitoring survey

In 1998, the Ministry of the Environment took over the monitoring program that has been ongoing in Sekisei Lagoon since 1983. Twenty-one new survey points were added around Iriomote Island (except for eastern areas) in 1999. The monitoring method employed is the same as that used in Sekisei Lagoon (refer to Section 6-1-7b).

2. Demonstration area monitoring

Sakiyama Bay on Iriomote Island was designated a nature conservation area in 1983. A wide range of surveys were conducted in 1989 and 1997. Since 2001, permanent survey points (one in the moat and two on the reef slope, 3 and 9 m in depth) have been used to monitor corals and other large benthic organisms.

3. Other monitoring

As part of the COTS control measure, The Nature Conservation Division of the Department of Cultural and Environmental Affairs, Okinawa Prefecture, has been conducting monitoring operations around the Yaeyama Islands since 2002. This study gives priority to density surveys of young starfish, in addition to the state of mature *A. planci*, with the objective of forecasting outbreaks and contributing to the formulation of more effective countermeasures.

4. 'My point' survey

The 'My point' survey is a monitoring program conducted by the Yaeyama Coral Reef Conservation Council (the Council consists of dive shop owners, fishermen, administrative bodies, researchers, etc.) throughout the Yaeyama region. Members choose their own points or locations, and once or twice a year they survey parameters, such as the general status of coral growth and COTS numbers. Compiled survey results are fed back to members as a newsletter.

5. Reef Check

Reef Check has been conducted around Iriomote Island since 1997, and around Yonaguni Island since 2001. New locations have been added to the original Iriomote Island checkpoint at Whoopi (Yonasone), off Amitori Bay.

5 Conservation

1. Nature conservation area

About 128 ha at the mouth of Sakiyama Bay, off Iriomote Island, were designated as a nature conservation area in 1983. Further designation as a special marine area put limitations on possible installations or construction, as

well as limiting the collection of specific organisms (and non-organisms) such as corals (or dead coral skeletons).

2. Crown-of-thorns starfish

In the 1980s, COTS extermination around Iriomote Island was conducted chiefly by the fishermen of the Yaeyama Fishery Cooperative. Dead starfish were purchased using a budget from the Fishery Agency. Although organized extermination programs have not been conducted recently, information about COTS' presence and numbers is regularly collected (as described in the section on monitoring). The Nature Conservation Division of the Department of Cultural and Environmental Affairs, Okinawa Prefecture, in cooperation with related organizations, is making an effort to formulate more effective countermeasures.

3. Fishery resource management program

In 1998, in an attempt to better conserve fishery resources, the Yaeyama Fishery Cooperative established an area in which fishing was prohibited at certain times of the year. For five years at this location, fishing was prohibited during the two-month spawning period of *Lethrinus atkinsoni*. Indabishi, in the northern area of Iriomote Island, and a place off western Hatoma Island have been designated conservation areas that are closed to fishing.

6 Necessary measures

Despite repeated strong disturbance (COTS outbreak, mass bleaching events) the coral communities of Iriomote Island appear to have recovered well. This is probably because other anthropogenic disturbances, such as eutrophication and/or sedimentation, have been limited in impact. The most important objective of conservation measures should be, therefore, the preservation of the status of healthy reefs.

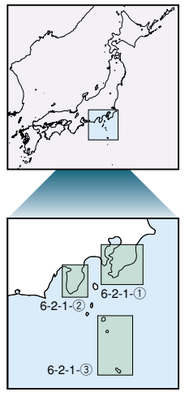
Past experience has shown that haphazard COTS extermination is not an effective measure for conserving coral communities. However, coral communities at two locations in Sekisei Lagoon were effectively protected by concentrated extermination programs, based on prior information and experience. Based on these lessons, limitation of the conservation area is probably critical to a realistic and effective COTS control program. Continuous monitoring of COTS populations is also essential for adequate conservation.

6-2-1 Boso Peninsula, Izu Peninsula and Izu Islands

(Map 6-2-1)

Province: Boso Peninsula: Chiba Pref.; Izu Peninsula: Shizuoka Pref.; Izu Islands: Metropolis of Tokyo **Location:** Boso Peninsula: east of Tokyo Bay; Izu Peninsula: between Sagami Bay (at east) and Suruga Bay (at west); Izu Islands: lies along 140˚E and between 35˚–33˚N **Air temperature:** 16.5˚C (annual average, at Irozaki, southern tip of Izu Peninsula) **Seawater temperature:** 20.5˚C (annual average, at west off Irozaki, Izu Pininsula) **Precipitation:** 1,834.8 mm (annual average, at Irozaki) **Total area of coral communities:** 425.3 ha **Protected areas:** Fuji-Hakone-Izu National Park: includes part of coastal area of Izu Peninsula and whole Izu Islands; Minami Boso Quasi-National Park: coastline of Boso Peninsula; Miyakejima Marine Park Zone in Izu Islands, and Katsuura Marine Park Zone in Boso Peninsula

＊“号”on this map means “site”.



a. Boso Peninsula

(Map 6-2-1-①)

Kazuyuki Shimoike

1 Corals and coral reefs

1. Geographical features

The coastal area of the southern Boso Peninsula was dominated by shallow coral reefs 7,000–5,000 years ago, but crustal movements produced upheaval with recurrent earthquakes in the Kanto region (flat land around Tokyo). Therefore, three to four steps of a marine terrace have developed below the cliff, and marine deposits containing fossil layers of corals and shellfishes extend 20 m or more above sea level (Kaizuka 2000). A fossil coral layer is located 15–20 m above sea level in the vicinity of Tateyama Bay, which is geologically important as the only upheaval coral reef on Honshu (the main island of Japan). Notably, a coral layer of Numa is well preserved in Tateyama City, and about 100 Scleractinian coral species have been confirmed (Eguchi 1971a).

2. Coral distribution

According to the report of the marine biotic environment survey in the 4th National Survey on the Natural Environment (Nature Conservation Bureau, Environment Agency 1994), hermatypic coral communities were distributed from Tateyama Bay, on the west coast of the Boso Peninsula, to Ohara on the east coast. Corals in Japan tend to extend their distribution according to a temperature gradient that is influenced by the Kuroshio Current, and the coral distribution on the Boso Peninsula is thought to reflect this gradient. In the coastal area of Chiba Prefecture (mostly in Tateyama Bay, e.g., Banda, Hazama, Okinoshima, and Daibusa), 32 species of hermatypic corals and four species of soft corals have been identified. The northern limit corals identified on the Boso Peninsula are *Goniopora* sp. and *Acropora* sp. at Cape Daibusa in Tomiura on the west coast and *Oulastrea crispata* at Amatsukominato on the east coast. The latter has been confirmed as the hermatypic coral species that is distributed at the highest latitude (Nishihira and Veron 1995). In Tateyama Bay, 25 coral species have been identified at depths of 10–15 m (Veron 1992a), but no corals have been found at depths shallower than 5 m, except in Okinoshima and Daibusa (Nature Conservation Bureau, Environment Agency 1994).

3. Water quality and physical environment

A four-year survey conducted in this region (Hagiwara 2003) found that the highest mean monthly water temperature was 23.8°C in August; the lowest means were 14.3°C in March and lessthan 18°C in December–May. salinity ranged from 33.0 to 35.0 PSU and mean Salinity was 34.3 PSU. The amount of suspended solids (SS) in seawater was 1.27 mg/l on average, i.e., 2.1–4.0 times the value reported at Akajima in Okinawa Prefecture.

4. Notable species and ecosystems

The region around Cape Myojin, near the city of Katsuura on the east coast, was designated the Katsuura Marine Park Zone (14.5 ha), Minamiboso Quasi-National Park, in 1974, and has thus been protected by law. The signature feature of this marine park zone is that it contains both warm and cold sea elements and the associated characteristic seaweeds (e.g., *Ecklonia cava*, *Eisenia bicyclis*, *Sargassum giganteifolium*, and *S. fulvellum*) and fishes (e.g., *Prionurus scalprum*, *Calotomus japonicus*, *Girella punctata*, Labridae, Chaetodontidae, and damselfish). The invertebrate community (e.g., *Solanderia secunda*, *S. misakiensis*, *Melithaea flabellifera*, and *Echinogorgia rigida*) is equally diverse (Marine Parks Center of Japan 2001).

In Tateyama Bay, mass spawning of *Acropora tumida* and *Favia* sp. (Sanpei personal communication) and larval dispersal of brooder *Alveopora japonica* (Harii *et al.* 2001) have been observed (Photo. 1). These findings suggest the possibility that the coral communities at their northern limits maintain their gene pool by sexual reproduction (Hagiwara 2003).

2 Situation of usages

1. Tourism

The Katsuura Underwater Observatory, one of the largest in the east, was constructed in 1980; it allows visitors to view underwater scenery at a depth of 6.5 m. In addition, the Coastal Beach of the Natural History Museum and Institute, Chiba, opened in 1999 and continues to attract numerous tourists.

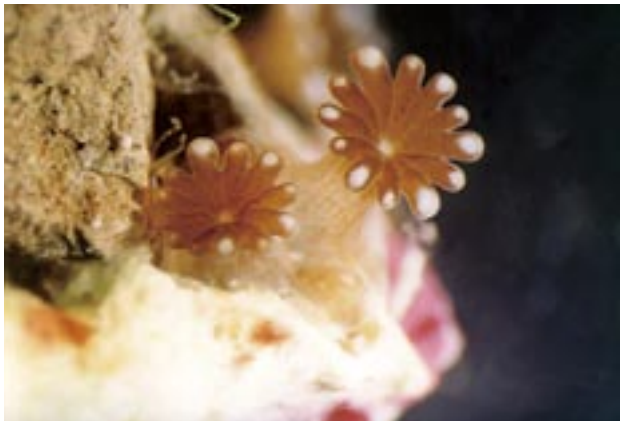


Photo. 1. Spat of *Alveopora japonica* recruited on a substrate in an aquaria in the Banda Marine Laboratory of Tokyo University of Marine Science and Technology. (photo by S. Harii)

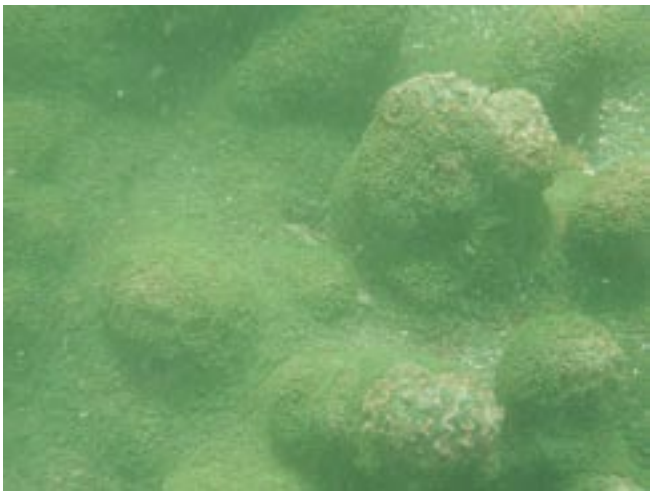


Photo. 2. *Hydnophora exesa*, observed in Okinoshima. (photo by M. Taguchi)

SCUBA diving is an attraction in this area. Popular diving spots include Katsuura and Kamogawa along the east coast, and Nishikawana, Banda, and Hazama on the southern coast. Fish are relatively dense year-round owing to the warm Kuroshio Current, and ocean-ranging fishes such as *Seriola latandi* and *S. dumerili* can be observed depending on the season.

2. Fishery

Fisheries are active at Katsuura, Choshi, and Chikura in the southern Boso region. The fishing port of Chikura boasts the highest landings in this region, mostly by the fishing boat and rocky shore fisheries. The former consists mainly of small boats (3 t or less) that catch primarily horse mackerel, chub mackerel, squid, and flying fish, while the latter fishery catches ear shell, *Turbo cornutus*, *Panulirus japonicus*, and seaweed along the natural rocky shores.

3 Monitoring and conservation

1. Research

The Banda Marine Laboratory of Tokyo University of Marine Science and Technology is located in Tateyama at the mouth of Tokyo Bay. The station was established in 1980, and since then research and education have been conducted related to the physiology, ecology, and resource production of marine fauna and flora (e.g., hermatypic coral, abalone, and algae) (Photo. 1).

2. Coral Monitoring Association of Okinoshima

This nonprofit organization was established in 1997 by citizens and persons concerned with education. The main activities are conducting coral research around Okinoshima (Photo. 2), organizing observation programs on rocky shores and shore cleanups, and actively working to conserve *Vargula hilgendorfii* (a light-emitting organism) in Tateyama Bay (Mitsui Public Relations Committee 1999).

3. Coastal Conservation Basic Plan

In accordance with the enforcement of the revised Coastal Law of April 2000, administrators have begun to establish the Coastal Conservation Basic Plan by incorporating regional opinions from academic experts, heads of local authorities, and coastal managers. On this basis, Chiba Prefecture has formulated plans for two coastal areas, i.e., along the east and west coasts of the peninsula. Integrated coastal conservation plans, which include the use of targeted areas as well as preservation of the environment, have been implemented*.

Cited website:

* http://www.pref.chiba.jp/syozoku/i_kasen/umihozen/

b. Izu Peninsula

(Map 6-2-1-②)

Shinpei Ueno

1 Corals and coral reefs

1. Geographical features

The targeted area in this section is the west coast of Izu Peninsula, from Cape Irozaki on the south end of the peninsula, to the back of Suruga Bay. The Suruga Trough runs north to south in the center of Suruga Bay, and reaches 2,500 m at the mouth of the bay. The submarine topography differs greatly in the east and west, with Suruga Trough acting as a boundary. The seabed topography on the west side is complex, supporting a shoal called 'Senoumi', and the Senoumi Basin. While the sandy beach coastline is fairly monotonous, there are no hermatypic corals adjacent to the beaches. On the other hand, on the east side of the trough, a monotonous slope continues from the coast to the trough basin, and the rocky shore coastline is complex and supports corals. The coastline of Uchiura Bay, an innermost bay of Suruga Bay, is also similar, but a gradual, insular shelf slope continues to depths of 61–75 m, where the bottom sediment is sandy mud (Nemoto *et al.* 1989).

2. Coral distribution

The water surface layer of Suruga Bay is under the influence of the warm Kuroshio Current, but the winter low water temperatures reduce the number of species and no reef development is evident. There have been 42 coral species reported in Nakagi, at Minamiizu Town and in Shimoda City (Nishihira and Veron 1995). In Uchiura Bay, 31 species (of 22 genera) were reported (Sugiyama 1937), and a further 29 coral species (of 17 genera) have been additionally reported (Minegishi and Ueno 1995). The coral community in Uchiura Bay extends to 5–10 m, covering approximately 5,000 m^2. It is almost the most northern coral community in the world (ICUN 1988). *Acropora tumida* (Photo. 1) is dominant in here, covering up to 80–100 % of the substrate, with an average colony height of 28 cm. However, the bedrock, or the rocks that function as a substrate for corals, are not exposed, but buried in sand 1.5–2.0 m below the ocean floor. Thus *A. tumida* colonies grow on the sandy bottom.

Apart from Uchiura Bay, corals are distributed in Tago, in Nishiizu Town and Mera, in Minamiizu Town on the west coast of Izu Peninsula, but the extent of coral coverage at both localities is small: 260 m^2 and 300 m^2, respectively. *A. tumida* dominates both localities, but there the base substrate is exposed, suggesting a significantly different sedimentary environment than Uchiura Bay.

3. Water quality and physical environment

Uchiura Bay is a sheltered bay, but the water quality is more akin to oceanic conditions because a branch

Photo. 1. Close-up of a *Acropora tumida* colony.

of the Kuroshio Current flows into the bay. Monthly measurements, from March 1993 to August 1994, of the bottom water at 10 m, where the *A. tumida* community thrives, recorded an average pH of 8.3, dissolved oxygen of 8.5 ppm, and salinity (PSU) at 34.3 (Minegishi and Ueno 1995). These values hardly fluctuated in four subsequent measurements in January 2003 while the values of surface water (1-3 m) fluctuated greatly, being affected by terrestrial runoff during the rainy season but these surface fluctuations appear to have little influence on the coral communities. Sediment deposition was measured using sediment traps, with monthly values, in June-September, amounting to 5-9 mm and 1-5 mm in October-January, suggesting sedimentation is higher in spring-summer than in autumn-winter. The annual amount of sediments deposited was 3.5 cm (Ueno 1996). It appears that the most significant factor affecting the *A. tumida* community in Uchiura Bay is water temperature. According to hourly measurements, using an *in situ* thermometer set up in the bedrock at 5 m, since 1993, the highest temperature recorded was 27-28°C in August and the lowest temperature was 12-13°C recorded in February, well below optimal for coral growth. Indeed, coral growth may stop for several months every year during the coldest season.

4. Notable species and ecosystems

A striking feature of the Izu Sea coast is that corals and large seaweeds coexist. In Uchiura Bay, from December to June, the brown algae *Colpomenia sinuosa* and *Undaria undarioides* grow in thickets alongside *A. tumida*. *C. sinuosa* can cause up to 90 % coral shading for up to five months a year, reducing the zooxanthellae density of *A. tumida* to 40-50 % (Nakanishi and Ueno 1998). Under such circumstances, *A. tumida* frequently bleaches and dies.

2 Situation of usages

1. Tourism

Most of the areas where corals are located are visited by SCUBA divers. In Uchiura Bay, however, diving is restricted to Cape Ohsezaki by the fisheries cooperative association.

2. Fishery

Corals live along the rocky shore where recreational line and net fishing is not common, except that octopus trap fishing is conducted on a small scale in Uchiura Bay.

3 Threats and disturbances

1. Bleaching

Coral bleaching, due to high water temperatures, have not been reported in the Izu area, but there have been reports of coral bleaching related to lowwater temperature (Kosaka *et al.* 2001). Especially in Uchiura Bay, which is located within Suruga Bay, water stagnation is common. The average water temperature at 5 m in January and February 1996 is around 12.6°C. The elapsed time of less than 13°C was 1,198 hours over January-April in 1996, and 209 hours in 1997. These figures are remarkable, compared with 0-2 hours for 1993-2000. Consequently, many of *A. tumida* colonies bleached and died, which resulted in a decline in coral coverage from approximately 85 % to 40 %. Live coral coverage has continued to decrease; some studies suggest that an increase in the density and grazing pressure of the sea urchin *Diadema setosum* are responsible for the coral decline (Okubo *et al.* 2003).

2. *Diadema setosum*

In monthly surveys, the highest number of *D. setosum* individuals in a 5,000 m^2 *A. tumida* community was 21,000 in April 2000, and the lowest was 15,000 in December, 2000. The amount of grazing damage by *D. setosum* was estimated to be 59 kg/month (Okubo *et al.* 2003). On the other hand, coral growth (*A. tumida*) was estimated to be 47 kg/month in May 2001, which suggests that *A. tumida* is gradually decreasing under the present situation.

Photo. 2. *Diadema setosum* and a cage to protect *Acropora tumida* from *D. setosum* grazing. The tips of branches are grazed and shown in white appearance.

4 Monitoring and conservation

1. Survey

The surveys conducted in recent years are as follows:
1991: The 4th basic survey on conservation of the Natural environment (Environment Agency)
1993: Coral survey in Uchiura Bay (Shizuoka Prefecture)
1993–2003 (present): Water quality diffusion monitoring survey of the coastal environment maintenance program in Nishiura fishing port (Numazu City)

2. Conservation measures

The principal cause of a recent decrease in *A. tumida* is considered to be related to grazing damage by the sea urchin *D. setosum*. Grazing damage prevention cages, of about 300 m^2 have been established since 2000. The cages are made of plastic net (Takiron), 62 × 62 × 31 cm/piece (Photo. 2). Within the experimental cages the coral coverage has increased by 20.6–35.2 % in eleven months compared with that of the control (Funakoshi and Ueno 2004).

c. Izu Islands

(Map 6-2-1-③)

Takeshi Igarashi

1 Corals and coral reefs

1. Geographical features

The Izu Islands are distributed along the Izu-Ogasawara ridge, which lies along the 140° meridian and stretches south to north between 35° and 33° N.

Miyakejima (Is.) is a round volcanic island located ca. 180 km south (34°04' N) of Tokyo. It is ca. 8.7 km in diameter, 55 km^2 in area, and made from basalt. Most of the island's coastline is rocky. Mt. Oyama is located at the center of the island; it slopes evenly toward the coastline on all sides and erupts about every 20 years (Kaizuka 1989). The most recent eruption, in 2000, was large and severely impacted the island's ecosystem (Kamijyo *et al.* 2002; Kato *et al.* 2002). Volcanic ash fell mainly on the northern shore, mud containing ash flowed along the eastern and southern shores, and mudflows and cliff failures occurred along the western coast. These events caused dimensional changes in the coastline and resulted in the accumulation of ash on the sea floor (Tokyo Metropolitan Fisheries Experiment Station 2001; Fig. 1).

Hachijojima (Is.) is a basaltic volcanic island ca. 300 km south of Tokyo, located at the southern end of the Izu Islands (33° 07' N). Outflow of lava and eruption of volcanic ash have not occurred since 1606. The island is oblong, with a periphery of ca. 59 km that covers 68 km^2, stretching in a south-north direction. Two mountains skirt the island's coastline: Mt. Hachijofuji (854 m above sea level) in the north and Mt. Miharayama (700 m above sea level) in the south. Most of the coastline consists of drop-offs and rocky shores that generally plunge sharply to the sea bottom (Takahashi 1983; Kaizuka 1989) (Fig. 2).

2. Outline of coral distribution

a) Miyakejima

Zooxanthellae corals (hereafter corals) on the island are abundant along the western and southern shores, but are rare along the eastern shore where an upwelling occurs. Eighty species from 36 genera and 13 families have been reported for the entire island (Tribble and Randall 1986).

Togahama, the southwest of the island, has the community that tabulate *Acropora* is dominant. The community lies on the large rocks and bedrocks that extend for about 1200 m^2, at depths between 1.5 m and 8.0 m, south of Togahama. Although facing the outer sea, the area is relatively protected from ocean waves by ledges in the offing. Six *Acropora* species (e.g., *A. solitaryensis*), *Pocillopora damicornis*, *Acanthastrea echinata* are well-represented. *Favites*, *Goniastrea*, *Montastrea*, *Montipora*, *Porites*, *Goniopora* and *Turbinaria* are also present (Igarashi 2002).

Fig. 1. Map of Miyakejima (Is.).

Fig. 2. Map of Hachijojima (Is.).

In 1979, Igaya, the western end of the island, had 59 coral species, 31.1 % coral cover, and a coral species diversity index (H_c') of 2.76. Moreover, it was the only area that exhibited development of a reef structure throughout the island (Tribble and Randall 1986): This structure was not a true coral reef, and consisted mainly of tabulate *Acropora* built on the framework of an old lava flow (depth of 6–8 m) along the shore next to the fishery harbor. Here, corals were relatively abundant, 33 species, 24.1 % coral cover, and H_c' = 2.53 were recorded. However, live colonies of *Acropora* were rare, and the most common corals were *Acanthastrea echinata*, *Psammocora vaughani*, Faviidae (e.g., *Favia speciosa*), *Hydnophora exesa*, and *Echinophyllia aspera*. Coral coverage was also high (31.1 %) at depths of 6–7 m on an offshore large lava flow from the harbor. Tabulate *Acropora* was relatively abundant, but a reefal structure was not seen. Species diversity was high at depths shallower than 15 m on the offshore lava flow, and highest at a depth of 4 m (H_c' = 2.76). This level of coral diversity is similar to that of the Line Islands (3° N) in the central Pacific Ocean, and at Eilat (29° N) in the Red Sea (Tribble and Randall 1986).

b) Hachijojima

At Hachijojima, 35 genera from 14 families were recorded, and most of the genera reported from Miyakejima were also found (Takahashi 1990). The most common genera were from the Faviidae (e.g., *Favia*, *Favites* and *Goniastrea*). *Acanthastrea*, *Echinophyllia*, and *Goniopora* were also abundant. Moreover, *Alveopora* was remarkably abundant in Sokodo and Kaminato, as compared to other areas of the Izu Islands, in July 1986 (Takahashi 1990; Igarashi unpublished data). Corals were abundant from Sokodo on the east coast, toward Kaminato. This area is made up of gently inclined but relatively diversified ledges, which are protected from typhoon waves. Coral-abundant areas also occurred around Yaene, on the east coast, and at Nazumado, on the north coast, but habitats there were relatively small and restricted by the bottom topography. The growth form of Hachijojima corals were generally encrusting or submassive influenced by waves; foliaceous and branching were extremely rare. Tabulate *Acropora* were common but they did not form large community, like those in Togahama, Miyakejima (Takahashi 1983).

3. Water quality and physical environment

The Izu Islands are located across the northern Kuroshio Current, along the coasts of mainland Japan. Thus, the main factors influencing this area are the direction and positioning of the Kuroshio Current, and the movement of cold water mass.

The average surface water temperatures around Miyakejima range from 14.2°C (February to March) and 27.0°C (July to August). Extreme temperatures are a low of 13.0°C in February and a high of 29.5°C in August. Waves are influenced by strong monsoons and typhoons. West to west-northwest winds dominate from December through to February, southwest or northeast winds occur from March through to May, southeast winds blow from June through to August, and northeast winds occur during September through to November (Hayashi *et al.* 1974).

The average monthly surface water temperature in Hachijojima ranges between 17 and 28°C, but in years when a cold water mass approached the shore, surface water temperature decreased to 13.9°C in February and 22.7°C in August (Tokyo Metropolitan Fisheries Experiment Station 1976). Waves are also strongly influenced by monsoons and typhoons, as they are in Miyakejima.

4. Organisms and ecosystems to be noted

The *Acropora* dominated community of Togahama, Miyakejima, is the largest in the Izu Islands (Hayashi *et al.* 1974). Moreover, *Chaetodon daedalma*, a fish species endemic to Japan, is distributed from the Izu Islands to the Ogasawara Islands.

2 Situation of usages

1. Tourism

In Miyakejima, Togahama and Igaya are SCUBA diving sites. Additionally, Choutaroike – a 200 m² tide pool, 2.5 m deep, located on the southern coast – is used for observing and learning marine organisms and for sea bathing. However, the island has seen limited landing since the volcanic eruption in June 2000. Sokodo, Kaminato, Yaene, and Nazumado in Hachijojima are also used as SCUBA diving sites.

2. Fishery

The Red algae (*Gelidium*), used to make agar-agar, and the shellfish (*Sulculus diversicolor*) are important aquatic resources in the island. However, fishing is not under-

taken in areas where coral communities are located. In Miyakejima, many of the fishing grounds were damaged by mud inflows, ash falls, and cliff failures resulting from the Miyakejima volcanic eruption in 2000 (Tokyo Metropolitan Fisheries Experiment Station 2001). In Hachijojima, these resources are decreasing because of rocky-shore denudation in recent years (Takahashi personal communication). Flying fish (e.g., *Prognichthys agoo*) are also an important fishery stock; these fish are caught by gill nets that are peculiar to this region.

3 Current state of the ecosystem, and points of transition

1. Miyakejima

At Igaya, many *Acropora* colonies in the reefal area have died due to (1) an inflow of terrestrial soils that resulted from engineering projects between 1972 and 1974, (2) predation damage by *Drupella fragum* and crown-of-thorns starfish (*Acanthaster planci*) during the late 1970s and early 1980s, and (3) typhoon damage (Moyer 1978; Moyer *et al.* 1982; Tribble *et al.* 1982). Moreover, about 90 % of *Acropora* and *P. damicornis* in the reefal area died from heavy silting during a breakwater expansion project in the late 1990s and part of the reef disappeared when it became a foundation for the breakwater (Unno personal communication). In the 2000 volcanic eruption, mudflows occurred, and up to 20 cm of volcanic ash accumulated on the sea floor of the reefal area (as of October 2001). Water transparency decreased to 5 m in turbid waters. The number of coral species in the reefal area decreased to 12, H_c' decreased to 1.56, and few live *Acropora* were observed. Coral cover was 6.7 % and consisted mostly of encrusting *A. echinata*, *Montipora* sp., and Faviidae (e.g., *F. speciosa*), concentrated at the lateral faces or on the bumps of the lava flow bed, where ash accumulation was relatively low. Although they avoided ash accumulation, these colonies still showed partial mortality, a decrease in zooxanthellae, and bleaching (Igarashi 2002). Volcanic ash also accumulated offshore from the harbor, killing nearly 80 % of tabulate *Acropora*. However, many encrusting coral colonies have survived outside the breakwater, where accumulated ash was washed away by oceanic water (Tokyo Metropolitan Fisheries Experiment Station 2001).

At Togahama, damages from soil inflow caused by construction operations in 1976 and 1978, and from predation by *D. fragum* and *A. planci* were observed. Predation damage extended to about 35 % of the *Acropora* colonies over a period of two years (1979–1981; Moyer 1978; Moyer *et al.* 1982). On the other hand, corals were healthy, even after the volcano erupted in 2000. Notable differences were not apparent when results from surveys conducted in August 1995 were compared with results from surveys conducted after the eruption occurred. Moreover, the impact of the eruption was limited in Choutaroike, where nine coral species, including *Cyphastrea serailia*, were observed (Igarashi 2002).

2. Hachijojima

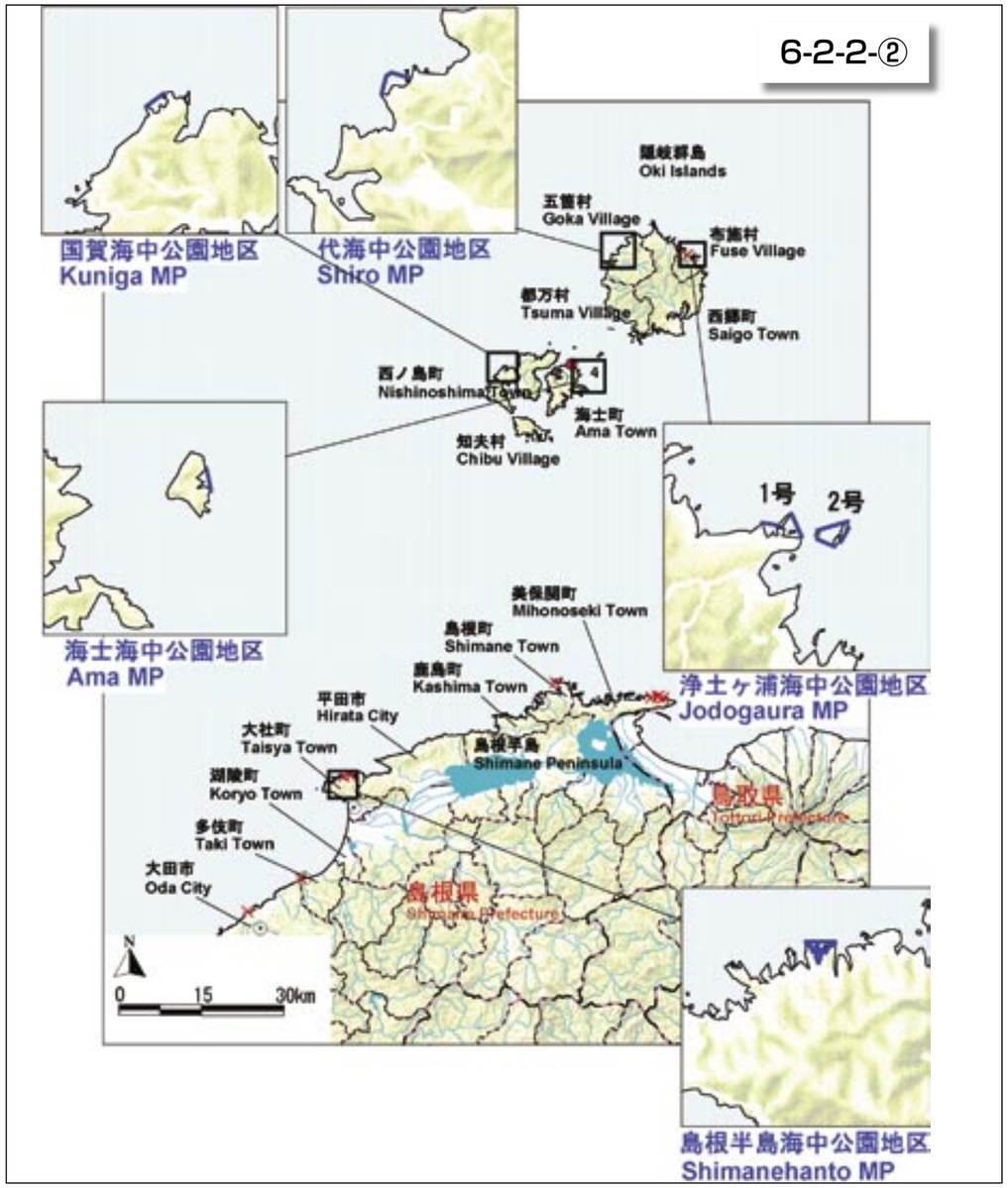
Coral communities in Hachijojima have also received the influence of physical factors, similar to those noted in Miyakejima, such as bottom topography, waves generated by seasonal winds and typhoons, low water temperatures (Takahashi *et al.* 1983), and construction works. Part of the coral community observed in Kaminato Port in July 1984 disappeared after the expansion of the breakwater; a decrease in zooxanthellae and partial mortality of colony were observed on remaining corals such as *Goniopora*, *Hydnophora*, and *Acanthastrea*. Likewise, part of the coral community disappeared in Sokodo after the offshore breakwater was constructed. However, foliaceous *Turbinaria* (ca. 7 m^2) developed along the inner side of the breakwater at depths of 3–5 m (Igarashi, obs. in July 2003). The maximum diameter of *Turbinaria* colonies in Sokodo before the breakwater construction (1961–1982) was 1 m; other colonies were 50 cm or smaller in diameter (Takahashi 1983).

4 Monitoring and conservation

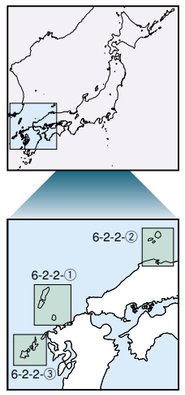
Togahama in Miyakejima has been designated as a marine park zone. However, no in-depth investigations of coral communities in the area have been conducted. Furthermore, there has been no thorough investigation of the coral communities of Igaya since the surveys conducted by Tribble and Randall (1986). The same is true for the other Izu Islands. Quantitative estimates of species abundance are needed, therefore, in order to understand the structure and dynamics of the coral communities, and to propose much needed conservation measures needed for the area, which should be implemented in the near future.

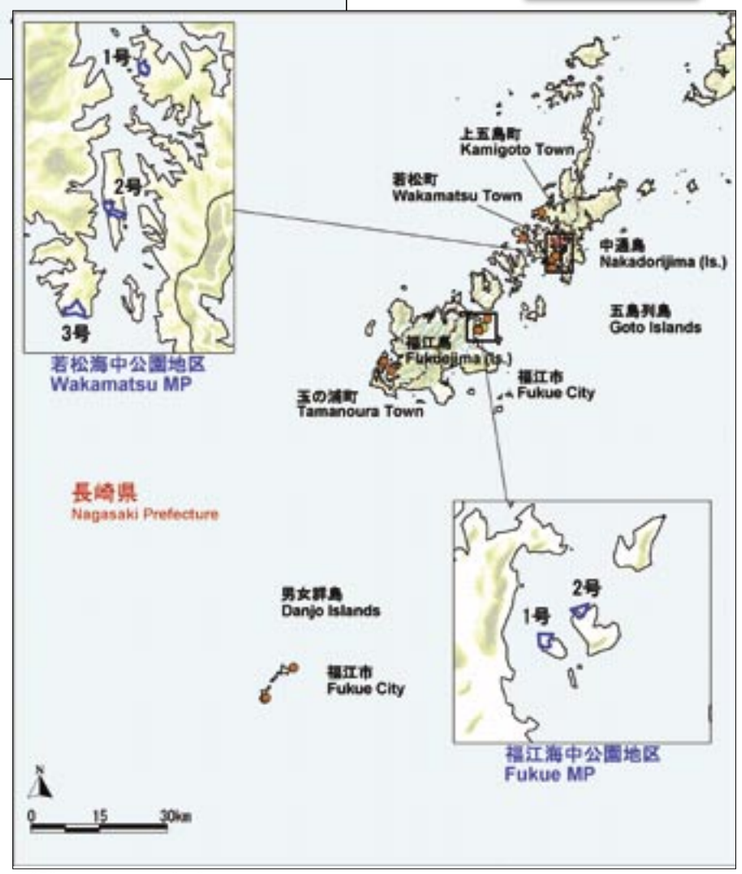
6-2-2 Sea of Japan
(Map 6-2-2)

Province: Iki Islands, and Tsushima and Goto Archipelago: Nagasaki Pref.; Oki Islands: Shimane Pref. **Location:** Iki Islands and Tsushima Archipelago at north, and Goto Archipelago at east of Nagasaki City; Oki Islands at north of Matsue City **Features:** Highest latitude coral reef was reported on Iki Islands **Air temperature:** 15.5˚C (annual average, at Tsushima) **Seawater temperature:** 19.4˚C (annual average, at northeast off Tsushima) **Precipitation:** 2,132.7 mm (annual average, at Tsushima) **Total area of coral communities:** 10.9 ha **Protected areas:** Daisen-Oki National Park: whole Oki Islands; Saikai National Park: part of Goto Archipelago; Iki-Tsushima Quasi-National Park: part of Iki Islands and Tsushima Archipelago; Marine Park Zone: 3 zones in Iki Islands, 2 in Tsushima Archipelago, 2 in Goto Archipelago, 4 in Oki Archipelago, and 1 in Shimane Peninsula.



＊“号” on this map means “site”.





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a. Iki Islands

(Map 6-2-2-①)

Hiroya Yamano, Kaoru Sugihara,
Tatsuo Nakai, Osamu Yamagawa

1 Corals and coral reefs

1. Geographical features

The Iki Islands are composed of Oligocene to early Miocene sedimentary rocks (Katsumoto Group), covered by early to middle Pleistocene volcanic rocks, mainly basalt (Nagaoka 2001). Hermatypic corals are distributed on these rocks throughout the islands. At Kurosaki, a coral reef has formed (Eguchi and Fukuda 1972; Yamano *et al.* 2001). It is the highest latitude coral reef ever reported and described (Yamano *et al.* 2001c). The reef appears to be a wave-resistant structure and shows both topographical and ecological zonation. This reef was established at least 1400 years B.P., and is composed mainly of faviid corals and mud infillings. The size and thickness of the reef are estimated to be around 900 m^2 and at least 3 m, respectively. Nakai (1990) showed that high latitude reefs tend to occur in wave-protected areas, in contrast to those in tropical and/or subtropical areas, which develop well in high-energy wave-exposed locations. The location of the Kurosaki coral reef is in agreement with this suggestion. No coral reef formation is known from other sites around the Iki Islands.

2. Coral distribution

Coral communities (mainly scleractinians) mostly occur inside small, turbid bays such as Honguu (Tsutsugata), Kurosaki (Isigataura), and Watarahigashi (Kouze, Itaura), all located on the western coast of Iki Island (Fig. 1). In these bays, massive faviids (*Cyphastrea*, *Favia*, *Favites*, and *Goniastrea*), foliose *Echinophyllia* and *Lithophyllon* dominate at 1–5 m depths. Some locally aggregated *Acropora* communities are also seen in these areas. Most of these coral colonies are large sized and in close proximity to each other. Thus, in these areas the local coral coverage is very high but the number of species is low.
Depth zonation of different coral species has been described at Kurosaki (Eguchi and Fukuda, 1972; Yamano *et al.* 2001). Terrestrial sand/mud with coral

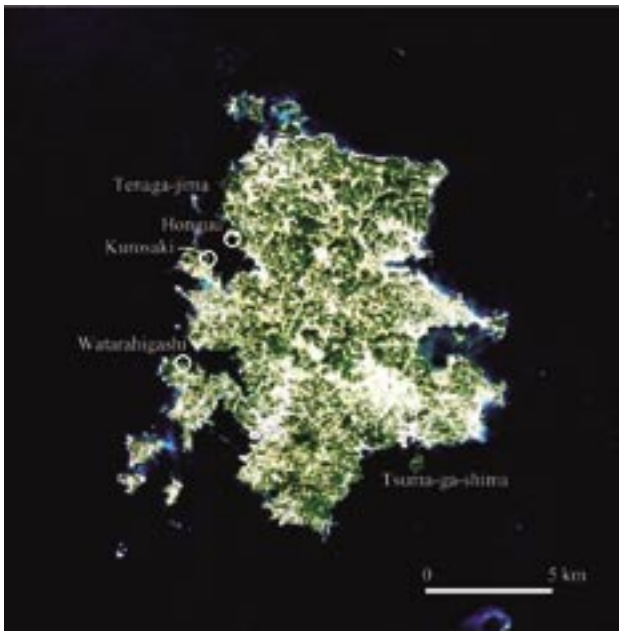


Fig. 1. Location of the coral communities investigated in the Iki Islands.

rubble, but no live corals, is found in the area 0–35 m from the shore (Fig. 2). Between 35 and 40 m from shore are raised topographic areas (1.5–2 m depth), dominated by *Caulastrea tumida* and *Favia speciosa*. *Echinophyllia echinata* and *Lithophyllon undulatum* occur on the outer reef slope (2–9 m depth), around 40–50 m from the shore (Fig. 2, Photo. 1, Appendix 1-7-Table 3). At Tenagajima and Tsumagashima there are shallow slopes (< 5 m depth) formed by basalt boulders that are inhabited by few corals but many species of macro-algae such as *Sargassum* spp. and *Ecklonia cava* (Fig. 1). Large faviid colonies (~50 cm in diameter) are scattered in the deeper areas adjacent to the slopes (5–8 m depth) where the substrate changes from boulder to sand.

Several reports have described coral distribution around the Iki Islands (Kimura 1965; Eguchi 1971b; Eguchi and Fukuda 1972). These reports were written during site selection procedures for marine park designation by Nagasaki Prefecture, and recognize 22 species of 19 hermatypic coral genera. Following extensive taxonomic revisions (Veron 1992c, 2000a, 2000b, 2000c) subsequent surveys have identified 39 species of 22 genera in the Iki Islands, including species recognized in our investigation during August–September, 2003 (Appendix 1-7-Table 4). Most of these species are widely distributed, from subtropical (reefal) to temperate (non-reefal) regions in Japan. *Caulastrea tumida*, *Favites russelli*, *Goniastrea australiensis*, *Platygyra contorta*, and *Oulastrea crispata* are common in the Iki Islands and in non-reefal areas

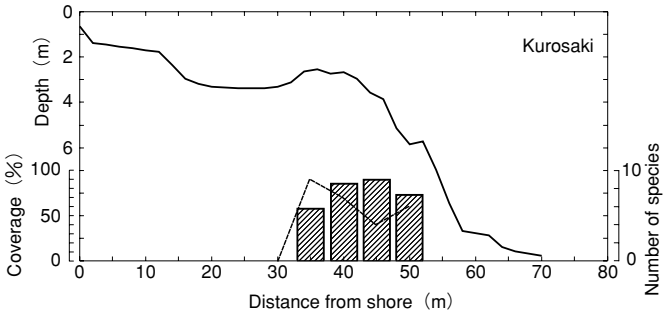


Fig. 2. Topographic profile (solid line), coverage (hatched bars), and number of coral species (dashed line) along the transect from shore to sea on the shallow slope at Kurosaki, Iki Island.

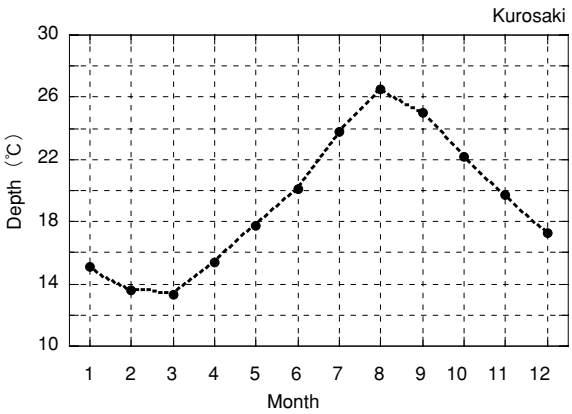


Fig. 3. Monthly mean sea-surface temperatures at Kurosaki, Iki Island (data averaged from 1986 to 2000 and provided by Tasaki Shinju Co. Ltd.).

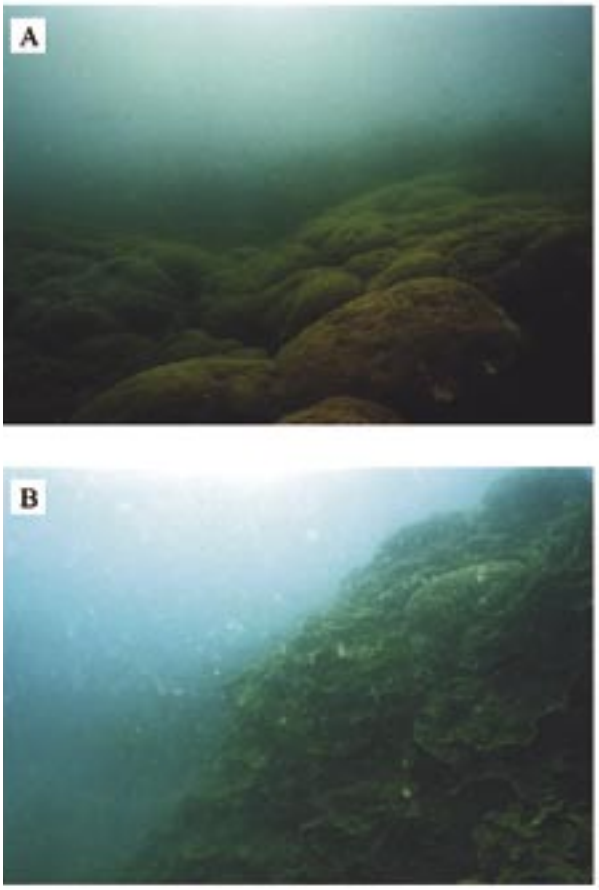


Photo. 1. Large colonies of *Favia* spp. and *Echinophyllia* spp. on the shallow slope at Kurosaki, Iki Island. Note that Favia spp. were found on the shallower parts of the slope (A) while *Echinophyllia* spp. occurred at greater depths (B).

(Nishihira and Veron 1995). *Acropora tumida*, *A. pruinosa*, and *Alveopora japonica* were found only in non-reefal areas.

3. Water quality and physical environment

The mean annual water temperature for the seas surrounding the Iki Islands is 20°C, with the annual low in March (14°C) and the annual high in September (27.5°C; Natsukari and Takita 1972). Nearshore mean water temperatures at Kurosaki were 13.3°C and 26.2°C in March and August, respectively (Fig. 3). Water temperatures in March at Kurosaki are clearly well below 18°C, which has generally been accepted as the lowest temperature at which coral reefs can form.

4. Notable species and ecosystems

The coral reef at Kurosaki is acknowledged to be the world's highest latitude coral reef (Yamano *et al.* 2001). Corals are generally distributed on slopes shallower than 5 m in the Iki Islands, but a few corals are found on the shallow slopes where macroalgai species such as *Sargassum* spp. and *E. cava* flourish. This suggests that the local distribution and abundance of most coral species in the Iki Islands depends mainly on competitive exclusion between corals and macro-algae (Johannes *et al.* 1983; Veron 1992c). Barnacles, bivalves (mainly *Saccostrea* and *Mytilus*), and gastropods (such as *Serpulorbis*) are attached not only to dead but also to live coral colonies. Large numbers of *Diadema setosum* and *D. savignyi* are found on and around living coral colonies in Kurosaki. Thus, high-latitude corals appear to have competitive relationships not only with macroalgae but also with other invertebrates.

2 Situation of usages

1. Tourism

Operators in the town of Gounoura run sea kayak tours

around Kurosaki coral reef. Otherwise, there are few if any options for tourists interested in local coral reef communities.

2. Fishery

Pearl culture occurs in some bays, including Kurosaki. Apart from this, there are no fishing activities associated with corals and coral reefs in the Iki Islands.

3 Threats and disturbances

Most coral colonies are large, and few colonies appear to have recently died. This indicates that there have not been any mass bleaching events or outbreaks of coral predators in recent years. Around Iki Island, corals are widely distributed in certain bays where relatively low-impact pearl culture operations have been set up. This may have shielded these coral communities from higher-impact human disturbances such as fishing and the construction of ports. However, sedimentation may be a problem. Red soil runoff is seen during the rainy season in some bays, in some cases reducing transparency to ~1 m. The impact of this on shallow-water fauna, including corals, is a matter of concern, especially as red sedimentation has been noticed on some live coral colonies.

4 Monitoring and conservation

Red soil runoff appears to be related to the development of farms, and to the maintenance and improvement of roads. Prompt action should be taken to preserve coral communities and their habitats, for example, by the construction of drainage ditches or ponds to filter out the soils. The highest-latitude coral reef should be designated a marine protected area, as should locations at Watarahigashi and Honguu, where rich coral communities occur. Of great concern in terms of conservation is the fact that neither visitors to, nor residents of, the Iki Islands (and the Tsushima Islands) are aware of the significance of local coral communities or the coral reef. This ignorance may result in the decline of the coral communities through careless development. An increase in levels of public awareness in this respect would be very helpful.

b. Tsushima Archipelago

(Map 6-2-2-①)

Kaoru Sugihara, Hiroya Yamano

1 Corals and coral reefs

1. Geographical features

The Tsushima Archipelago are composed of Oligocene to early Miocene marine sedimentary rocks (Taishu Group), and Miocene granite and hornfels (Nagaoka 2001b). Ria coasts are common in the Tsushima Archipelago, especially in Asou Bay, which is in the central part of Tshushima Archipelago. Hermatypic corals are found throughout the islands (Fig. 1), and achieve high coverage in Kaseura and Senoura. Some accumulated carbonate structures are found in Senoura (Eguchi 1973), but these are not regarded as coral reef formations because of their small scale. No other coral reef-like formation has been reported from the Tsushima Islands.

2. Coral distribution

Originally, 26 coral species of 20 genera were reported from the Tsushima Archipelago (Kimura 1965; Eguchi 1973). However, similar to the situation in the Iki Islands (Eguchi and Fukuda 1972), the identification of many of these species was affected by Veron's (1992c) extensive taxonomic reclassification of corals. Recent surveys utilizing the latest taxonomic opinion (Veron 2000a, 2000b, 2000c) have identified 38 species of 23 genera, including species found in our investigation during December, 2002 (Appendix 1-7-Table 5).

Corals (mainly scleractinians) are mainly distributed in small, shallow, and turbid bays that are sheltered from waves, especially Asou Bay. Species diversity of corals is high on the slopes at bay mouths (1–5 m depth). Coral communities in Kaseura and Senoura (Fig. 1) are composed mainly of *Caulastrea tumida*, *Echinophyllia aspera*, *Favia speciosa*, and *Lithophyllon undulatum*, colonies of which extensively occupy the slopes, forming several patches (Photo. 1). As depth changes, so do the dominant coral species. At Kaseura, small colonies of *Oulastrea crispata* are scattered on the basal rock near the shore at a depth of 1 m, while *F. speciosa* and *E. aspera* are abundant at depths of 2.0–2.5 and 2.5–5.0 m, respectively (Appendix 1-7-Table 6). At Senoura, the coverage of *C. tumida* is high at depths of 1.0–1.5 m, while high coverage of *F. speciosa* and *L. undulatum* occurs at depths of 1.5–2.0 m. *E. aspera* is found in areas ranging in depth from 1.5 to 6.0 m, occupying the slope below 2 m depth (Appendix 1-7-Table 6). The distribution patterns of coral communities are similar in these areas, in that while coverage is high, species diversity is low (Fig. 2). Dense populations of *Acropora tumida* occur at Ohtaura and Oura on the southeastern coast of Tsushima Archipelago (Fig. 1).

Comparison of coral communities in the islands of Tsushima and Iki shows that 25 species in 18 genera are common. However, a limited number of sites have been surveyed at both islands, so the number of identified and common species is expected to increase in future surveys. Other common features of coral communities at these two islands are: 1) coral communities are found on shallow slopes (1–5 m depths) in sheltered and turbid bays; 2) coverage of these communities is high but the number of species is low; 3) *F. speciosa*, *E. aspera* (*E. echinata* in Iki Islands), and *L. undulatum* are dominant species, while *Acropora* spp., which dominate in the Ryukyu Islands, are rare; and 4) most of the colonies are large, some more than ten centimeters in diameter. Similar communities have not been reported from any other regions in Japan. Of particular interest is the fact that habitat ranges (in terms of depth) may be very different for coral species off the islands of Tsushima and Iki, relative to more tropical locations. For example,

Photo. 1. *Favia* spp., *Echinophyllia aspera*, and *Lithophyllon undulatum* found at < 5 m depth on the shallow slope at Senoura, the Tsushima Islands.

Fig. 1. Locations of the coral investigated in the Tshushima Archipelago.

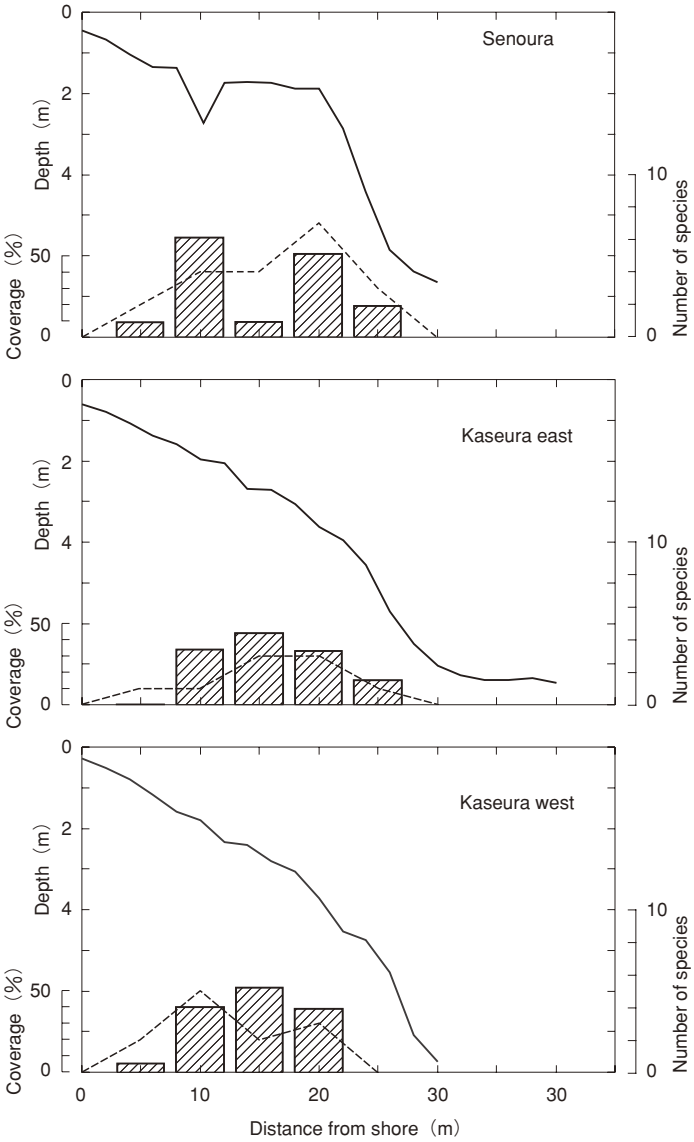


Fig. 2. Topographic profile (solid line), coverage (hatched bars), and number of coral species (dashed line) along the transect from shore to sea on the shallow slope at Senoura and Kaseura, Tsushima Archipelago.

most species found at < 2 m depth at Tsushima and Iki never occur at this depth in other, non-reefal regions in Japan, such as Amakusa in Kyushu, Kushimoto in the Kii Peninsula, Suruga Bay facing the Izu Peninsula, and Tateyama in the Boso Peninsula (Veron 1992c; Minegishi and Ueno 1995; Nojima and Yeemin 1999; Hagiwara 2003). In a further example, *Favia* spp., *Echinophyllia* spp., and *L. undulatum*, which at Tsushima and Iki are distributed on slopes shallower than 5 m, are found mostly at depths > 5 m in the Amakusa and Kushimoto regions, and on still deeper reef slopes in the Ryukyu Islands (Nakamori 1986; Nishihira and Veron 1995; Nojima and Yeemin 1999). These latitudinal differences in the depth distribution of coral communities are probably generated by latitudinal gradients in physical/chemical environmental characteristics such as temperature, light intensity, water motion, and turbidity, etc. (Done 1982; Rogers 1990; Veron and Minchin 1992). However, quantitative data are scarce for high-latitude communities and further studies are needed.

A similar coral community, including 55 species of 33 genera, is fossilized in the Holocene beds of Numa in Tateyama, Chiba Prefecture (Veron 1992b) (Chapter

6-2-1). The physical environment that formed this fossilized community may have been similar to that of the present-day Tsushima and Iki islands. Yamano *et al.* (2001c) suggested that dominant species (genera) might be reflective of the mean low sea surface temperatures (SSTs) of their habitats. The Iki Island coral reef is composed mainly of massive *Favia*, while reefs in the subtropical Ryukyu Islands are formed mainly by tabular *Acropora* (Kan *et al.* 1995). Although fossil coral communities dominated by *Favia* have been found in deposits off Miyako Island in the Ryukyu Islands, these formed during the last glacial maximum (around 21,000 years ago; Omura and Tsuji 1997), when the predicted winter SST for this area was 15–18°C (Li *et al.* 1997). This value is somewhat higher than, but certainly similar to, present-day values for the islands of Tsushima and Iki (Natsukari and Takita 1972; Natsukari *et al.* 1973; Yamano *et al.* 2001). In summary, the coral communities of Tsushima and Iki will help us to understand relationships between environmental gradients and coral reefs through the late Holocene, and to estimate Quaternary SST fluctuations through glacial-interglacial cycles.

3. Water quality and physical environment

Despite the high latitude, the Tsushima Current from the East China Sea keeps the Tsushima Islands relatively warm. The mean annual water temperature for the seas surrounding the islands is 19.5°C, with the annual low in March (13°C) and the annual high in September (27°C; Natsukari *et al.* 1973). Periodic winter winds from the north lower the islands' air temperature, relative to that experienced at a similar latitude on Honshu (Japan's main island). Snow is rare in this area (Tsushima Branch Office, Nagasaki Prefectural Government 2002).

The steep topography of Tsushima Archipelago means that the river catchment area is small, and terrestrial inflows happen abruptly after rainfall. Corals in Asou Bay are considerably influenced by frequent terrestrial inflows.

4. Notable species and ecosystems

Coral communities around the islands of Tsushima and Iki, near the northern limits of coral habitat in the Northwestern Pacific, are biologically important for evaluation of the reproductive and growth capabilities of corals under climatic stress. They would also serve as useful materials for discussing reef responses to environmental change, as previously noted.

2 Siruation of usages

1. Tourism

SCUBA divers visit the *A. tumida* communities at Ohtaura and Oura.

2. Fishery

Pearls are cultured in some bays. Apart from this, no fishing activities are associated with coral communities or coral reefs.

3 Threats and disturbances

Coral distribution is decreasing in some small bays owing to destruction and sedimentation that has occurred during the construction of fishing ports. Some communities have been degraded by red soil runoff as a result of road construction works. In some inlets at Senoura, large numbers of live coral colonies have already been reclaimed or removed during shore protection works. Anthropogenic pollutants, including oil, are sometimes seen flowing down rivers or leaking from fishing boats into the sea.

4 Monitoring and conservation

Our knowledge of coral distribution in Tsushima Archipelago is still limited; future surveys are expected to increase the number of known coral species around the islands, especially in the Asou Bay area, where there are many small inlets. Most coral habitats are close to villages, fishing ports and/or areas where pearls are cultured. Some of those habitats have disappeared as a result of harbor construction and repair. Immediate conservation measures are necessary to protect the critically vulnerable coral communities of the Tsushima Archipelago; such measures should include the establishment of marine protected areas.

c. Oki Islands and Goto Archipelago

(Maps 6-2-2-②, ③)

Hiroya Yamano

In a survey of hermatypic corals of the Goto Archipelago, Nagasaki Prefecture, Eguchi (1971b, 1975) reported 31 species of 20 genera in the sea area off the town of Goto, and 31 species of 20 genera in the Kami-Goto Islands. Off the islands of Hirado and Tsukumo, in Shimabara, 22 species of 16 genera were reported (Eguchi 1975). As has occurred at the islands of Iki and Tsushima, these species have since been taxonomically revised and further investigation is needed to establish true species numbers.

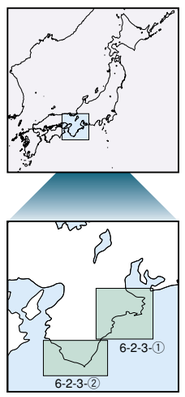
The only hermatypic coral species Nomura *et al.* (1994) identified from the Oki Islands (Shimane Prefecture) were *Alveopora japonica*, *Psammocora profundacella*, and *Oulastrea crispata*. This indicates that species richness decreases from the Goto Archipelago through the Oki Islands to the islands of Iki and Tsushima, in accordance with the latitudinal decrease in water temperature. Veron and Minchin (1992) have also observed this for the Japanese Pacific coasts. Coral reef formation has not been reported from any of the islands of the Oki Islands and Goto Archipelago.

6-2-3 Kii Peninsula
(Map 6-2-3)

Province: Wakayama Pref. at south and west coast, and Mie Pref. at east coast of the peninsula **Location:** The peninsula lies at south of Osaka **Features:** Kii Peninsula is the largest peninsula in Japan, and southern tip of the peninsula (Cape Shiono) is the southernmost part of Honshu **Air temperature:** 17.0˚C (annual average, at Cape Shiono) **Seawater temperature:** 22.0˚C (annual average, at west off Cape Shionomisaki) **Precipitation:** 2,534.4 mm (annual average, at Cape Shiono) **Total area of coral communities:** 113.9 ha **Protected areas:** Ise-Shima National Park: around Shima Peninsula at north of Kumanonada; Yoshino-Kumano National Park: coastal area of southern Kumanonada and around Cape Shionomisaki including Kumanonada Nigijima and Kushimoto Marine Park Zone.

6-2-3-①

＊“号” on this map means “site”.



6-2-3-②

＊“号” on this map means “site”.

Kii Peninsula

(Maps 6-2-3-①, ②)

Keiichi Nomura

1 Corals and coral reefs

1. Geographical features

The Kii Peninsula is located at the southern end of the mainland Japan (Lat: 34° N, Lon: 136° E), and straddles Osaka, Wakayama, Nara, and Mie prefectures (Fig. 1). The length of the coastline totals 1,956 km (223 km in Osaka, 628 km in Wakayama, and 1,105 km in Mie). There are 486 islands (none in Osaka, 253 in Wakayama, and 233 in Mie). Except in Osaka, the natural coastline is generally undisturbed, showing distinctive topographical features such as coastal erosion cliffs, coastal terraces, and ria coasts. Ria coasts are especially well developed from Shima to Owase, along the east coast of the Kii Peninsula. The coasts are generally steep, with the depth contour of 100 m closely following the coastline from Gobo, in Wakayama Prefecture, to Daiozaki on the Shima Peninsula, in Mie Prefecture. The area is mainly based on igneous rock, except for the area west of Cape Shionomisaki (southern edge of the Kii Peninsula), which incorporates mudstone strata.

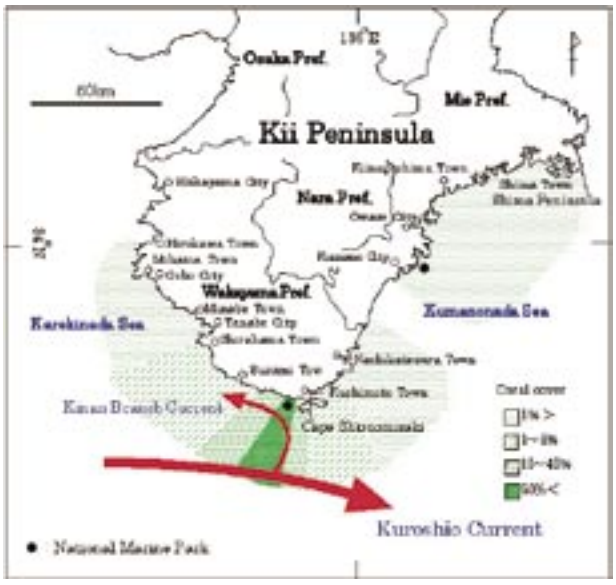


Fig. 1. Schematic diagram of the Kii Peninsula and distribution of corals of the Kii Peninsula. The red arrow indicates Kuroshio Current and its branch current.

Coral reefs are regarded not to form in this region. However, coral reef-like features (bedrock of coralline origin) distribute at Sabiura coast and west coast of the Cape Shionomisaki (Nojima 1990; Uchida 1994; Nomura *et al.* 2003a). Cape Shionomisaki is an island that is connected to the mainland by a coastal terrace. East coast from the Cape is called the Kumanonada Sea, and west of that is the Karekinada Sea.

The Kinan Branch Current, divided from the main Kuroshio Current, flows westward along the west coast of the Kii Peninsula (Fig. 1). The Kuroshio Current and the Kinan Branch Current supply the Karekinada coast with warm clear seawater from the south, along with abundant eggs and larvae of tropical organisms. In consequence, coral reef organisms are remarkably abundant around Kushimoto, and a subtropical biological community has formed in which tropical features are joined with temperate ones. East of Cape Shionomisaki, however, the coasts are influenced by water that flows into the Kumanonada. These waters have lower temperatures and lower salinity than those of the southern Karekinada, and this region shows temperate biological communities. The following meteorological observations were made at Sabiura in Kushimoto (Nomura *et al.* 2003a), where strongly influenced by the Kuroshio Current. The annual average sea surface water temperature was 21.1°C, with a low of 16.3°C in winter (February), and a high of 27.2 °C in summer (August). The average annual air temperature was 17.5°C, with a low of 8.7°C in winter (January), and a high of 26.7°C in summer (August). The annual average salinity was 35.0 PSU and the annual average underwater transparency was 14.7 m.

2. Coral distribution

Around the Kii Peninsula, hermatypic corals occur between south of Takashima in Hirokawa (Wakayama Prefecture) and south of Wagu in Shima (Mie Prefecture). The number of observed species in each place in the Kii Peninsula is as follows. Karekinada coast; Kushimoto (109 species), Shirahama (77 species), Tenjinzaki in Tanabe (12 species), Gobo and Mihama (21 species) and Takashima (3 species), and Kumanonada coast; Myougajima of Kushimoto (12 species), Miminohana in Nachikatsuura (16 species), around Nigishima in Kumano (10 species), Kiinagashima

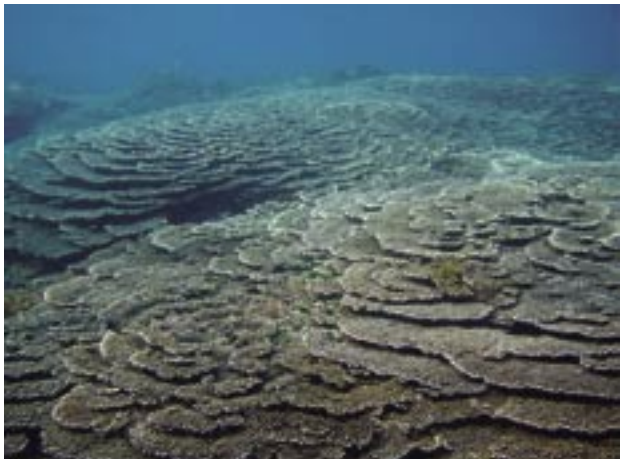


Photo. 1. Monospecific community of *Acropora hyacinthus* (Sabiura, Kushimoto).

(8 species) and Wagu (1 species). Areas of over 1 % coral coverage occur between south of Gongenzaki at Shirahama in the Karekinada, and south of Miminohana at Nachikatsuura in the Kumanonada. Areas of high density coral cover (> 50 %) are distributed from Azumame to Tago in Kushimoto (Fig. 1). Coral communities with 5 % coverage are found in Kumano and Kiinagashima, but their distribution is local and restricted (Hiraga and Koda, unpublished data; Hiraga 1994; Miyawaki 1994; Nishihira and Veron 1995; Nomura *et al.* 2003a; Nomura and Hirotsuji 2001; Nomura and Fukuda 2000; Uchida 1994). Coral distribution in the Kii Peninsula is centered on the western region of Cape Shionomisaki in Kushimoto. As distance from this point increases along the coastlines, both the number of coral species and the coverage decreases, especially on the Kumanonada side.

Tabulate *Acropora hyacinthus* dominates shallow water (< 10 m in depth) in Kushimoto; large-scale communities of this species are seen in Azumame (Kushimoto Marine Park Site 1), Sabiura (Kushimoto Marine Park Site 2, Photo. 1), Najikasaki (Kushimoto Marine Park Site 4), Soshima, and around Tako.

Especially in Azumame, a monospecific community, of about 100 m × 20 m (0.2 ha), forms a beautiful seascape. Other dominant species in the shallow water include *Acropora* aff. *gemmifera*, *Cyphastrea serailia*, *Montastrea valenciennesi*, *Goniastrea australensis*, *Platygyra contorta*, *Favites flexuosa*, *G. aspera*, and *Acropora solitaryensis*. In deeper zones (10–20 m depth), *Echinophyllia aspera* (Photo. 2) dominates. Peculiar communities of the following species are seen in the following places: inner bay area (*Acropora tumida*; Photo. 3 and *Lithorhyllon undulatum*; Photo. 4), the northern coast of Soshima (*Goniopora* sp.; Photo. 5), Najikazaki (*Acropora microphthalma*; Photo. 6), Sambira (*Acropora formosa*), Kamiura to Andonohana (*Pavona decussata*; Photo. 7), Andonohana (*Catalaphyllia jardinei*; Photo. 8), north of Sumisaki (*Astreopora incrustans*, *Pavona cactus*, and *Merulina ampliata*), and Sumisaki (*Acropora cuneata*). Huge, massive coral colonies (3–5 m along the major axis) of *Porites lutea*, *Coscinaraea columna* and *Turbinaria peltata* are seen scattered in the inner bay area. However, most of these *P. lutea* colonies are now dead (Nomura 2001, 2002, 2003, 2004; Nomura and Fukuda 2000, 2001, 2002; Nomura *et al.* 2003a).

The coral fauna becomes monotonous with the rise in the latitude from Cape Shionomisaki, the frequency of *Acropora* gradually decreases and, simultaneously, the frequency of species such as *Porites heronensis*, *Psammocora profundacera*, *Hydnophora exesa*, *Cyphastrea serailia*, *Montastrea valenciennesi*, or *Plesiastrea versipora* increases. The northern limit of coral distribution on the Karekinada side is at Takashima in Hirokawa, and the species that occur here are *Acanthastrea* sp., *Favia speciosa*, and *Cyphastrea serailia*. On the Kumanonada side, the northern limit is at Wagu in Shima, and the only species that occurs there is *Hydnophora exesa* (Fukuda, unpublished data; Hiraga and Koda unpublished data; Nomura and Hirotsuji 2001; Uchida 1994). The northernmost point at which a coral community with over

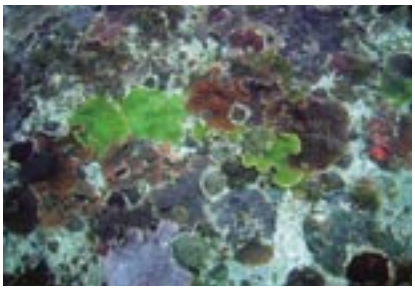


Photo. 2. *Echinophyllia aspera*

Photo. 3. *Acropora tumida*

Photo. 4. *Lithophyllon undulatum*

Photo. 5. *Goniopora* sp.

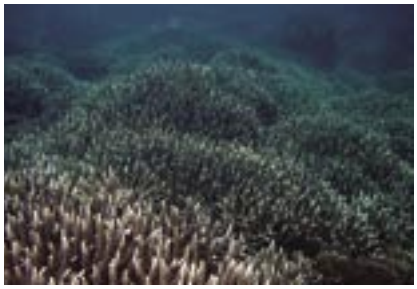


Photo. 6. *Acropora microphthalma*

Photo. 7. *Pavona decussata*

50 % coverage was known to occur at Esumi in Susami (Miyawaki 1994) but, recently, the existence of a high density, large scale communities of *A. hyacinthus* was confirmed in Okinose (Fukabae), Tanabe Bay (Akagi 2003).

There are two coral species (*Acropora hyacinthus* and *Catalaphyllia jardinei*) of particular note in the Kii Peninsula. *A. hyacinthus* (Photo. 1) not only forms high density communities in the southern peninsula, to the point that it becomes the main constituent of the marine landscape, but it is also highly important as a species resource and as an ecological base. *C. jardinei* (Photo. 2) is very rare species in Japanese waters, and forms the domestic large-scale community in Kushimoto.

Taxonomical study of corals in the mainland Japan has not been sufficient, and many unidentified or undescribed species are recognized. As taxonomical knowledge increases, it is expected that further important species will be added.

Photo. 8. *Catalaphyllia jardinei*

2 Situation of usages

1. Tourism

Major marine tourisms in the Kii Peninsula are sea bathing (especially Shirarahama in Shirahama), SCUBA diving (especially southern part of the Peninsula), and recreational fishing (all coastal areas).

2. Fisheries

Fisheries are prosperous in the Kii Peninsula. Typical fishing methods include line fishing (skipjack, tuna, red sea bream, horse mackerel, pigfish and squid), buoy gill net fishing (saury and flying fish), bottom gill net fishing (flatfish, lobster, and top shell), coastal dragline fishing (coastal fish), fixed net fishing (coastal fishes), towed net fisheries (anchovy, sand eel, and halfbeak), trawling (hairtail, red sea bream, prawn), stick-held dip net fishing (sardine, banded blue-sprat, horse mackerel, mackerel, and saury), net fishing (sardine, horse mackerel, and mackerel), drive-in fishery (small whales), and dive fishing (ear-shell and top shells). And also aquaculture is prosperous: main species are sea bream, yellowtail, flatfish, bluefin tuna, prawns, noble scallops, and pearls (Nakajima *et al.* 1985).

3 Threats and disturbances

The major disturbances for the coral communities of the Kii Peninsula are discussed below.

1. Typhoon waves

Although strong typhoons approach the Kii Peninsula once in about 10 years, the accompanying big waves can cause damage to coral communities. Such a situation could chiefly cause damage to the seascape of *Acropora hyacinthus* communities in Kushimoto. However, areas

that have been affected thus far have been able to recover to their previous state within a few years (Nomura *et al.* 2003a).

2. Abnormal water temperature

Abnormally high and low water temperatures have caused bleaching and the subsequent death of corals such as *Acropora hyacinthus* around Kushimoto. Coral bleaching by the low water temperatures has been confirmed three times (1980, 1982, and 1984) since 1971; in terms of damage, 1984 was the most severe event. On this occasion up to 50 % of *A. hyacinthus* died in general, and suffered catastrophic damage in some places. This severity was probably due to a long period of under 14 ˚C water temperatures (20 days or more). Since 1971, coral bleaching during episodes of high water temperatures has been observed four times (1984, 1994, 1998 and 2001) in Kushimoto. Bleaching was also recorded in infralittoral zones (except in 2001) but, in each case, the death rate was insignificant. The 2001 bleaching event was limited to corals growing in intertidal pools, where the death rate was > 50 %, particularly for the dominant species *Cyphastrea serailia* (Nomura *et al.* 2003a).

3. Damage by other organisms

Abnormal proliferation of crown-of-thorns starfish (*Acanthaster planci*) or coral-eating gastropods can cause massive coral damage and death. A proliferation of *A. planci* was identified around Cape Shionomisaki in the 1970s, but this group of starfish had disappeared by the 1980s without causing serious damage to coral communities. Totally 1,400 individuals were removed during this period. At present, several individuals of starfish can always be observed on submerged rocky reefs off Kushimoto, but the distribution density remains low. However, it is possible that this population spread to coastal areas, and thus monitoring is required (Nomura *et al.* 2003b).

The coral-eating gastropod *Drupella fragum* has proliferated abnormally for about five years around Kushimoto, causing damage to *Acropora hyacinthus* and other *Acropora* species. Systematic removing projects were commenced in this area soon after their increased numbers were noted, but this proliferation is probably a chronic problem. A large-scale monospecific community of *A. hyacinthus* disappeared from marine park Site 4, where *Drupella* had initially caused a lot of damage, but colonial regeneration has been observed taking place (Nomura *et al.* 2003a). High predation pressure by another coral-eating gastropod, *Coralliophila costularis*, is occurring in coral communities from Gobo to Mihama.

Damage to coral communities during a red tide has also been observed. In 1984 *Gymnodinium nagasakiense*, a species of dinoflagellate, proliferated in large quantities in the Kumanonada, over an extended period (June–July). This species forms a vast red tide, causing extensive damage to coastal organisms. Corals in the area are assumed to have received catastrophic damage at this time, and the present inhabitants probably developed after this occurrence (Hiraga 1994).

4. Anthropogenic disturbances

Inner bay coral communities have been disturbed, to varying degrees, by the reclamation and construction that have accompanied harbor improvements, limited water exchange, and sedimentation of silts and mud, among other things. Healthy colonies of *Porites lutea*, which are popular in particular to inner bay areas, are now very rare in the sea near Kushimoto. These anthropogenic disturbances (along with *Drupella*-induced damage) have caused many *Acropora tumida* communities, which were also once distinctive inner bay areas, to decrease altogether. Coral communities at the mouth of Arita Bay at Kushimoto (including colonis of *Catalaphyllia jardinei*) appear to have been largely destroyed by repeated anchoring of a harbor maintenance ship (Nomura 2001, 2002, 2003, 2004; Nomura and Fukuda 2000, 2001, 2003). Although no reliable data exist, it is suspected that aquarists are illegally collecting invertebrates, including corals and coral rubble (live rock), together with fish.

4 Monitoring and conservation

Several national parks along the coast of the Kii Peninsula have been designated, and are conserved by the Natural Parks Law. They are: Setonaikai National Park (near Kada in Wakayama), Yoshino-Kumano National Park (from Kushimoto to Owase), and Iseshima National Park (on the Shima Peninsula). In Yoshino-Kumano National Park, two marine park zones have been designated at Nigishima (two sites, totaling 14.4 ha), and at Kushimoto (four sites totalling 39.2 ha); in these zones, construction works and the collection of marine organisms are restricted (Nature Conservation Bureau, Environment Agency 1999c). Moreover, the fishery adjustment law formulated in each municipality generally

restricts the collection of marine organisms.

It is probable that important marine biological communities are disappearing without our notice, because of the difficulty in looking around the features in the sea. This disappearance seems to increase concomitantly with the environmental pressures imposed by human activities. The trend is particularly noticeable in inner bay areas, where anthropogenic influences are strong. In the southern Kii Peninsula, coral communities, composed mainly of *Acropora tumida*, *Lithophyllon undulatum* and *Pectinia aylen*, occur inner bays, but their continued existence could be difficult because of the environmental degradation. Occurrence of a huge earthquake named the Nankai or the Tonankai Earthquake is predicted in the near future, and Kii Peninsula is forecasted to suffer tsunami damage. Consequently, plans for construction of breakwaters to protect vulnerable coastal villages are now rapidly in progress with little or no reference to the fact that their construction will cause further damage to inner bay coral communities.

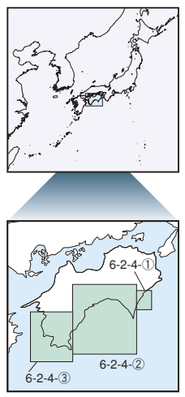
To prevent important biological communities from disappearing, it is essential to first understand their nature and distribution. However, it isn't attained satisfactorily in the Kii Peninsula. As a necessary first step towards conservation, more surveys of these communities should be undertaken, and appropriate protective measures must be implemented when the importance of the communities were detected and ascertained.

6-2-4 Shikoku
(Map 6-2-4)

Province: Tokushima Pref. at east, Kochi Pref. at south and Ehime Pref. at west of Shikoku **Location:** Shikoku lies at southwest of Osaka and east of Kyushu **Air temperature:** 16.6˚C (annual average, at Sukumo City, Kochi Pref.) **Seawater temperature:** 21.7˚C and 22.7 ˚C (annual average, at east off Cape Muroto and west off Sukumo, respectively) **Precipitation:** 1,990.9 mm (annual average, at Sukumo City) **Total area of coral communities:** 159.4 ha **Protected areas:** Muroto-Anan Kaigan Quasi-National Park: coastline from Cape Gamoda (Tokushima) to Cape Muroto (Kochi), including 2 Marine Park Zones; Ashizuri-Uwakai National Park: coastline from Cape Ashizuri (Kochi) to Cape Yura (Ehime), including 6 Marine Park Zones.

6-2-4-③

＊“号”on this map means“site”.



6-2-4-①

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6-2-4-②

a. East of Muroto

(Map 6-2-4-①)

Fumihito Iwase

1 Corals and coral reefs

1. Geographical features

The east coast of Shikoku, from Cape Gamoda to Cape Muroto, is composed of sedimentary rock with a layer of sand and mudstone. Crustal movements and a repeated cycle of glacial and interglacial sea-level change formed typical coastal terraces. Anan Coast is a bow-shaped, and predominantly rocky coast that stretches from Cape Kamouda to Toyo. There is a well-developed coastal terrace with 4-km-long sea cliff. The coast is characterised by capes and small bays interspersed with small islands. Comparatively, the coastline from Toyo to Cape Muroto is straight and lacks bays, capes, and islands. This raised coastline consists of ledges and large rocks that give way to a steep underwater topography with submarine valleys.

The area was designated the Muroto-Anan Kaigan Quasi-National Park in 1964. Its unique geological and subtropical vegetation is fed by the warm Kuroshio Current, which flows offshore. Benten Island off Anan City boasts a tropical plant community was selected as a national treasure in 1922. There is the beautiful underwater scenery, and coral communities that surround the islands of Oshima off Mugi and Takegashima (Is.) off Shishikui gained these two areas designated as marine park zones in 1971 and 1972, respectively.

2. Coral distribution

Hermatypic corals (hereafter, corals) occur south of Hiwasa (Tokushima Prefecture 1978), and areas with more than 5 % coral cover are found at three locations within a total area of 7.25 ha: Oshima, Takegashima, and Bishago Rock off Muroto (Nature Conservation Bureau, Environment Agency 1994). Within these areas, 52 species from to 12 families have been identified, (Tokushima Prefecture 1997, 2002), the most prevalent of which are *Acropora tumida*, *Lithophyllon undulatum*, *Porites lutea*, *Goniastrea deformis*, *Physophyllia ayleni*, and *Turbinaria peltata* (Tokushima Prefecture 2002). Three-quarters of these species have encrusting morphology, and the remaining quarter has branching morphology, for example, *A. tumida* (Nature Conservation Bureau, Environment Agency 1994).

3. Water quality and physical environment

The Kii channel lies between Shikoku's southeastern shore and the Kii Peninsula. The channel is connected to the Seto Inland Sea through Osaka Bay, but could be regarded as a large bay due to the existence of Awaji Island at the northern end of the channel. The flow of the ocean current entering this large bay has a predominantly counterclockwise drift. The northward flowing Kuroshio Current diverges at the tip of the Kii Peninsula, then heads westward along the bay, and turns southward along the east coast of Shikoku. At times, the Geitou Branch Current, which has a northward drift from the sea off Cape Muroto, is dominant, with occasional, infrequent appearances of coastal waters from the Seto Inland sea. However, geomorphologically the area is open to the Sea, and is charactrised by combined effect of ocean and bay. The coral communities that exist near the northern boundaries of the area have bay-like characteristics (Tokushima Prefecture 1986).

4. Notable species and ecosystems

A large scale communities of *Entacmaea actinostoloides* can be seen in Awa Oshima Marine Park (Site 1). In the inner bay on the west coast of Oshima, there is a large colony of *Porites heronensis*, about 7 m in height and 6–8 m width (Photo. 1). There used to be a large community of *A. tumida* in Awa Takegashima Marine Park (Site 1), but after 1981 it declined and was replaced by *Lithophyllon undulatum* (Tokushima Prefecture 1988, 1997, 2002). Large colonies of *Styloconiella guentheri* with approximately 2 m in diameter are dominant somewhere around Takegashima (Nature Conservation Bureau, Environment Agency 1994).

The beaches of the Kamouda Coast near Anan, the Ohama Coast in the vicinity of Hiwasa, and the Osato Coast near Kainan are well known spawning grounds of loggerhead turtle (*Caretta cretta*). Of the three, only the Ohama coast has been designated a National Treasure and a Tokushima Prefectural Nature Treasure (Sea Turtle Association of Japan 2001).

Photo. 1. A large colony of *Porites heronensis* (about 7 m in height and 6–8 m in width) in the inner bay on the west coast of Oshima (Is.).

2 Situation of usages

1. Tourism

Surfing and scuba diving are the most popular water sports in the area. Diving services are available in Mugi and Shishikui, Bishago Rock also attracts divers, but in lesser numbers. Area attractions include a shellfish museum at Mugi, an underwater interpretive center at Takegashima, and a glass-bottomed boat that makes excursions into the marine park. Surf fishing and boat-based fishing are popular, and charter fishing boats are available.

2. Fishery

The numerous ledges and the exposure to the high seas of the Pacific limit fishing mainly to fixed shore net, gill net, long-line, and single-rod fishing; shells and seaweed are collected along the shores. The population of fishermen is aging, and the production of the fishing industry is declining. Aquafarming is rare because there are few calm inner bays to accommodate it. A few aquafarms that raise yellowtail snapper and red sea bream are located in the towns of Yuki, Kainan, and Shishikui.

3. Threats and disturbances

1. Water temperature changes

It is by the grace of the Kuroshio current that coral grows this far north. However, die-off occur when, for example, the Kii Channel brings cool inland water, or there is a seasonal winter cold wave. In February 1981, the water temperature declined to below 9°C for about 15 days, owing to the southward flow of inland water. As a result many *A. tumida* and *Pavona decussata* died (Tokushima Prefecture 1986).

2. Harbor construction

Construction, dredging, aquafarming, harbor improvements, and the installation of breakwater walls for shore line protection are reported to have changed the habitat around the port of Kan-no-ura. Coral communities in Awa Takegashima Marine Park, which is adjacent to the port, have experienced a decline or surffered transition to more inside-bay environments (Tokushima Prefecture 1997).

3. Coral-eating predators

Damage caused by the crown-of-thorns starfish (*Acanthaster planci*) and coral-eating gastropods (e.g., *Drupella fragum*) has not been noted until recently. However, in a survey of corals and other organisms conducted in 2001, predation damage by *Drupella* was reported in both the Awa Takegashima (Site 2) and the Awa Ohshima (Site 2) marine parks (Tokushima Prefecture 2002). A damage assessment plan is necessary to deal with the emergence of these gastropods.

4 Monitoring

The responsibility for a survey of marine park zones that was begun by the Tokushima Prefectural government in 1977 was assumed by the Marine Parks Center of Japan, but the surveying methods used have proved to be inconsistent. (Tokushima Prefecture 1977, 1978, 1986, 1988, 1997, 2002).

5 Conservation

Following the report that coral communities in Awa Takegashima Marine Park are in decline and are beginning to change into bay-like communities, Tokushima Prefecture began a survey in 2003 as part of the Nature Restoration Promotion Plan. The survey will continue until 2004, and the succeeding nature restoration and Maintenance Project will begin in 2005.

6 Necessary measures

A survey taken in the Awa Takegashima Marine Park as part of the Nature Restoration Promotion Plan produced results that are expected to lead to conservation measures. Of primary concern is the issue of predation damage by *Drupella*, especially in Oshima and Takegashima.

b. Tosa Bay

(Map 6-2-4-②)

Fumihito Iwase

1 Corals and coral reefs

1. Geographical features

The area from Cape Muroto to Cape Ashizuri in Kochi Prefecture is arc-shaped, forming Tosa Bay. In winter, the predominant cold north-northwest winds are blocked by the mountains, and in summer strong south-southeast winds, sometimes generated by typhoons, hit the area directly. Geologically, Tosa Bay is in the same region as the eastern coast of Shikoku. This region of sedimentary rock, consisting of a layer of sandstone and mudstone, is called the 'Shimanto Belt'.

There is an urban area centering on Kochi at the innermost part of Tosa Bay between the Monobe and Niyodo rivers. The human population decreases toward both the eastern and western ends of the bay. The shoreline of this area is mostly sandy beaches. Rocky shores increase in frequency toward the west. The large Shimanto River mouth is situated in this part of the bay.

There are seven natural parks along the coastline of Tosa Bay. From east to west, these are: Muroto-Anan Coast Quasi-National Park, Tei-Sumiyoshi Prefectural Natural Park, Yokonami Prefectural Natural Park, Susaki Bay Prefectural Natural Park, Okitsu Prefectural Natural Park, Irino Prefectural Natural Park, and Ashizuri-Uwakai National Park.

2. Coral distribution

Tosa Bay is in a boundary zone between temperate and subtropical areas, featuring both warm-temperate and subtropical districts and the coral community reflects this. The community is dominated by *Acropora solitaryensis* and *Cyphastrea serailia* (Port and Harbor Section of Kochi Prefecture 1994).

Coral communities dominated by *A. solitaryensis* have been reported from the following locations: Muroto Port (18 species from 9 families), Murotsu Port (18 species from 7 families), Cape Gyoto (21 species from 7 families), Cape Hane (25 species from 8 families) in Muroto, Yanagare in Aki, Tei in Yasu (47 species from 11 families), south shore of Yokonami Peninsula (35 species from 11 families), Kamishima Island in Susaki, and Kamikawaguchi in Ohgata (Nature Conservation Environment Agency 1980; Fujioka 1994, Nature Conservation Bureau Environment Agency 1994, Port and Harbor Section of Kochi Prefecture 1994). Since 2000, newly discovered coral communities have been reported from Karyogo and around the Nahari Port breakwater (69 species from 11 families) in Nahari and from Nomi Bay in Susaki to Yaiga in Nakatosa.

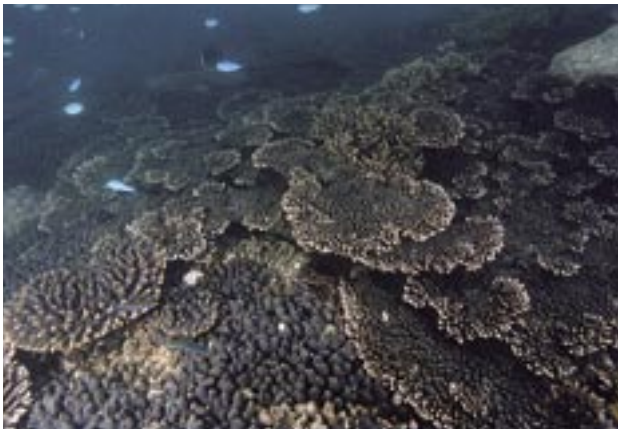


Photo. 1. Corals growing in high density behihd the constructed breakwater in Tei, Yasu, Kochi Prefecture. The large colonies are mainly tabulate *Acropora*.

3. Water quality and physical environment

The Kuroshio Current flows from southwest to northeast at the opening of Tosa Bay. However, a counterclockwise drift is common inside the bay owing to a divaricated westward drift from Cape Muroto.

4. Notable species and ecosystems

A breakwater was constructed on the rocky shore of Tei in Yasu, artificially creating a relatively calm area that is suitable for coral growth. As a result, many coral colonies, mainly tabulate *Acropora*, have grown to large sizes and high densities (Marine Parks Center of Japan 1994; Photo. 1). A similar situation occurred around Nahari Port; an offshore breakwater was constructed on the sandy shore, and a new coral community developed as a result of the relatively calm conditions and hard substrate. In these rare and interesting cases, civil engineering works have accidentally created a suitable envi-

ronment for coral communities and have fostered their settlement and growth.

2 Situation of usages

1. Tourism

Scuba diving is popular in Muroto, Karyogo, and areas from the south shore of Yokonami Peninsula to Yaiga. Dive shops in Kochi often run scuba diving day trips in the area. Around the Nahari Port breakwater, glass-bottomed boats enable tourists to view the coral communities. Local nonprofit organizations irregularly hold nature observation events, which include snorkeling and the use of glass-bottomed boats in Tei and around the Nahari Port breakwater.

2. Fishery

The region sustains many fisheries. Single-rod fishing for skipjack, trolling line fishing for skipjack and tuna, and encircling net fishing for dolphin fish occur offshore from Tosa Bay. Closer to the coast, methods include conventional angling, long-line fishing, and batch-net fishing for whitebait, as well as sand-borer fishing using dragnets and gill nets. Along the shallow rocky shore, people collect shells and seaweeds, and use gill nets to take lobster (*Panulirus*). Additionally, fixed shore-net fishing is conducted all over Tosa Bay, especially around Cape Muroto and Cape Ashizuri. Aquafarms are found in Nomi Bay in Susaki and in Uranouchi Bay, at the innermost region of Tosa Bay. The cultivation of sea lettuce (*Monostroma*) and green laver (*Enteromorpha*) occurs around the river mouths. Deep-water netting for jewel corals was common around Cape Muroto and Cape Ashizuri, but this practice has declined in recent years owing to the depletion of resources.

3 Threats and disturbance

1. Coral predators

Coral predation by the crown-of-thorns starfish (*Acanthaster planci*) has never been recorded in Tosa Bay. Damage caused by corallivorous gastropods (e.g., *Drupella fragum*) has been reported from areas around Muroto, but the impact appeared to be limited (Nomura 1991; Nature Conservation Bureau, Environment Agency 1994). In no case has a detailed study concerning the effects of coral predators been undertaken.

2. Water temperature changes

Average water temperatures in Tosa Bay are increasing as the Kuroshio Current tends to move closer to the coast. This seems to have caused a decline of large-scale seaweeds and an expansion of coral distribution, although detailed surveys of the impact on coral distribution are lacking.

4 Monitoring

In 1987, a new large-scale development called the 'Marine Town Project' was planned in Tei; the plans described the construction of a new marina, bathing beach, and enlargement of the fishing port. A survey of marine organisms including corals and oceanographic conditions was initiated as part of the planning process (Port and Harbor Section of Kochi Prefecture 1989a, 1989b, 1990a, 1990b, 1990c, 1991; Kochi Prefecture Hankoku Civil Engineering Office Kochi Prefecture Hankoku Civil. 1992a, 1992b, 1992c, 1993a, 1993b). Local residents protested against the damage that would be caused to coral communities, particularly during the construction of the marina, and an additional survey was conducted to assess whether the development should proceed (Port and Harbor Section of Kochi Prefecture 1990; Marine Parks Center of Japan 1994). As a result, the project was brought to a halt. A nongovernmental nature conservation organization called 'The Association to Preserve Ohte Beach' played a major role in the protest campaign and continues local environmental education and surveillance, although their survey methods are not very systematic. Another preliminary survey was conducted in 1999 to assess the area's usefulness for environmental education (Port and Harbor Section of Kochi Prefecture 1999). In 2001, some coral communities in the area were buried by sand, and Kochi Prefecture Harbor's Section convened a study committee and survey team to investigate the cause and recommend preventative measures. Consequently, more data exist for the sea area of Tei than for any other location in Tosa Bay.

In 2002, it was reported that a new coral community developed on the offshore breakwaters around Nahari Port. In response, the Aki Kochi Civil Construction Office commenced a survey to describe the current status of coral growth. The construction of these offshore breakwaters commenced in 1975, occurred sequentially

along the coast, and is ongoing; therefore, surveys of coral settlement and growth will produce a time series that will be valuable for monitoring purposes.

5 Necessary measures

Information about the nature, distribution, and status of coral communities in Tosa Bay is still limited, except in specific areas such as Tei. Further survey work is essential to understand and monitor the coral communities of this region.

c. Ashizuri-Uwakai

(Map 6-2-4-③)

Fumihito Iwase

1 Corals and coral reefs

1. Geographical features

The coastline of the Uwa Sea, south of Cape Sata on the west coast of Shikoku, is ria coastline that consists of complex, steep, rocky slopes that extend underwater. However, in areas from Cape Ashizuri to Kashiwajima Island, the coastal terrace is well developed owing to upheaval. Rocky coastlines are also found in the area, but the slope of the sea floor is more gradual than that in the Uwa Sea.

The strong influence of the Kuroshio Current running eastward allows abundant subtropical marine flora and fauna to occur in the area in spite of its high latitude. The distinctive coastline, formed by upheaval and subsidence, and the beautiful scenery, produced by diverse biological communities, led to this area being designated as the Ashizuri Quasi-National Park in 1955. The Uwa Sea (Uwakai) was later added to the designated area, which became the Ashizuri-Uwakai National Park in 1972. Inside the national park, 19 marine park zones have been designated for their underwater scenery, focused on coral communities. In 1965, the Satamisaki Hanto Uwakai Prefectural Natural Park was established. In the same year, the temperate sea biotope of the Uwa Sea, including coral communities, was also designated a natural treasure of Ehime Prefecture for the Uwa Sea special marine resources.

2. Coral distribution

Hermatypic corals (hereafter, corals) are most abundant on the west coast of Shikoku, and 127 species have been recorded around Cape Ashizuri in Tosashimizu (Veron 1992c; Nishihira and Veron 1995). Corals are distributed all around the rocky coasts from Cape Ashizuri to Uwajima. The highest abundance of coral is found in the areas extending from the west coast of Cape Ashizuri to Otsuki, around Okinoshima Island in Kochi, and in the coastal area of Nishiumi Town in Ehime. In Kochi, many species of *Acropora*, such as *Acropora solitaryensis*, *A. hyacinthus*, and *A. formosa*, are commonly distributed. *Acropora* communities are also found in Ehime, but *A. formosa* is scarce; instead, most areas are dominated by Alcyonacea, an order of octocoral, and *Tubastraea micrantha*, an ahermatypic coral (Nature Conservation Bureau, Environment Agency 1995b). It is suggested that corals are also distributed to the north of Uwajima toward Cape Sata (Nature Conservation Bureau, Environment Agency 1994), but details of these communities have not yet been clarified.

3. Water quality and physical environment

Okinoshima and Cape Ashizuri are promontories at the southwest tip of Shikoku, where the Kuroshio Current runs eastward. Consequently, the coast around Tosashimizu and Otsuki is under the direct influence of this warm current. The Uwa Sea is also strongly influenced by the divaricated Kuroshio Current throughout the year, which causes warm water, high salinity, and high transparency. These characteristics are also associated with the facts that there are no big rivers in the area and that water from the Seto Inland Sea is blocked by the Cape Sata.

4. Notable species and ecosystems

In Minokoshi Bay in Tatsukushi, Tosashimizu, there is a huge colony of *Pavona decussata* that extends to 45 × 26 m and is designated a national natural treasure (Photo. 1). In Ushirohama in Kashiwajima, Otsuki, there is a luxuriant coral community in which 90 % or more of the cover is composed of *A. solitaryensis* (Nature Conservation Bureau, Environment Agency 1995b). From the same area, 884 species in 143 families of fishes have been recorded (Hirata *et al.* 1996), exemplifying the extreme richness of the ecosystem.

The northernmost records of many species of coral have been documented in this area (Nature Conservation Bureau and Marine Parks Center of Japan 1995). In addition, tropical species such as *Leptoseris papyracea* have been newly recorded (Hirata personal communication). It could be possible that the continuing trend of increasing seawater temperatures in this area in recent years has expanded the distribution of coral species that did not occur here previously.

2 Situation of usages

1. Tourism

In Tatsukushi, facilities include an underwater observatory, an aquarium, shellfish exhibition pavilions, and coral museums, which attract large numbers of tourists, and the area was designated a National Park Group Facilities' Zone. However, tourist numbers are in decline, along with a marked recent decline in coral communities. A glass-bottomed boat is also operated around Nishiumi Town Marine Park, but the number of visitors to this area is also decreasing (Sanyo-Shikoku RONC 2003). While such conventional tourism is declining, SCUBA diving is gaining in popularity. Kashiwajima is the most famous diving spot in Shikoku, and the diving population is constantly increasing along with the number of diving services. Recreational fishing on rocky shores and offshore is also common, and many recreational fishing services exist.

2. Fishery

The main fisheries in the Ashizuri Sea area are trolling line fishing for skipjacks, angling for mackerel and squid, and fixed shore net fishing. In the Uwa Sea area, whitebait fishing by dragnet and seine net fishing for sardines and mackerel are common. Aquaculture is also popular, taking advantage of the complex coastline; not only fish, but also bivalves, including Akoya pearl oysters (*Pinctada fucata*) and Noble scallops (*Mimachlamys senatoria*) are common. The area's production of pearl oysters is one of the most important in Japan.

3 Threats and disturbances

1. Crown-of-thorns starfish

A crown-of-thorns starfish (*Acanthaster planci*) extermination project has been conducted by the Ministry of the Environment (former Environment Agency) in the marine park zones since 1973. Extermination has also been funded by other agencies and conducted by volunteers; therefore, the Ministry of the Environment statistics do not cover all the eradication data for this area. Nevertheless, according to these statistics, the number of crown-of-thorns exterminated peaked during 1977–1979, and amounted to 10,000–15,000 individuals annually. These numbers later declined, and have plateaued since 1990 at around 100–500 individuals per year, mainly from Okinoshima (Sanyo-Shikoku RONC 2003). *A. planci* were observed at various points during a survey in 2003, but these sightings were not considered an outbreak (Nature Conservation Bureau, Ministry of the Environment 2003d).

2. Coral-eating gastropods

When the major damage by *A. planci* ended around 1990, coral predation by coral-eating gastropods, mainly *Drupella fragum*, started to be reported. Extermination programs have been carried out by local authorities, the prefectural government, the Ministry of the Environment, and volunteers (Suga 1994; Tominaga 1998). No comprehensive statistical data exist because these programs have been undertaken by many organizations and people, but the number of exterminated individuals peaked at about 100,000–200,000 per year during

Photo. 1. Large community of *Pavona decussate* at Minokoshi Bay in Tatsukushi, Tosashimizu, Kochi Prefecture.

1995–2000 (Sanyo-Shikoku RONC 2003).

An outbreak of coral-eating gastropods was observed in the Shirigai Marine Park in 1989. To address this problem, the town of Otsuki at once began a feasibility study to research the possibility of eradication and to determine the distribution and life history of corals and gastropods. The results of this study confirmed the necessity of extermination, and extermination methods were examined. In order to conserve high coral coverage in an area dominated by *A. hyacinthus* and *A. formosa*, a 50 × 50-m protected area was established based on a consideration of the resource expenditure that could be allotted to extermination. Although outbreaks of *Drupella* occurred continuously for more than ten years, intensive extermination on this protected area allowed a high average coral cover of 54 % to be maintained (Nomura and Tominaga 2001).

3. Sedimentation

During the Kochi southwest torrential rain that affected Tosashimizu, Otsuki, and Sukumo in September 2001, a large amount of soil flowed into the Ashizuri Sea at several different locations. The most heavily damaged area was the Tatsukushi Marine Park, where many corals inside Tatsukushi Bay died as a result of sedimentation (Kuroshio Biological Research Foundation 2002, Nature Conservation Bureau, Ministry of Environment 2003). At the Shirigai Marine Park, a landslide caused an influx of soil, burying corals (Machida 2001).

The Ministry of the Environment removed the accumulated soil in part of the Tatsukushi Marine Park, and the Ministry and the town of Otsuki did the same in the Shirigai Marine Park (Hayashi 2002; Iwase 2002). Some coral communities in areas where the soil was removed were saved, but the extent of the damage remained unclear in many other areas.

4 Monitoring

1. Reef Check

Reef Check, an international protocol for coral reef monitoring, has been undertaken in Kashiwajima since 2001, mainly by the nonprofit Kuroshio Zikkan Center organization.

2. Monitoring by volunteer organizations

At four marine park zones in Otsuki, members of a volunteer organization, the Ashizuri-Uwakai National Park Otsuki Park Zone Volunteers' Association, are monitoring corals and coral predators on a regular basis; these volunteers implement practices, including extermination activities, to remedy any abnormalities.

5 Conservation

1. Nature Restoration Project

As previously stated, coral communities in Tatsukushi Bay, the location of four marine park sites, suffered extensive damage when a large amount of soil flowed in and accumulated during torrential rain in September 2001. In March 2002, the Ministry of the Environment removed the soil Tatsukushi Marine Park (Site 4) where a *Pavona* community designated as a natural treasure occurs. The community of *Pavona* was conserved, but it was impossible to remove all of the soil in all area of Tatsukushi Bay owing to the extent, the amount, and budget limitations. The Ministry of the Environment and Kochi Prefecture conducted surveys to investigate the extent of the damage and to take appropriate measures, and at the same time clarified the state of the coral communities (Kuroshio Biological Research Foundation 2002; Nature Conservation Bureau, Ministry of Environment 2003e). The research revealed the existence of well-developed coral communities in part of Tatsukushi Bay, despite the fact that there had already suffered flood damage. The findings suggested that if measures are taken to mitigate the influence of river runoff and human activities, the coral communities in Tatsukushi Bay may be restored. Following this result, the Ministry of the Environment started a two-year Nature Restoration Promotion Survey in 2003. After examining the results of the survey of restoration and conservation measures applied to coral communities have been examined, a natural reproduction project is scheduled to be conducted after 2005.

2. Coral transplantation

Coral transplantation projects have been undertaken in Tatsukushi Marine Park since 2000, with the aim of restoring the underwater scenery along a glass-bottomed boat route. Similarly, coral transplantation projects have been ongoing since 2001 in the Uwa Sea Marine Park

to aid in the recovery of coral communities damaged by *Drupella predation* and by a typhoon struck in 1993. Another transplantation project has been conducted by a volunteer organization in the Shirigai Marine Park since 1999; its aim is to recover coral communities by using coral fragments generated during the *Drupella* extermination project. The data, including those on coral growth, are available to the public (Miyazaki 2002).

6 Necessary measures

1. Construction of a monitoring system

The marine area of the west coast of Shikoku contains a rich coral community, eminent among the non-coral reef regions of Japan. Although as many as 19 marine park sites are designated here, but only ten of these marine park sites have a monitoring system. Moreover, outside the designated zones, information is severely limited except at dive sites. It could be possible that the structure of coral communities has largely changed in this area in recent years as a result of damage by coral predators, sedimentation, the rise of seawater temperatures, and other causes. Factors that limit monitoring include the length of the coastline, the abundance of islands to be covered, and the existence of the administrative boundary between two prefectures (Kochi and Ehime); however, it is necessary to immediately construct a region-wide monitoring system to understand the current status of the area.

2. Construction of an extermination system for a coral predator

In Ashizuri-Uwakai National Park, a decrease of coral coverage owing to *Drupella* predation has been noted, although this is variable between areas. It is commonly accepted that haphazard extermination is ineffective. Therefore the scientific construction and implementation of an extermination system are needed, based on the successful experience in the Shirigai Marine Park.

3. Regulation of marine use

Conflicts have occurred among dive shop owners, recreational fishing vessel owners, and fishermen, over the use of marine areas and the fishing port. There are also conflicts concerning culture and tradition between older local people and young diving visitors. It is necessary to promote mutual understanding and to regulate usage.

6-2-5 Kyushu
(Map 6-2-5)

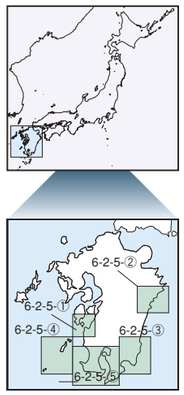
Province: Kumamoto Pref. at west, Oita Pref. at northeast, Miyazaki Pref. at southeast, and Kagoshima Pref. at south of Kyushu **Location:** Kyushu lies at west of Shikoku and southwest of Honshu **Air temperature:** 17.8˚C (annual average, at Ushibuka City, Kumamoto.) **Seawater temperature:** 22.9˚C, 22.2 ˚C and 20.9 ˚C (annual average, at east off Aburatsu, southwest off Kushikijima (Is.) and Yatsushiro Sea, respectively) **Precipitation:** 2,027.9 mm (annual average, Ushibuka City, Kumamoto) **Total area of coral communities:** 581.8 ha **Protected areas:** Unzen-Amakusa National Park: at around Amakusa, including 3 Marine Park Zones and 2 Protected Water Surfaces; Nippo Kaigan Quasi-National Park: coastline at south of Oita and north of Miyazaki, including 2 Marine Park Zones; Nichinan Kaigan Quasi-National Park: coastline at south of Miyazaki and east of Kagoshima, including 1 Marine Park Zone; Kirishima-Yaku National Park: a part of coastline in Kagoshima, including 2 Marine Park Zones.

6-2-5-①

＊ “号” on this map means “site”.

6-2-5-②

＊ “号” on this map means “site”.



6-2-5-④

6-2-5-③

＊ “号” on this map means “site”.

6-2-5-⑤

＊ “号” on this map means “site”.

a. Kumamoto Prefecture

(Map 6-2-5-①)

Satoshi Nojima

1 Corals and coral reefs

1. Geographical features

On the west of Kyushu in Kumamoto Prefecture lie the Amakusa Islands. About 120 islands, including Ohyano Island, Amakusa Kamishima, and Amakusa Shimoshima, are surrounded by the Ariake Sea, the Yatsushiro Sea, and the Sea of Amakusanada, which is part of the East China Sea. Amakusa Shimoshima is the westernmost and largest island; its oval shape measures about 45 km in the north-south direction and 23 km east to west. While large rivers are not found in the Amakusa area, small rivers include the Shimotsufukae, Icchoda, Kamegawa, and Hirose rivers. The northern parts of the coastline are relatively smooth, while the southern parts involve a more complex ria coast.

The western coasts of the Amakusa Islands are subtropical. Marine park zones have been designated at seven sites – two in Reihoku (Tomioka Marine Park), one in Amakusa (Amakusa Marine Park), and four in Ushibuka (Ushibuka Marine Park) – in recognition of their subtropical nature and distinguished marine landscapes (Department of National Park, Ministry of Health and Welfare National Parks Department 1970).

2. Coral distribution

In Kumamoto Prefecture, corals are mostly found around the Amakusa Islands and the southern Yatsushiro Sea including Minamata Bay. Ninety-eight hermatypic coral (hearafter, coral) species have been recorded from around Amakusa (Veron 1992a, c; Nishihira and Veron 1995). Colonies are observed all along the west-facing rocky shores from Itsuwa, Reihoku, Amakusa, and Kawaura to Ushibuka on Amakusa Shimoshima. In fact, corals are found on 94 % of this southern area's rocky shores (Nature Conservation Bureau, Environment Agency 1994). Coral communities can cover several to a dozen hectares around Ushibuka and the neighboring islands, such as Katashima, Oshima, and Kuwashima (Photo. 1) (Nature Conservation Bureau Environment Agency 1994).

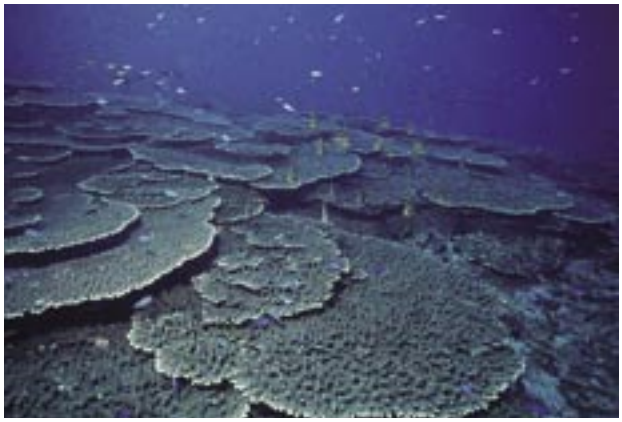


Photo. 1. Tabulate *Acropora* dominant community in Kuwashima (Is.), Ushibuka City, Kumamoto Prefecture.

Near Ushibuka, the dominant coral species is *Cyphastrea serailia*, followed by *Acropora solitaryensis*, *Favia speciosa*, *Mycedium elephantotus*, *Favites abdita*, *Porites heronensis*, *Hydonophora exesa*, *Goniastrea australiensis*, and *Psammocora superficialis* (Nojima and Yeemin 1999). Tabulate corals, such as *A. solitaryensis*, *A. hyacinthus*, and *A. gemmifera*, are found at depths of less than 10 m, while massive or encrusting colonies of *C. serailia*, *Echinophyllia aspera*, and *Favia speciosa* are seen at depths from 10 m to at least 30 m (Nojima and Yeemin 1999). Partial bleaching of some coral colonies was observed in 1998, but subsequently these well-developed coral communities appear to have remained in a relatively stable condition (Nature Conservation Bureau, Environment Agency 1999b).

3. Water quality and physical environment

The Tsushima Warm Current, flowing from the East China Sea, influences the seas around the Amakusa Islands. Diverging from the Kuroshio Current at the edge of the continental shelf to the west of Amami Oshima (Is.), the Tsushima Warm Current flows to the west of the Danjo and Goto archipelagos, through the Tsushima Straits, and into the Sea of Japan. The Tsushima Warm Current mixes with cold continental coastal water, and its water quality becomes quite different from that of the parental Kuroshio Current (Kumamoto Prefecture 1968).

A shunt current of the Tsushima Warm Current diverges from the main stream southwest of Kyushu, changes direction south of the Goto Archipelago, and then flows

southward as an anti-current along the western coasts of the Amakusa Islands, influencing the coastal region. The western shores of Kyushu, including Amakusa, have a tidal range that generally exceeds 3 m, and the range can be even greater in the inner bays. Big waves and strong currents are common features of the seas west of Amakusa facing to the East China Sea. During the rainy season, the salinity can drop as low as 14 PSU in the Hayasaki and Nagashima straits at the entrances to the Ariake and Yatsushiro seas, while the west coast, washed by oceanic water, generally has salinities above 30 PSU.

The water temperature usually fluctuates between 16 and 28°C in the course of the year near Ushibuka. In February 1963, a year known for heavy snow, a record low water temperature of 12.6°C occurred, and a large number of coral colonies died. During the 40 years since this event, however, the average monthly water temperatures for February, the month with the lowest water temperatures of the year, have gradually risen.

4. Notable species and ecosystems

A large *Porites* colony (ca., 3 m in diameter), probably the largest in Kumamoto Prefecture, was found in 1995 in the inner bay of Haruhai off Ushibuka. A specimen of *Acanthastrea amakusensis* (= *Micromussa amakusensis*) was collected off Ushibuka in 1990 by J.E.N. Veron, who described it as a new species; it was subsequently designated a rare species of Kumamoto Prefecture (Environment Conservation Division Kumamoto Prefecture 1998). *Cycloseris vaughani* was collected in Tomioka Bay in northern Amakusa Shimoshima in 1965, but it has not been observed since and has thus been designated an extinct species in the red data book for Kumamoto Prefecture (Environment Conservation Division Kumamoto Prefecture 1998). Moreover, at two locations, reef-like accumulations of coral carbonate have been found; these could be an evidence of the former existence of patch reefs.

2 Situation of usages

1. Tourism

Many of the Amakusa Islands are within the boundaries of Unzen-Amakusa National Park, with different park districts located in various areas. Glass-bottomed boats, including a half-submersible glass-bottomed boat that has been gaining in popularity since its recent introduction, operate in concentrated marine park zones in Ushibuka. The number of visiting SCUBA divers has increased in recent years, and, according to a 1994 questionnaire, many dive shops (mostly in Kumamoto) use the "Famous 15" dive spots in Amakusa and Ushibuka. Locations in Myokengaura in Amakusa are popular training spots for those seeking to acquire diving certification (Study Group for Undersea Scenery Resources in Amakusa District 1995). Additional activities on the western coasts of the Amakusa Islands include recreational surfing, offshore recreational fishing, and boats for hire.

2. Fishery

Small-scale fisheries target diverse species in the Amakusa Islands; ventures include net fishing for *Trachurus japonicus*, *Scomber japonicus*, and *Sardinopus melanostictus*; dragnet fishing for *Penaeus japonicus*; and rod fishing, fixed-net fishing and gill-net fishing for *Parapristipoma trilineatum*, *Pagrus major*, *Trachurus japonicus*, *Scomber japonicus*, squids, *Coryphaena hippurus*, and *Trichiurus japonicus*. Fishes such as *Pagrus major*, *Seriola quinqueradiata*, and *Takifugu rubripes*, shellfishes such as pearl oysters and *Mimachlamys nobilis*, and prawns (*Penaeus japonicus*) are actively cultivated in aquaculture facilities near the inner bay of the Yatsushiro and Ariake seas.

3 Threats and disturbances

1. Crown-of-thorns starfish

The first crown-of-thorns starfish (*Acanthaster planci*) reported from the Amakusa Islands was in Katashima in 1994, and one or two individuals of *A. planci* have been reported from the area every year since. However, funded by a grant from the Ministry of the Environment, members of the Ushibuka Diving Club collected and exterminated approximately 200 *A. planci* in Katashima between July 2002 and August 2003, and this starfish has not been seen in the area since then (Nature Conservation Bureau, Ministry of the Environment 2003; Ushibuka Diving Club 2003d, 2003f).

2. Coral-eating gastropods

Six species of coral eating gastropods have been found around Ushibuka: *Habromorula spinosa*, *Drupella fragum*, *Coralliophila bulbiformis*, *C. erosa*, *C. costularis*, and *C. radula* (Nojima 1993). In September 1991, the sequen-

tial typhoons Nos. 17 and 19 heavily damaged the coral communities of this area, and predation damage caused by coral-eating gastropods became obvious shortly afterward. Volunteer divers, mostly from the Ushibuka Diving Club, collected and exterminated these gastropod species during the subsequent 6 years. This activity continues mainly in Ushibuka Marine Park as it is a priority site. 46,607 individual coral-eating gastropods, chiefly *H. spinosa*, had been collected by the end of March 2003.

4 Monitoring

In several dive spots, the Ushibuka Diving Club has been monitoring water temperature and populations of coral-eating gastropods and *A. planci*. The Amakusa Marine Biological Laboratory (Kyushu University) has been monitoring water temperature and regularly conducting surveys of coral coverage, spawning events, and juvenile coral recruitment.

5 Conservation

The typhoons of 1991 caused the destruction and collapse of many *A. solitaryensis* colonies at Gesushima in Ushibuka Marine Park. Volunteer divers, mostly from the Ushibuka Diving Club, retrieved broken colonies from where they had fallen into deeper areas and transplanted them to their former locations. These corals are showing some signs of recovery.

6 Necessary measures

Outbreaks of *A. planci* or coral-eating gastropods are not occurring around the Amakusa Islands at present. However, preventative measures have not been taken at Koshikijima (Is.) in the south of Amakusa, where there was an *A. planci* outbreak in the past. It is very possible that the *A. planci* outbreaks at Ushibuka arose from populations in Kohiskijima, and preventative measures around Koshikijima should be necessary in the future.

Disagreements between stakeholders (traders, recreational fishers, professional fishers) regarding the use of the marine resources of Amakusa have not yet caused major problems, but conflicts concerning sites are occurring between divers and glass-bottomed boat companies. It will be necessary to seek mutual understanding and agreement between all interested parties for the future management of the area.

b. Oita Prefecture

(Map 6-2-5-②)

Satoshi Nojima

1 Corals and coral reefs

1. Geographical features

Oita Prefecture is located in the north east of the island of Kyushu, facing the Suonada Sea to the north; Beppu Bay is located at the center, and along the coast, Bungo Strait is located at the south. From the Suonada coast at Nakatsu, a vast tidal flat extends to Bungotakada. Most of the coastline of Beppu Bay is reclaimed land or has revetments. The Kunisaki Peninsula, from Bungotakada to Kitsuki, was formed by volcanic activity and is surrounded primarily by rocky shores. The southern coastline from Saganoseki to Fukashima Island, near the border of Miyazaki Prefecture, has a ria coastline. This part of the southern coastline falls within the Nippo Kaigan Quasi-National Park, where four sites were designated as the Kamae Marine Park in 1974. The adjoining Minamikitaura Marine Park in Miyazaki Prefecture was also established in 1974 (Nature Conservation Bureau, Environment Agency 1974).

2. Coral distribution

The temperature, salinity, and transparency (Yanagi 1985) of the waters in Oita Prefecture support hermatypic corals (hereafter corals) around Kamae Marine Park in the south and Kunisaki Peninsula in the north. In Kamae Marine Park, a 1965 survey recorded 21 identified coral species (Table 1) and many unidentified species, suggesting that the total number of coral species in the park is approximately 40 (Oita Prefecture 1969). In the Kamae Marine Park area *Pavona decussata* and *Acropora tumida* dominates along the mainland Kyushu coast. *Acropora hyacinthus* and *Montipora* sp. are dominant on Yakatajima Island, and a tabulate *Acropora* (possibly *A. solitaryensis*) dominates near Fukashima (Oita Prefecture 1969). Around Kamae Marine Park, a 1990 survey revealed 14 sites occupied by coral communities, whose area reached 133 ha in total. 65 % of this total 86.2 ha, were located within Kamae Marine Park. Of the communities, the largest coral community, measuring 51.5 ha and dominated by tabulate corals, was found near Fukashima (Nature Conservation Bureau, Environment Agency 1994).

3. Water quality and physical environment

The sea between Sekizaki in southern Oita Prefecture and Cape Sata in Ehime Prefecture (Shikoku) is constrained, forming a narrow pass in the Bungo Suido Channel that is called 'Hayasuinoseto'. The current in the Bungo Suido Channel moves at 80–100 cm/s during the rise and fall of the spring tide and reaches a maximum flow rate of 200 cm/s at Hayasuinoseto (Yanagi 1985). The water transparency in the Bungo Strait is comparatively high at 15–20 m, while it decreases to 4-10 m near the Kunisaki Peninsula; The salinity in this area is influenced by the open sea and measures 33.5 PPt or greater, throghout the year (Yanagi 1985). A survey of Kamae Marine Park conducted in 1966–67 found that the seawater temperature in Kamae Bay fluctuated between 13°C (in February) and 25.5°C (in September); the same survey found that the water temperature off Udozaki ranged from 15 to 28°C, owing to the influence of the open sea. The inner bay frequently exhibits a low transparency of 10 m or less, while the transparency outside the bay, in waters facing Yakatajima and Fukashima, often exceeds 12 m both in winter and summer (Oita Prefecture Fisheries Experiment Station 1967).

4. Notable species and ecosystems

A 1968 survey revealed large coral communities dominated by *Pavona* and *Acropora* (possibly *A. pruinosa*) off Koetao near the town of Kamae, and coral communities comprised mainly of *Acropora* (possibly *A. pruinosa*) along the west coast of Nagoyahana. In addition, an extensive tabulate coral community of *A. solitaryensis* (identified from photographs) and *A. hyacinthus* was found offshore near Yakatajima and Fukashima (Oita Prefecture 1969).

2 Situation of usages

On tidal flats facing the Suonada Sea, *Meretrix lusoria*, *Scpharca broughtonii*, and *Penaeus japonicus* are raised by aquaculture; *Pleuronectes yokohamae* is cultivated in Beppu Bay at Hinode Town; *Seriola quinqueradiata* and pearl oysters are raised at several locations along southern stretches of the ria coastline. The Bungo Suido Channel is known for the *Trachurus japonicus* and *Scomber japonicus* that are hauled in with single-rod fishing.

3 Thereats and disturbances

Although only limited information is available, there is no indication of any recent outbreaks of the crown-of-thorns starfish (*Acanthaster planci*). However, several individuals of *A. planci* were collected in waters off the adjacent Miyazaki Prefecture in 1973 (Liaison Conference of Marine Parls 1975), raising the possibility that this species may be found within Oita Prefecture. An outbreak of *Drupella fragum* was reported in Nichinan Marine Park in Miyazaki Prefecture (Takayama and Shirasaki 1990; Nature Conservation Bureau, Environment Agency 1994), but no sightings of this coral-eating gastropod have been reported in Oita Prefecture.

4 Conservation

Active aquaculture of yellowtail and pearl oysters can be found in the bays along the ria coast, but it is feared that these operations will result in the deterioration of water quality and coral habitat (Oita Prefecture 1969; Liaison Conference of Marine Parls 1975). Of the four marine park zones, two are actively used for surf-casting, and the lack of proper garbage disposal has been noted there. This problem has become evident since the areas were designated as the marine parks (Liaison Conference of Marine Parks 1975). *A. planci* has not been observed in Oita Prefecture, but the outbreaks have occurred off Amakusa in Kumamoto Prefecture. The similarity of the seawater temperatures in Oita and Kumamoto areas argues that monitoring and a precautionary approach should be implemented in Oita Prefecture (Nature Conservation Bureau, Ministry of the Environment 2003a).

Table 1. Hermatypic coral species list in Kamae Marine Park Zone by Oita Prefecture (1969).

Listed species	Remarks
Pocillopora damicornis	
Montipora sp.	
Acropora squarrosa	*A. tumida* at present
Acropora pectinata	*A. hyacinthus* at present
Acropora studeri	possibly *A. pruinosa*
Acropora leptocyathus	possibly *A. solitaryensis*
Porites sp.	
Goniopora planulata	*G. lobata* at present
Pavona decussata	
Podabacia sp.	*Lithophyllon undulatum* at present
Pectinia lactuca	*Physophyllia ayleni at* present
Acanthastrea hemprichi	identified as *A. hemprichii*
Lobophyllia sp.	
Hydonophora exesa	
Caulastrea tumida	
Favia speciosa	
Favites abdita	
Platygyra lamellina	possibly *P. daedalea* or *P. contorta*
Euphyllia fimbriata	*E. ancora* at present
Turbinaria peltata	
Turbinaria sp.	

Total : 21 species

c. Miyazaki Prefecture

(Maps 6-2-5-②,③)

Satoshi Nojima

1 Corals and coral reefs

1. Geographical features

Miyazaki Prefecture is located to the east of mainland Kyushu; it has a 400-km coastline that faces Shibushi Bay in the southern region, the Hyuganada Sea in the south-central region, and the Bungo Strait in the northern region. The coastline in the northern and southern regions is characterized by complex rocky shores. In the central region, the coastline consists of flat beaches and sandy beaches. The southern coastal region has been designated as the Nichinan Kaigan Quasi-National Park, and six sites (total area, 55.9 ha) within the park district have been designated as the Nichinan Marine Park (Department of National Parks, Ministry of Health and Welfare 1970). The northern coastal region was designated as the Nippo Kaigan Quasi-National Park. Six sites within the park, along with Kamae Marine Park, were designated as Minamikitaura Marine Park (total area, 62.2 ha) (Nature Conservation Bureau, Environment Agency 1974).

2. Coral distribution

In Miyazaki Prefecture, hermatypic corals (hereafter referred to as corals) are distributed throughout Shibushi Bay and the Nichinan Coast in the south and in the Minamikitaura Marine Park in the north (Nature Conservation Society of Japan 1967; Nature Conservation Bureau, Environment Agency 1994). In a survey of the Minamikitaura Marine Park conducted in 1966, seven coral species were recorded (Table 1; Nature Conservation Society of Japan 1967). In a similar survey conducted in 1991, 22 species, including *Acropora solyitaryensis* and *A.* af. *hyacinthus*, as well as large colonies of *Turbinaria peltata* (Fukuda *et al.* 1991), were recorded. Based on this survey, the average coral coverage in the region was estimated to be 13 %.

Seven species of coral were recorded in the Nichinan Marine Park (Table 1; Nature Conservation Society of Japan 1967). In a survey of Komeotoura Bay conducted in 1991, the mean coral coverage was found to be low (8 %); however, 52 coral species were recorded. The coral community at this site was dominated by tabulate corals such as *A.* af. *hyacinthus*, *A.* af. *solitaryensis*, and *A. gemmifera* (Fukuda *et al.* 1991).

In a survey conducted in 1990, coral communities were located at 49 sites in the prefecture, giving a total coral coverage area of 460 ha. In the Nichinan Marine Park, the total coverage area for six of the sites totaled approximately 75 ha. However, in the Minamikitaura Marine Park, the total coverage area for six of the sites totaled only about 3.4 ha. Coral communities with high coverage were also found in areas adjacent to these marine park zones. The communities at these sites were dominated by tabulate forms (especially *A.* af. *hyacinthus*), which accounted for 60–70 % of the total coral abandance (Nature Conservation Bureau, Environment Agency 1994).

3. Water quality and physical environment

The Kuroshio Current exerts a strong influence on the dynamics of water movement in the region from Hyuganada to Bungo Strait. This current flows close to Miyazaki Prefecture and forms a return current near Hososhima Island that flows in the direction of Okinoshima Island. The current then flows toward Cape Ashizuri (Shikoku) and Cape Shionomisaki on the Kii Peninsula (Nature Conservation Society of Japan 1967).

At Aburatsuhigashi, located near the Nichinan Marine Park, the lowest and highest seawater temperatures recorded in 1975 were 17.6°C in March and 25.4°C in August, respectively. The salinity at this site remains constant throughout the year, at around 34 PSU, which is close to that of the open ocean. Transparency at the site exceeds 10 m (Nature Conservation Society of Japan 1967).

At Miyanoura Bay, located close to the Minamikitaura Marine Park, the lowest and highest seawater temperatures recorded in 1975 were 15°C in February and 26°C in August, respectively. The salinity at this site is 34 PSU. Transparency is about 10 m inside the bay, but can reach 15 m near Shimanourajima Island (Nature Conservation Society of Japan 1967).

4. Notable species and ecosystems

Large-scale tabulate coral communities are observed

at Mimihokesho (ledge) and in the southern regions of Shimanourajima Island, close to the Minamikitaura Marine Park. Similar types of community are also found at Oshima Island, Meotoura Bay, and on the Tsuchishimazaki/Dojima Islands in the Nichinan Marine Park (Nature Conservation Society of Japan 1967). Large colonies of *T. peltata*, reaching 2–3 m in diameter, are found at several sites in the Minamikitaura Marine Park (Site 1) (Nature Conservation Bureau, Environment Agency 1994). *Merulina ampliata* and *Echinopora lamellosa* are present at Komeotoura, which is likely to be the northern distribution limit for these species (Fukuda *et al.* 1991; Veron 1992; Nishihira and Veron 1995).

2 Situation of usages

Coastal waters in this region are strongly influenced by the Kuroshio Current which flows in a northerly direction. This current produces complex oceanographic conditions in areas where it mixes with river inflow water and coastal water from the Bungo Strait. This region is important as a fishery for sardines and mackerel. Further offshore, this region is important as a fishing area for skipjack and tuna.

The fisheries in this zone rely on net fishing techniques and the use of encircling nets and dragnets. In the northern area, the aquaculture of yellowtail and red sea bream represent important industries. In the central areas, patch net, pole-and-line, dragnet, long line, and trawl nets are used as the primary fishing techniques. Offshore, in the southern regions, pole-and-line fishing for skipjack and long line fishing for tuna are important deep-sea fishing industries (Miyazaki Prefecture 2002).

3 Threats and disturbances

1. Crown-of-thorns starfish

Several crown-of-thorns starfish (*Acanthaster planci*) were collected in Miyazaki Prefecture during a survey conducted in 1973 (Liaison Conference of Marine Parks 1975). However, no outbreaks have been reported in this area in recent years.

2. Coral-eating gastropods

Outbreaks of *Drupella fragum* have been frequently reported in the Meotoura region since 1988 (Takayama and Shirasaki 1990; Fukuda *et al.* 1991; Nature Conservation Bureau Environment Agency 1994). A survey conducted in 1990 found the damage to corals located at various sites in the Nichinan Marine Park (Nature Conservation Bureau Environment Agency 1994).

4 Necessary measures

Predation damage caused by *D. fragum* (Nature Conservation Bureau Environment Agency 1994) represents the most immediate threat to the coral communities in Miyazaki Prefecture. Occurrence of *A. planci* has been reported since 1973 (Liaison Conference of Marine Parks 1975). The abundance of these coral predators should be carefully monitored, especially considering that the dominant coral species in the marine park zones, *A.* af. *hyacinthus*, is preyed upon by both *D. fragum* and *A. planci*.

Table 1. Hermatypic coral species list in Minami Kitaura and Nichinan Marine Park Zones by Nature Conservation Society of Japan (1967).

Species	Minami Kitaura Marine Park Zone	Nichinan Marine Paerk Zone	Remarks
Pocillopora damicornis	○		
Stylophora pistillata	○	○	
Acropora studeri	○	○	possibly *A. pruinosa* or *A. tumida*
Acropora leptocyathus	○	○	possibly *A. hyacinthus*
Porites tenuis	○		*P. australiensis* at present
Caulastrea tumida		○	
Favia speciosa	○	○	
Platygyra lamellina		○	possibly *P. daedalea* or *P. contorta*
Turbinaria undata	○	○	possibly *T. peltata*
Total	7	7	

d. Kagoshima Prefecture

(Maps 6-2-5-①,③～⑤)

Satoshi Nojima

1 Corals and coral reefs

1. Geographical features

Both the Coral reef and High-latitude coral community regions exist in Kagoshima Prefecture. These two regions both have their boundaries at the Tokara Archipelago, which is the reported northern limit of coral reefs, except for the recently discovered Iki Islands (Yamano *et al.* 2001).

This section describes the non-coral reef region that is located primarily around mainland Kyushu. For Coral reef region, refer to Chapter 6-1-2. The northern part of Kagoshima Prefecture is in southern mainland Kyushu and features two big peninsulas, the Satsuma and Osumi peninsulas. Between them lie Kagoshima Bay and Sakurajima Island, which is the most eminently active volcano in Japan. Kagoshima Prefecture faces both the East China Sea and the Pacific Ocean. In the south, a chain of islands extends from Tanegashima Island and Yakushima Island to the Amami Archipelago. In addition, the Kusanagi, Uji, and Koshikijima archipelagos face the East China Sea in the west. Nagashima and Shishijima islands are located in the northwest and face the Yatsushiro Sea.

In the Kyushu area, two marine park zones, Sakurajima and Satamisaki, encompass a total of 26.5 ha. These marine parks were among the first to be designated in Japan, in 1970. (Department of National Parks, Ministry of Health and Welfare 1970).

2. Coral distribution

Many hermatypic corals (hereafter, corals) have been recorded in the Kyushu area, including in Nagashima and Shishijima to the north (Nature Conservation Bureau, Ministry of the Environment 1994). In a coral survey conducted in 1968, 17 coral species were identified in Sakurajima Marine Park and eight species on Chiringashima Island near Ibusuki (Table 1). Moreover, in Nagasakibana at the tip of the Satsuma Peninsula, 11 coral species were identified. In Satamisaki Marine Park at the tip of the Osumi Peninsula, 23 species were identified (Table 1; Kagoshima Prefecture 1969).

A 1990 survey reported coral communities in 24 locations, totaling 45 ha, around the Osumi and Satsuma Peninsula, the Uji and Koshikijima Archipelago, and Nagashima. One of the 24 locations, an area of 3 ha, disappeared as a result of reclamation following the survey. Communities that had especially high coral coverage, with on branching *Acropora* in calm areas and tabulate *Acropora* in wave-exposed areas, were found around the Uji and Koshikijima archipelagos (Nature Conservation Bureau, Environment Agency 1994).

3. Water quality and physical environment

The sea area around Kagoshima area of mainland Kyushu is relatively warm owing to the influence of the warm Kuroshio and Tsushima currents, The water temperatures range from 15 to 28°C even off Nagashima which is located at the northernmost Kagoshima. Kagoshima Bay is long and narrow, being about 15 km wide and 100 km long; the depth drops rapidly to 200 m. The current during spring tides reaches approximately 50 cm/s in the center of the bay and about 90 cm/s at the fastest point, around the Nishisakurajimasuido waterway. The salinity is high at 33 PSU or higher throughout the year (Sakurai 1985). The seawater temperatures of inner Kagoshima Bay range from 15 to 28°C, as in Nagashima, but Cape Sata, at the entrance of the bay, experiences slightly higher winter temperatures of between 17 and 29°C (Kagoshima Prefecture 1969; Sakurai 1985).

4. Notable species and ecosystems

Around the Uji and Koshikijima Archipelago, the main coral community type is that of so-called 'southern Japan coastal type,' (Fukuda *et al.* 1991), as seen on the Shikoku and Kii Peninsula. In the comparatively wave-exposed areas of the Uji and Koshikijima archipelagos, Nagasakibana, and Cape Sata, coral communities are formed primarily by tabulate corals, such as *Acropora hyacinthus*, *A. solitaryensis*, and *A. gemmifera* (Nature Conservation Bureau, Ministry of the Environment 1994).

2 Situation of usages

Aquaculture is actively undertaken in Kagoshima

Prefecture; for example, *Seriola quinqueradiata* is cultivated around Nagashima and Shishijima in the north, and *Seriola dumerili* is raised in Kagoshima Bay. Drifting gill-net fishing is prevalent in Hokusatsu of the northern Satsuma area and in the Koshikijima Archipelago.

3 Threats and disturbances

An outbreak of the crown-of-thorns starfish (*Acanthaster planci*) was found off Kannonzaki near Sakurajima Marine Park in the summer of 2003. Since that time, about 200 individual starfish have been successfully exterminated by local divers. An outbreak of *A. planci* also occurred around the Koshikijima and Uji archipelagos, which are not marine parks, some time in 1990 (Nature Conservation Bureau, Ministry of the Environment 1994). Fragmentary information showed that *A. planci* still inhabits the area, but a current, detailed status survey of the area is needed.

4 Necessary measures

As mentioned above, an outbreak of *A. planci* occurred around the Koshikijima and Uji archipelagos in 1990 (Nature Conservation Bureau, Ministry of the Environment 1994), but no specific measures have yet been taken to deal with this. Damage caused by *Terpios* (see also Chapter 2-2) has also been reported in the Uji Archipelago. Koshikijima and Uji archipelagos could serve as the supply sources of *A. planci* larvae to the Amakusa Islands in Kumamoto Prefecture and to the Goto Archipelago in Nagasaki Prefecture to the north. Therefore, it should be necessary to immediately survey of all of these areas in order to understand their current status and design appropriate actions.

Table 1. Hermatypic coral species list in Kagoshima Prefecture (Kagoshima Prefeture 1969).

Species	Sakurajima Marine Park Zone	Chiringashima	Nagasakibana	Satamisaki Marine Park Zone	Remarks
Pocillopora damicornis	○			○	
Stylophora pistillata				○	
Stylophora mordax				○	
Montipora informis	○			○	
Montipora cuctus	○			○	
Montipora sp.			○		
Acropora pectinata	○	○	○	○	possibly *A. hyacinthus*
Acropora reticulata	○				
Acropora nasuta		○			
Acropora nasuta crassilabita	○				
Acropora leptocyathus			○	○	possibly *A. solitaryensis*
Acropora humilis			○	○	possibly *A. gemmifera*
Acropora danai				○	
Acropora cf. danai			○		
Acropora specifera	○	○			
Acropora cymbicyathus	○				
Acropora sp.	○	○		○	
Porites tenuis	○	○	○	○	*P. australiensis* at present
Porites singporensis				○	
Goniopora lobata	○				
Psammocora exesa				○	
Pavona decussata	○		○	○	
Lobophyllia robusta				○	
Symphyllia recta				○	
Hydnopora exesa	○	○	○	○	
Hydnophora microconos				○	
Caulastrea tumida				○	
Favia speciosa	○	○	○	○	
Favites abdita	○	○	○	○	
Goniastrea pectinata	○				
Platygyra lamellina	○		○	○	possibly *P. daedalea* or *P. controta*
Oulastrea crispata				○	
Total	17	8	11	23	

Column

A glimpse of coral reef studies in pre-westernized Japan

Kenji Konishi

Description of corals and coral reefs can be found in Japanese folklore and myths. In ancient times, ruby coral (*Corallium rubrum*; imported from the Mediterranean, via China) was used in one of the Seven Treasures, and limestone from uplifted reefs was used to build castle walls, bridges, and pavements. The first identification of scleractinian coral coincided with the advent of western-style natural history in Japan. Hard corals were originally assigned to rock during the Nara Period (710-784) and then as a plant under the Edo Period (1603-1867) of herbalism. In 1775-1776, a Swedish scientist, Thunberg, staying in Nagasaki, recognized *Acropora* corals as an animal (Kajishima 1997). He was recommended visiting Japan by Linne (Linnaeus), his Mentor and the founder of modern taxonomy (Japan Academy 1960). Thereafter, scleractinian corals were classified in a kind of shellfish by virtue of their hard skeletal tissue. Not until the late Edo Period was it recognized that corals thrived along the coast of Japan (Suzuki 1999). The Japanese names of coral species referable to *Favia*, *Fungia* and *Acropora* are seen in the herbalist literature of the Edo Period. The first accounts of corals in markets were documented in late Edo Period, when traded species included *Corallium japonicum kishinouye* and *C. elatius ridley*, harvested from adjacent waters along Honshu, the main island of Japan. Corals were first exported from Japan at the end of the nineteenth century.

Reports and hydrographic charts from the late eighteenth and early nineteenth centuries show reefs and uplifted reefs on the Ogasawara and Ryukyu Islands (Okinawa) (Konishi 2004). In "Structure and Distribution of Coral Reefs", Darwin (1842) refers to the voyage records of Hall (1811) and Beechey (1831). The Tokugawa government, while responsible for the naval defense of the Japanese coast, revised a map of Japan in the Genroku Era (1688-1704) (Culture Division Okinawa Prefecrural Board of Education 1992), from a Shouhou Era (1644-1648) map drawn half a century before (Culture Division Okinawa Prefecrural Board of Education 1991; Tokyo National Museum, and The Historiographical Institute, The University of Tokyo 2001, 2002). This map illustrates the coral reef distribution of Okinawa in the Ryukyu Islands in fair detail.

A portion of the Miyako Archipelago can be seen in a map made during the Shouhou Era (Fig.1). The Yaebishi (Yabiji) reefs, 5–15 km north of Ikema Island, can be clearly seen, stretching approximately 7 km from east to west (Konishi 2002). It has been believed that the 400-ton sloop vessel "Providence" was stranded there on 17 May 1797, with 115 crews onboard including W.R. Broughton. A map from the Genroku Era showing Sekisei Lagoon within the Yaeyama Archipelago indicates coral development as extensive as present (Fig. 2). In 1972, a part of the Yaeyama region was designated as Iriomote National Park. Five years later, the area was named a Marine Park Zone. This area currently plays a major role in coral reef research in Japan, including investigation of reef rehabilitation. The area acts as a base field for surrounded by six research institutes: the Seikai National Fisheries Research Institute, International Coral Reef Research and Monitoring Center, WWF Coral Reef Conservation and Research Center, Yaeyama Marine Park Research Station, Iriomote Branch of the Tropical Biosphere Research Center of University of Ryukyus, and Okinawa Regional Research Center, Tokai University. Other associated organizations include the Yaeyama Fisheries Cooperative, Yaeyama Coral Reef Conservation Association, and Yaeyama Diving Association.

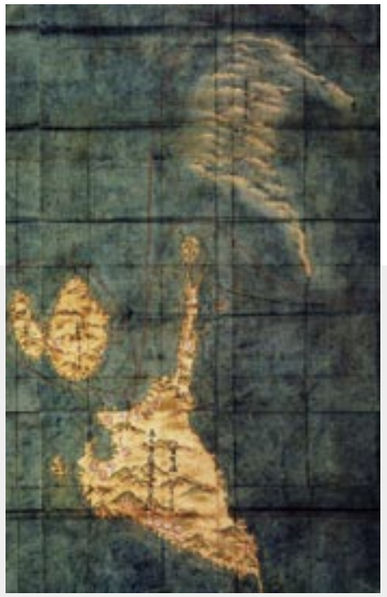


Fig.1. Map of the Shouhou Era (1644-1648), showing the Yaebishi (Yabiji) reefs north of Ikema and Miyako Islands of the Miyako Archipelago.

Fig. 2. Map of the Genroku Era (1688-1704), showing the reefs of Sekisei Lagoon, which is surrounded by the islands of Yaeyama Archipelago; Ishigaki on the east: Kuroshima on the south: and Iriomote on the west.

Both maps of Shouhou and Genroku Periods were complemented with the help of the Satsuma Domain, which ruled the former maritime Kingdom of the Great Lew Chew. The knowledge required to make these maps must be supplied by people in Ryukyus, who traded with neighboring countries as early as the twelfth to fourteenth centuries (through to the Dynasty Era in the fifteenth to seventeenth centuries) and that they had an extensive knowledge of coral reef distribution, developed through sailing and fishing (Konishi 2002). Okinawan fishermen (*uminchu*) from Ikema Island used to call Yabiji a 'marine farmland'. They had a detailed understanding of the topography of individual patch reefs and channels in Yabiji, as well as the associated distribution of fish habitats (Setoguchi 2003).

Studies of coral reefs in Japan are now comparable to those of the western world. Like coral habitats worldwide, the reefs (especially in Okinawa) are suffering from the threats of interactive stresses by global climatic changes and anthropogenic activities (e.g., over-fishing, unchecked tourism).

In Sekisei Lagoon, it has begun to protect and restore local reefs, in order to save there as refugia for corals and keep to recruit the larvae to rehabilitate deteriorated habit (Buddemeier *et al.* 2004). Scientists, managers, policymakers, and local communities will accomplish such goal with multiple efforts (Hughes *et al.* 2003), through international collaboration (Wilkinson 2002). We, *Homo sapiens*, can look back what coral reefs have taught us, and think over what shall be learned from them. The time has come.

Column

Reef Check in Japan

Yasuaki Miyamoto

Reef Check

Reef Check is a voluntary, community-based monitoring protocol designed to measure the 'health' of coral reefs on a global scale, by measuring a few key coral reef organisms. Reef Check is managed by the Reef Check Foundation at the University of California, USA. Monitoring is undertaken every year and data is collected by trained divers, local residents, and coral reef scientists. Reef Check aims to: 1) provide scientific data to further our understanding of anthropogenic impacts upon coral reefs globally, and 2) promote public awareness of coral reefs to avoid further human impacts.

Reef Check is an important partner of the ICRI (International Coral Reef Initiative) and GCRMN (Global Coral Reef Monitoring Network), and the data collected is offered to the GCRMN and to ReefBase (a global coral reef database).

Dissemination of Reef Check data is the responsibility of the Reef Check coordinators within each country. In Japan, there are two coordinators working from within the Coral Network. The Coral Network organizes briefings and study sessions, develops execution tools, translates manuals into Japanese, manages and maintains the Japanese web site, and seeks out sponsorship and support.

Reef Check activity results

The details of involvement over the past eight years in Japan are shown in Table. 1. The reason why neither the number of sites nor the number of participants has increased in 2003 was that many teams could not carry out monitoring due to typhoons and high waves. In 2004, Sakuraguchi on Ishigaki Island, Chichijima, and south of Sotobanare Island off the northwest of Iriomote Island were added as new monitoring sites. Although it was abandoned, there were also plans to add Tanabe Bay in Kii Peninsula, Chiibishi off Okinawa Island, and Tokashiki Island as new monitoring sites.

Diver awareness toward coral reef environment conservation has clearly increased in recent years in Japan. In order to widen the opportunity for participation divers, Coral Network is planning to increase the number of working teams. For that purpose, raising the awareness of local host organizers (e.g., local administrations, Non-profit Organizations (NPOs), diving services) may be a top priority.

Reef Check team

The majority of the teams undertaking Reef Check in Japan are volunteers. The organizers are: 12 teams from joint-hosts of diving services and NPOs. 2 teams from diving services, 6 teams from NPOs, and 2 teams from local governments. Coral Network acts as either a host, or joint host, and hopes to continue playing a collaborative role among scientists, local residents, and volunteers. Participation by local scientists has recently increased and we plan to invite more scientists whose residence, or research field, is close to the monitoring sites. In fact, the majority of voluntary participants, excluding professional divers, are from remote locations. We plan to include more local residents by holding seminars and public relations activities.

Future issues

Reef Check is aiming at community-based-surveys. In that respect, it is necessary to involve more local divers, diving services, and local communities. We hope to further expand and enhance Reef Check activities in Japan.

Table 1. Number of sites and participants involved in Reef Check in Japan over the past eight years.

Year	Sites	Participants
1997	2	12
1998	12	74
1999	11	133
2000	16	ca. 190
2001	17	ca. 250
2002	21	ca. 300
2003	22	ca. 300

Column

International Coral Reef Research and Monitoring Center

—For conservation of coral reefs in Japan and the world—

Takahiro Okano

Viewing Japan's richest coral reef, "Sekisei lagoon", International Coral Reef Research and Monitoring Center is located at Ishigaki Island, in Yaeyama islands area, the south end of Japan (Photo. 1). The center was established in May 2000 as the base station of the Global Coral Reef Monitoring Network (GCRMN) in Japan and in East Asia. The GCRMN is one of the major activities of International Coral Reef Initiative (ICRI) that is a comprehensive international program for coral reef conservation.

The major roles and functions of this center are collecting and providing information concerning coral reefs. The database holds the information about the reference on coral reef related scientific and management studies, related organizations, and coral reef monitoring data in the covered area. The center also offers the information to the public through Internet. The monitoring survey of coral reefs is another major activity of the center. In 1998, Ministry of the Environment of Japan initiated coral reef monitoring in Sekisei lagoon and around Ishigaki Island. Coverage and type of corals, sedimentation level, etc. are investigated by Spot-check method (see Chapter 3-1) each year. In addition to the monitoring, the center vigorously assists coral reef related studies by individual scientists as well as citizens. It is essential for coral reef conservation to have as many people as possible understand the importance of coral reefs. The center gives special exhibitions of coral reefs so that people can know more about the value and importance of coral reefs, as well as the need for their conservation. The center coordinates and conducts some educational programs using the neighboring Iriomote National Park as its field. Through lectures and seminars, Junior Park Ranger activities, and cooperation with the local elementary schools, the center is taking an important role for promoting awareness of the local people (Photo. 2).

The center has a laboratory, a specimen room, a material room, tools and materials for the surveillance study maintained, and they are offered to the researchers. Moreover, a multipurpose room is available for conferences, special exhibitions, and lectures, etc. concerning coral reef conservation.

Implementation of "Monitoring Sites 1000" project (see Chapter 3-1) and promotion of international cooperation for coral reef conservation are also major functions of the center. As the base of coral reef monitoring network in Japan and in East Asia, International Coral Reef Research and Monitoring Center have been playing an important role for the conservation of the coral reefs in the region.

Photo. 1. International Coral Reef Research and Monitoring Center.

Photo. 2. A educational program for local people at adjacent reef.

Appendix

１．Related statistic data of coral area
　１－１　Meteorological condition
　１－２　Population and number of households
　１－３　Number of employed in each industry
　１－４　Number of tourists visited
　１－５　Fishery statistics
　１－６　Protected areas
　１－７　Additional information on the Daito Islands and Sea of Japan

２．The 5th National Survey on the Environment

３．Spot Check Method for coral reef survey

４．A list of hermatypic corals in Japan

５．Japanese organizations related to coral reef study and conservation

６．Cited references

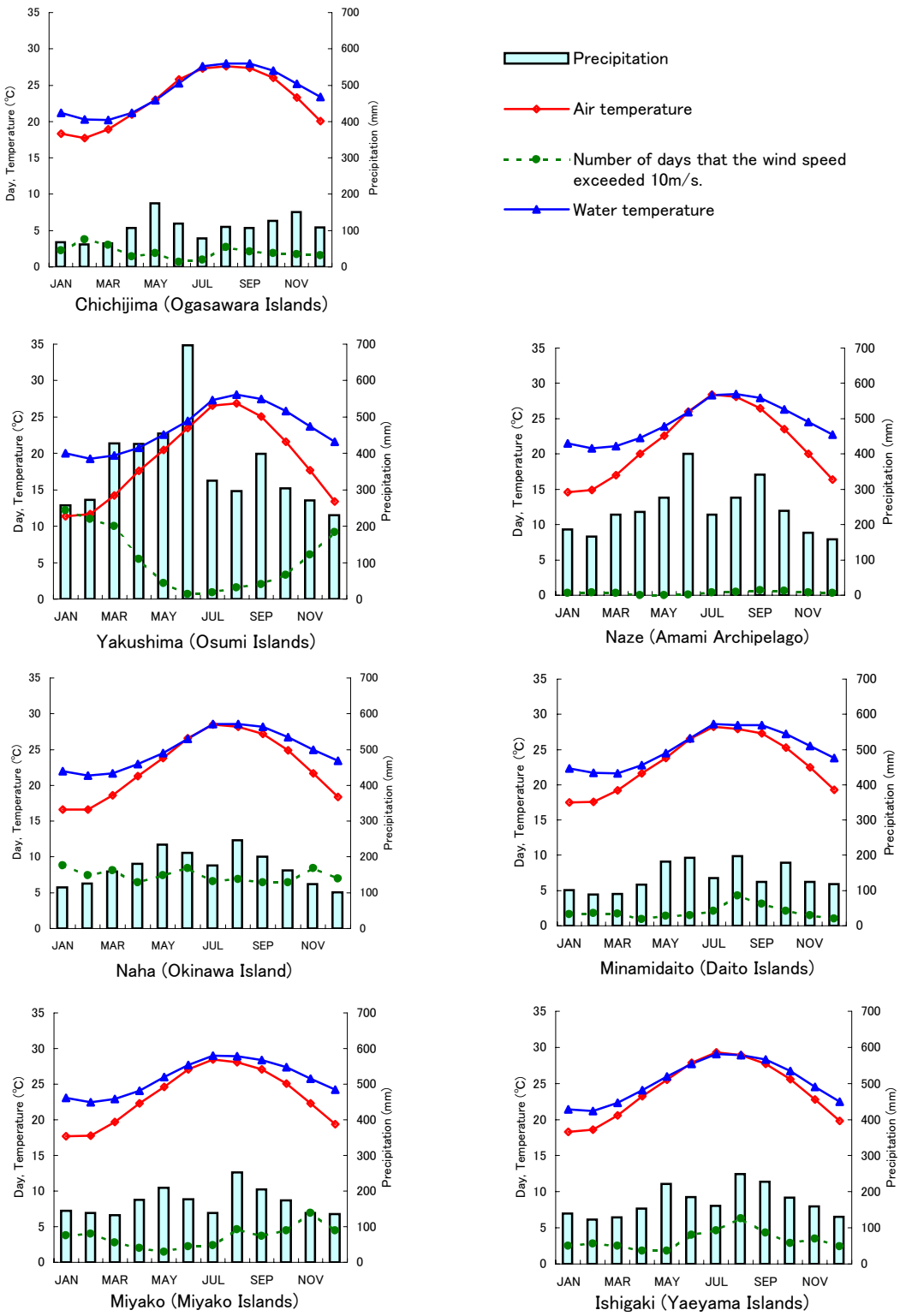
７．Authors

Appendix 1 Related statistic data of coral area

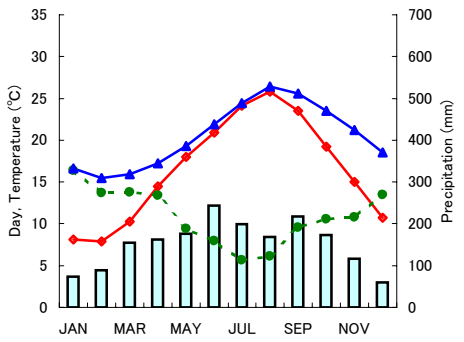
Appendix 1-1 Meterological condition

All the meterological data are from the Japan Meterological Agency. The data at observation points are described at the beginning of Chapter 6. The annual average (during 1971-2000) of the atomosheric temperature, precipitation, the number of days that the wind speed exceeded 10m/s, and water temperature at each observation points are indicated.

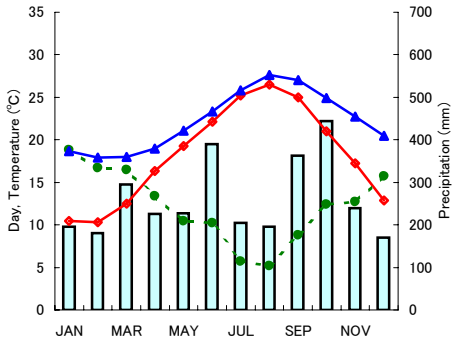
Coral reef region



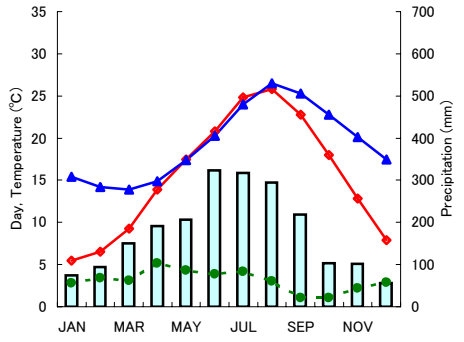
High-latitude coral community region



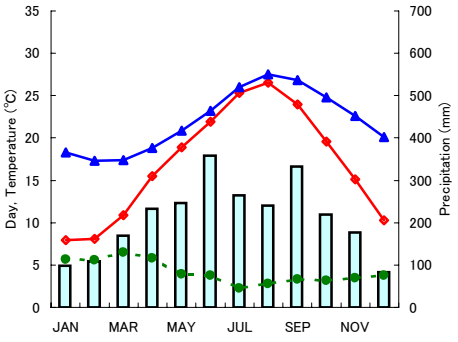
Irozaki (Izu Peninsula)



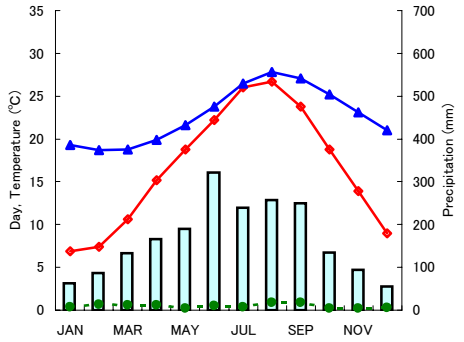
Hachijo (Izu Islands)



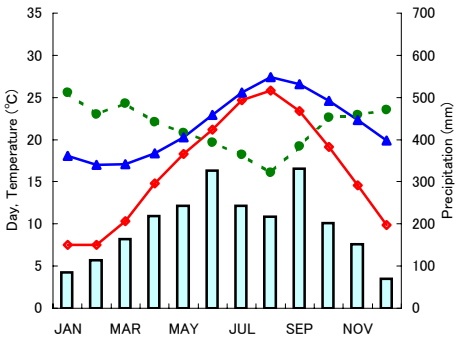
Tushima (Sea of Japan)



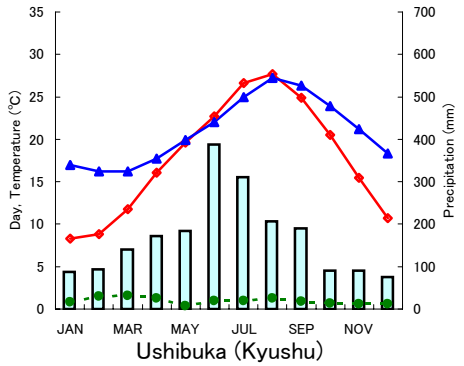
Shionomisaki (Kii Peninsula)



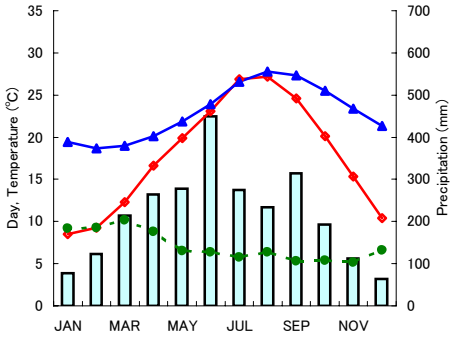
Sukumo (Shikoku)



Cape Muroto (Shikoku)



Ushibuka (Kyushu)



Aburatsu (Kyushu)

Appendix 1-2 Population and number of households

The population and number of households are shown for respective local authorities from the national census (in fiscal 2000).

Division number	Regional division	Population				number of households
		0-14 years old	15-64 years old	65 years old ≦	Total	
6-1-1	Ogasawara Islands	384	2,210	230	2,824	1,365
6-1-2	Osumi Islands, Tokara Archiperago	8,327	29,371	13,128	50,826	21,489
6-1-3	Amami Archipelago	23,189	74,607	34,189	132,315	52,904
6-1-4	Okinawa Islands	230,114	756,612	155,173	1,151,379	389,957
6-1-5	Daito Islands	417	1,386	313	2,116	1,014
6-1-6	Miyako Islands	10,709	33,101	11,711	55,587	20,042
6-1-7	Yaeyama Archipelago	10,251	30,526	7,917	48,705	18,265
6-2-1	Boso Peninsula, Izu Peninsula, and Izu Islan	57,558	274,520	88,308	420,443	153,675
6-2-2	Sea of Japan	47,988	193,997	86,297	328,323	115,733
6-2-3	Kii Peninsula	105,650	474,063	158,975	738,862	272,642
6-2-4	Shikoku	29,858	127,841	55,421	213,132	80,956
6-2-5	Kyushu	234,584	962,875	285,873	1,484,197	598,749
Total		759,029	2,961,109	897,535	4,628,709	1,726,791

＊An unknown age is included in total

Appendix 1-3 Number of employee by industries

The number of employee by industries are shown for respective local authorities from the national census (in fiscal 2000).

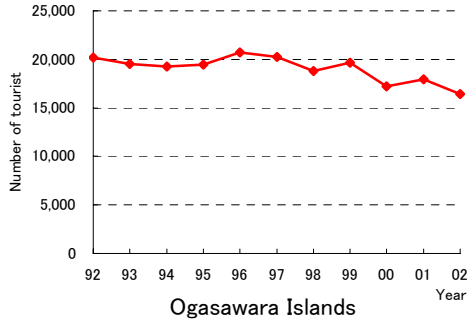
Division number	Regional division	Primary industry			Secondary industry		
		Agriculture	Forestry	Fishery	Mining	Construction industry	Manufacturing
6-1-1	Ogasawara Islands	60	0	94	0	320	18
6-1-2	Osumi Islands, Tokara Archiperago	6,288	135	575	77	3,735	1,170
6-1-3	Amami Archipelago	9,059	78	894	171	7,896	3,548
6-1-4	Okinawa Islands	19,412	186	2,508	507	63,499	24,863
6-1-5	Daito Islands	272	0	9	5	402	98
6-1-6	Miyako Islands	6,160	3	320	31	3,886	1,088
6-1-7	Yaeyama Archipelago	2,641	16	474	58	3,031	1,250
6-2-1	Boso Peninsula, Izu Peninsula, and Izu Islan	13,755	105	3,581	184	20,255	39,898
6-2-2	Sea of Japan	10,611	378	8,292	468	21,377	22,517
6-2-3	Kii Peninsula	16,878	552	7,820	220	33,820	56,738
6-2-4	Shikoku	8,578	453	10,464	221	10,879	10,412
6-2-5	Kyushu	37,705	895	9,586	432	72,435	77,189
	Total	131,419	2,801	44,617	2,374	241,535	238,789

Division number	Regional division	Tertiary industries							
		Electricity, gas, heat supply, and water service industry	Transportation and communication industry	Wholesale and retail trade and restaurant	Finance and insurance	Real estate industry	Service industry	Official duties(Besides, one not classified.)	Total
6-1-1	Ogasawara Islands	26	38	262	6	3	554	618	1,999
6-1-2	Osumi Islands, Tokara Archiperago	182	1,128	4,152	331	28	6,709	1,530	26,040
6-1-3	Amami Archipelago	471	2,698	10,803	935	144	16,146	4,119	56,962
6-1-4	Okinawa Islands	3,121	29,960	120,264	12,299	5,278	163,103	29,125	474,125
6-1-5	Daito Islands	16	33	163	0	0	217	155	1,370
6-1-6	Miyako Islands	137	1,328	4,434	326	62	6,634	1,864	26,273
6-1-7	Yaeyama Archipelago	168	1,421	4,285	265	115	7,269	1,518	22,511
6-2-1	Boso Peninsula, Izu Peninsula, and Izu Islan	1,219	12,195	50,861	5,377	1,951	58,654	7,502	215,537
6-2-2	Sea of Japan	1,347	8,514	32,823	2,832	350	42,853	7,402	159,764
6-2-3	Kii Peninsula	2,686	19,348	79,671	9,116	2,686	93,359	13,583	336,477
6-2-4	Shikoku	591	5,278	20,958	1,884	256	24,941	3,903	98,818
6-2-5	Kyushu	3,868	40,119	173,579	21,075	5,667	214,189	30,569	687,308
	Total	13,832	122,060	502,255	54,446	16,540	634,628	101,888	2,107,184

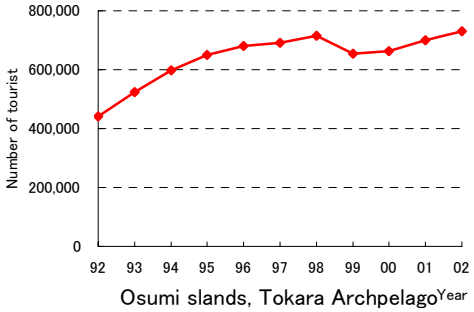
Appendix 1-4 Number of tourists visited

The number of tourist to each concerned municipalities are compiled from the data of each municipal government.

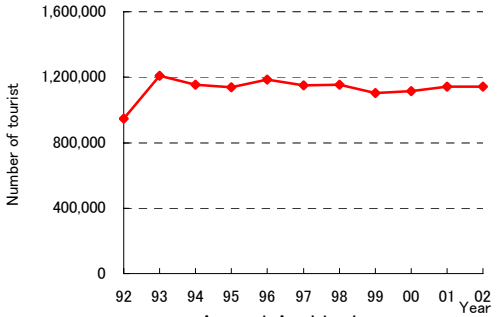
Coral reef region



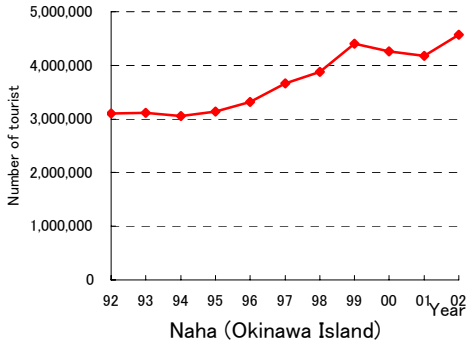
Ogasawara Islands



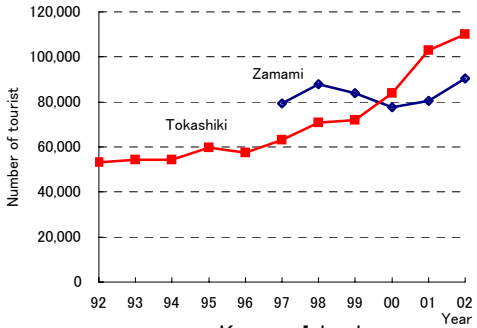
Osumi slands, Tokara Archpelago



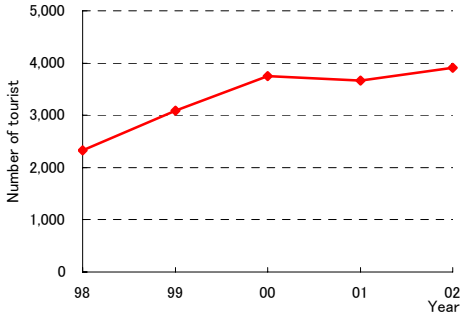
Amami Archipelago



Naha (Okinawa Island)



Kerama Islands



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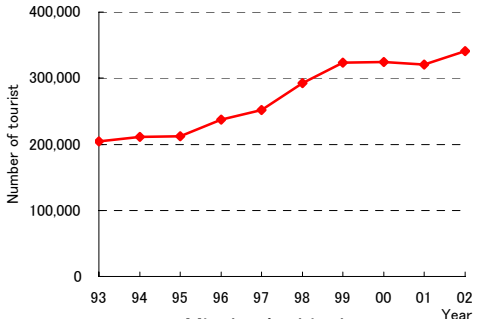
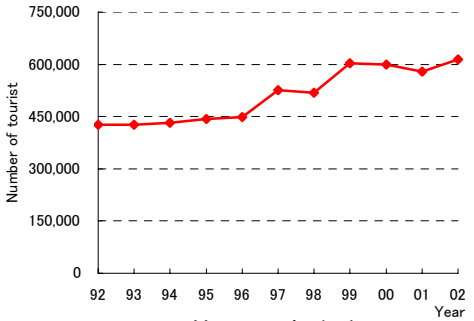
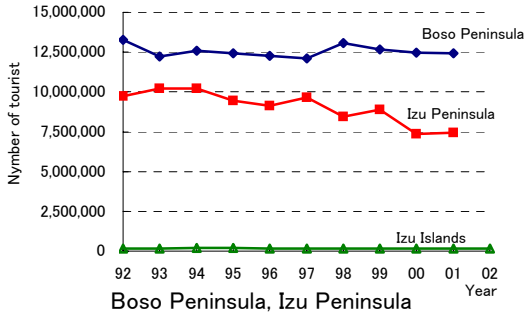


Miyako Archipelago

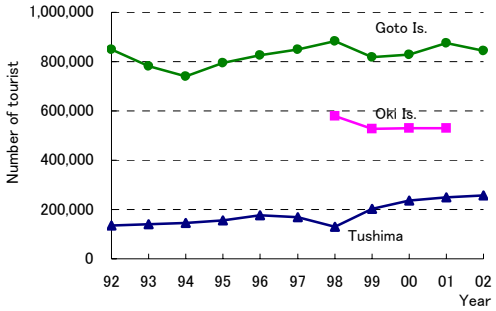


Yaeyama Arcipelago

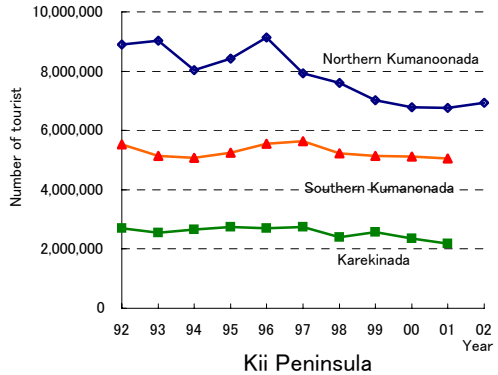
High-latitude coral community region



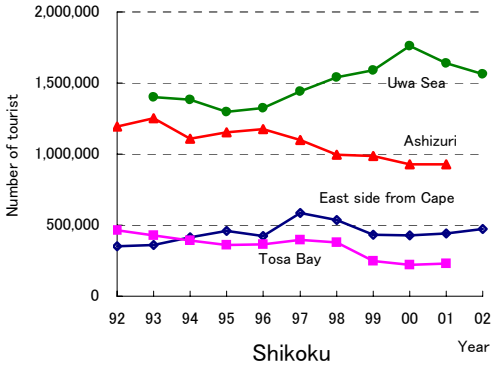
Boso Peninsula, Izu Peninsula and Izu Islands



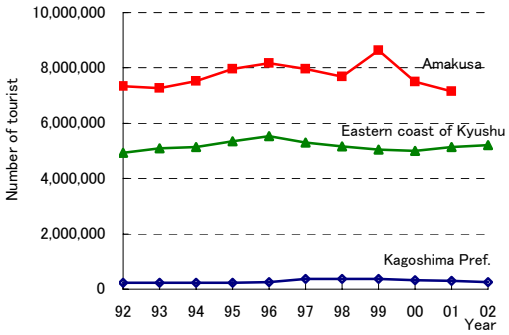
Sea of Japan



Kii Peninsula



Shikoku

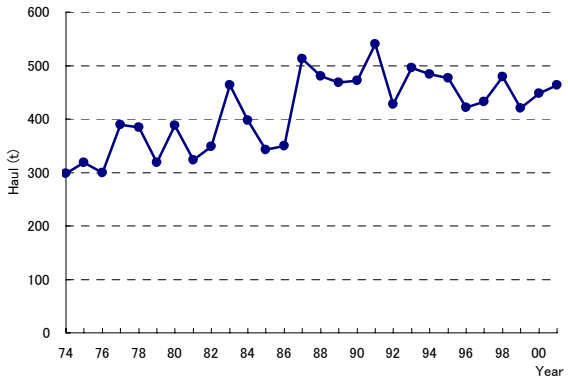


Kyushu

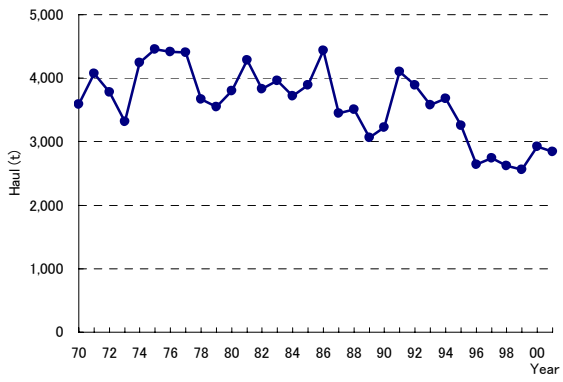
Appendix 1-5 Fishery statistics

Transition of fishery production at each concerned local authorities were compiled from the Satistical Information Center of Ministry of Agriculture, Forestry and Fisheries, and the statistical data of each authonomous bodies. The data of fishery production that does not directly relates to coral reefs (e.g., distant-water fisheries) for Tokyo and Okinawa were deleted from the statistics. However, differentiation of data were not possible for other prefecture' statistics, therefore, they included all the fishery productions.

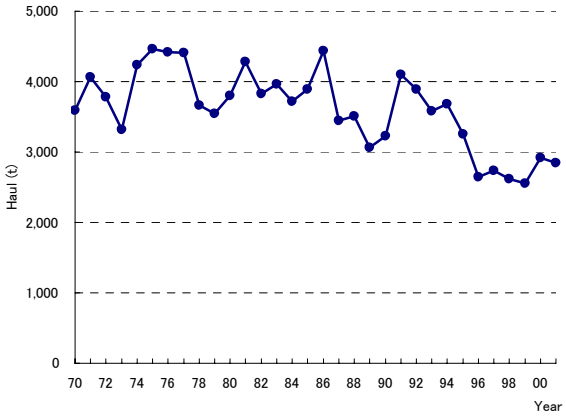
Coral reef region



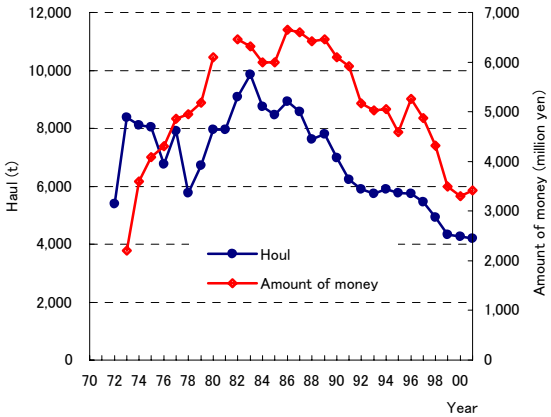
Ogasawara Islands



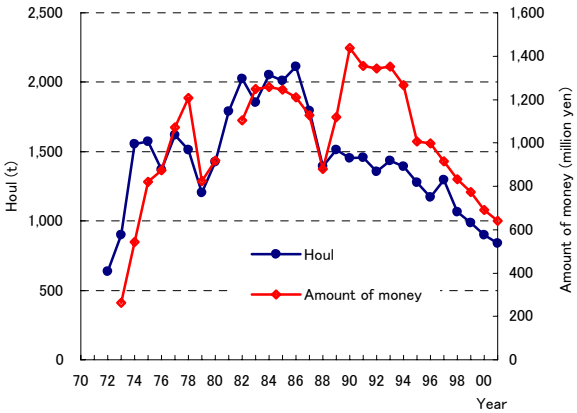
Osumi Islands and Tokara Archipelago



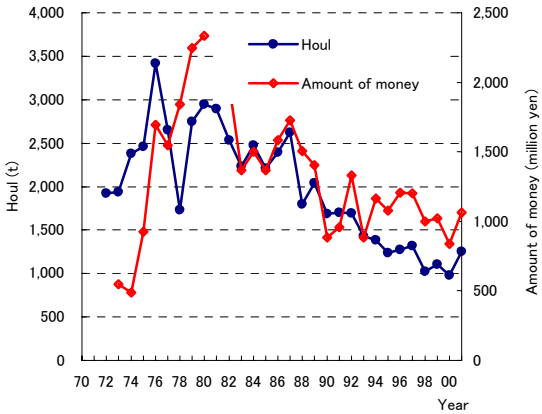
Amami Archipelago



Okinawa Islands

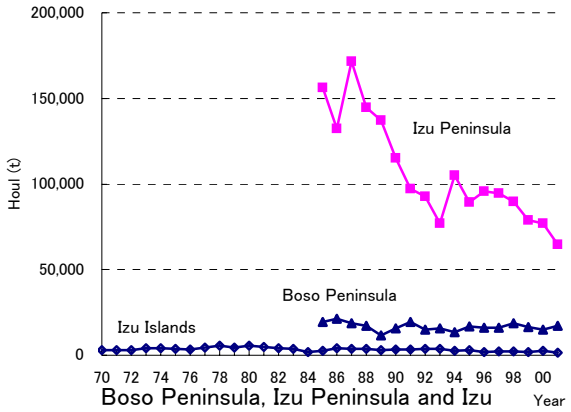


Miyako Archipelago

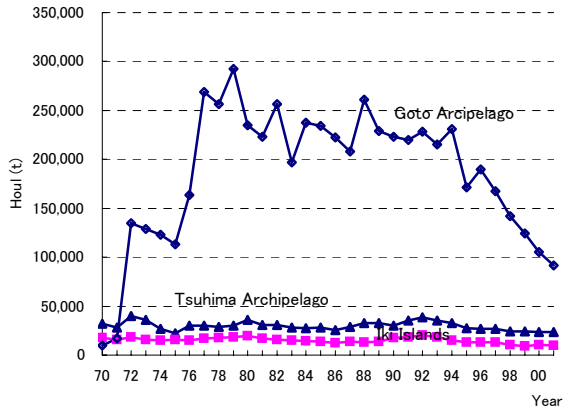


Yaeyama Archipelago

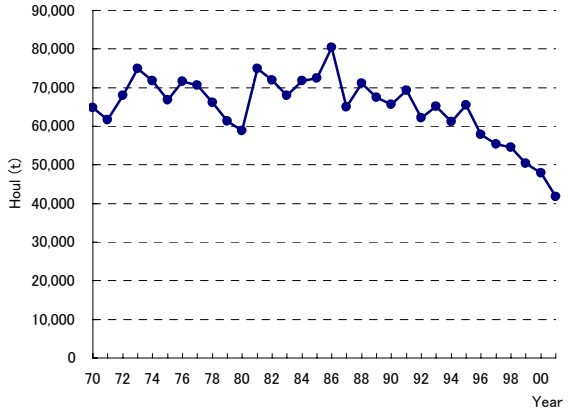
High-latitude coral community region



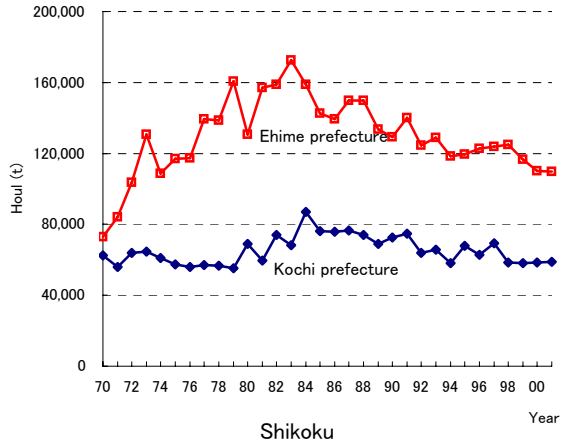
Boso Peninsula, Izu Peninsula and Izu Islands



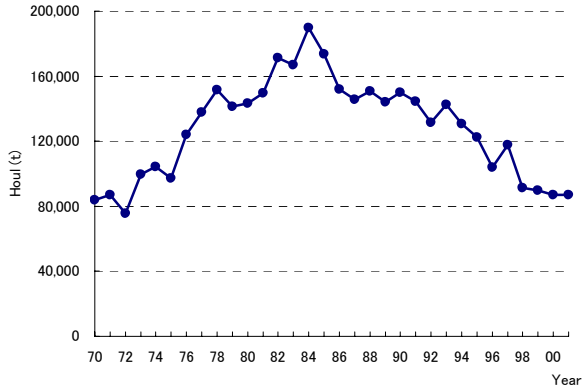
Sea of Japan



Wakayama Prefecture (Kii Peninsula)



Shikoku



Kagoshima Prefecture (Kyushu)

Appendix 1-6 Protected areas in coral distribution

Marine Parks

Name of Park	Name of Marine Park Zone	Location	Area(ha)	Date Designated	Outstanding Characteristics *1 and Pertinent Data	Category *2
Ogasawara N.P.	Ogasawara	Hyotanjima, Hitomarujima, Anijimaseto(2), Minamishima, Miyukinohama, Hirashima, Ogasawara, Tokyo Metropolis	Site 1 25.0 Site 2 18.0 Site 3 27.0 Site 4 11.0 Site 5 263.0 Site 6 36.0 Site 7 83.0 Total 463.0	16 Oct.1972	Consisting of two kinds of districts, i.e. (1) Hyotanjima, Hitomarujima, Anijimaseto and Hahajima with topography of complicated volcanic rock, agglomerate and tuff seabed; (2) Minamishima with its submerged karst topography of lime stone. Mainly *Acropora leptocyathus* of Scleractinia forms good underseascapes and large-sized tropical fishes like *Paracanthurus hepatus* and *Calotomus japonicus* are sailing around in crowds. Minamishima is the only submerged karst island in our country and has doline underseas; coral like *Euphyllia fimbriata* is abundant.	1
Fuji Hakone Izu N.P.	Miyakejima	Miyake, Tokyo Metropolis	Site 1 29.0 Site 2 22.6 Total 51.6	7 Nov. 1994	Kuroshio flows through this area, and draw a boundary between warm and temperate-sea regions. Mainly, tabular Acropora forms large-sized colonies, and shore fishes such as *Amphiprion clarkii*, *Chromis notatus miyakeensis* and *Chaetodon auripes* can be seen in abundance.	2
Yoshino-Kumano N.P.	Kumano-Nada Nikijima	Kumano, Mie Pref.	Site 1 7.8 Site 2 6.6 Total 14.4	19 Dec.1975	Sea cliffs extend to undersea; on wall-side numerous *Melithaea flabellifera*, and *Solandelia secunda* are sticking; on shore rocks table type coral *Acropora solitaryensis*, *Dendronephthya habereri*, *Platygyra lamellina* and *Favia speciosa* are seen, whereas seaweeds such as *Delisea japonica*, *Padina arborescens* and *Eckloniopsis radicosa* are growing. Fishes: *Goniistius zonatus*, *Prionurus scalprus*, *Chaetodon auripes*, *Apogon semilineatus*, Ditrema temmincki and Labridae are abundant.	2
	Kushimoto	Sabiura, Kushimoto, Wakayama Pref.	Site 1 9.6 Site 2 9.8 Site 3 7.1 Site 4 12.7 Total 39.2	1 July 1970	Scleractinia grows finely. Especially, a large-scaled coral community can be seen at Nachikazaki and its vicinity. Around Fudeshima mainly Acropora hyacinthus as well as *Hydnophora exesa*, *Platygyra* and *Pavona decussata* grow in crowds; kinds and quantities of those are extremely abundant. Besides, Alcyonacea and *Anthoplexaura dimorpha*, tropical fishes can be seen abundantly.	2
Daisen-Oki N.P.	Shimane Hanto	Taisha, Shimane Pref.	7.0	16 Oct.1972	Rocky coast of igneous rock like quarts porphyry with marked pillar-shaped joint; complicated shoreline with inlets and convex angles. Feature of fauna and flora is as of southern part of temperate zone; *Sargassum* forming seaweed forest, whereas Ulvaceae and *Codium fragile* in plain-like shape. Fishes: *Pterogobius zonoleucus*, *Pterogobius elapoides*, *Ditrema temmincki*, etc. Invertebrates: *Melithaea flabellifera*, *Tubastrea faulkneri*, *Euplexaura erecta*, etc.	3
	Jodogaura	Fuse, Oki, Shimane Pref.	Site 1 12.5 Site 2 8.3 Total 20.8	11 Dec.1975	Vagetative-scape is composed of *Sargassum tortile* and *Sargassum ringgoldianum*, *Eisenia bicyclis* and *Phyllospadix japonica*; besides, fishes like *Chromis notatus notatus*, *Ditrema temmincki* and *Girella punctata* are numerous, and also large-sized fishes like *Oplegnathus fasciatus* can be seen abundantly. In underwater caves and around Coelenterata such as *Melithaea flabellifera*, *Tubastraea faulkneri*, Dendronephthya, etc., and also Comatulida, *Pseudocentrotus depressus* and sponge can be seen.	3
	Shiro	Gokamura, Oki, Shimane Pref.	14.8	11 Dec.1975	A group of Sargassum tortile forms a beautiful seaweed plain; fishes only a few species but Labridae such as *Chromis notatus notatus*, *Oplegnathus fasciatus*, *Girella punctata* and *Ditrema temmincki* are abundant. Behind rocks invertebrata like *Solanderia secunda*, *Acabaria japonica*, top shell and *Certonardoa semiregularis* can be seen.	3
	Kuniga	Nishinoshima, Oki, Shimane Pref.	7.3	11 Dec.1975	At rocky part *Eisenia bicyclis* and *Phyllospadix japonica* grow thick, whereas at large-gravel part *Sargassum tortile*, *Sargassum ringgoldianum* and at fine-gravel part small-sized seaweeds like Nemacystus decipiens and *Colpomenia sinuosa* can be seen abundantly. As for fishes, *Sebastes inermis* is abundant, and also *Girella punctata*, *Ditrema temmincki*, Labridae, etc. Besides, as to *invertebrata*, *Melithaea flabellifera* and *Aglaophenia whiteleggei* of Coelenterata, and *Anthocidaris crassispina*, *Pseudocentrotus depressus* and *Certonardoa semiregularis* can be seen.	3
	Ama	Ama, Oki, Shimane Pref.	7.6	18 Sept.1997	This area locates a inlet of Matsushima being on the east side of Okinoshima(Touzen). From the seaside to offshore, stones pile up and form a gentle slope of seabed followed by flat sandy bottom. At the stone area, seaweeds such as *Eisenia bicyclis*, *Sargassum patens* and *Sargassum macrocarpum* form large community, and in the shoal, Cnidaria such as *Aglaophenia whiteleggei*, *Anthogorgia bocki*, Dendronephthya, and mollusc such as *Nordotis discus discus*, top shell live densely. And on the stones near the sandy bottom, Scleractinia such as Alveopora japonica, *Psammocora profundacella*, *Oulastrea crispata* are seen. *Oplegnathus fasciatus*, *Chromis notatus notatus*, *Pteragogus flagellifera*, Sebastes inermis are sailing around in corals.	2
Ashizuri-Uwakai N.P.	Uwakai	Nishiumi, Ehime Pref.	Site 1 12.0 Site 2 3.5 Site 3 0.8 Site 4 1.5 Site 5 9.0 Site 6 5.5 Total 32.3	10 Nov.1972 (designated on 1 July 1970 as a part of Ashizuri Quasi-National Park)	Species of colorful Alcyonacea is abundant; presenting flower-garden form is characteristic. It makes a very beautiful underseascape with species of large-sized Scleractinia growing in high density, tropical fishes abundant and *Tubastrea faulkneri*, Melithaea flabellifera and *Anthoplexaura dimorpha* sticking to seawater-eroded caves at Kashima-no-hora.	2
	Okinoshima	Sukumo, Kochi Pref.	Site 1 8.0 Site 2 8.0 Site 3 3.5 Site 4 11.1 Site 5 5.7 Total 36.3	10 Nov.1972	Due to north-going Kuroshio branch passing through, subtropical fauna and flora grow finely whereas large-sized *Acropora leptocyathus* and Alcyonacea grow in crowds; furthermore fishes around coral community, temperate fishes and sometimes large-sized migratory fishes can be seen abundantly. Scenicly as well as scientifically very valuable treasury of marine fauna and flora.	2
	Tatsukushi	Tosashimizu, Kochi Pref.	Site 1 8.1 Site 2 5.5 Site 3 5.8 Site 4 2.5 Total 21.9	10 Nov.1972 (designated on 1 July 1970 and 22 Jan., 1971 as a part of Ashizuri Quasi-National Park)	Species of Scleractinia grow markedly making underseascapes a very splendid one; particularly in Minokoshi Bay a large colony of *Pavona decussata* is magnificent and valuable from a scientific angle. Tropical fishes like *Pomacentrus coelestis* and *Chaetodon auripes* are abundant, making a beautiful underseascape.	2
	Kashinishi	Otsuki, Kochi Pref.	Site 1 6.3 Site 2 10.5 Total 16.8	10 Nov.1972	Strongly affected by Kuroshio, subtropical fauna and flora grow. Due to an environment rather similar to inland bay, reef-building corals are distributed widely; corals and fishes are abundant and partly seaweeds can be seen.	2
	Tsutomezaki	Otsuki, Kochi Pref.	8.3	21 Aug.1995	In the inlet on the south side of Tsutomezaki, largely covered tabular Scleractinia grows. On big gravel and complicated topography of sea bed near the point of Tsutomezaki, soft coral species like Alcyonacea are seen abundantly.	2
	Shirigai	Otsuki, Kochi Pref.	10.4	21 Aug.1995	In the shallow area on the northwest side of the Shirigai bay, largely covered tabular Scleractinia grows. Around the Matsuhae, soft coral species like Alcyonacea thrive.	2

Name of Park	Name of Marine Park Zone	Location	Area(ha)	Date Designated	Outstanding Characteristics *1 and Pertinent Data	Category *2
Saikai N.P.	Fukue	Fukue, Nagasaki Pref.	Site 1 5.5 Site 2 5.7 Total 11.2	16 Oct.1972	Northwestern area of Takenokojima and Yaneojima off Fukue port. Due to warm current, growth in crowds of Scleractinia like *Acropora squarrosa* and *Podabacia elegans lobata*, soft coral species like *Melithaea flabellifera* and *Alcyonacea*, seaweeds like Sargassum and *Zostera marina* growing in mixed condition and tropical fishes like Labridae and *Chromis notatus notatus* can be seen in abundance.	2
	Wakamatsu	Wakamatsu, Nagasaki Pref.	Site 1 4.2 Site 2 6.7 Site 3 8.3 Total 19.2	16 Oct.1972	A district bearing volcanic submerged coastal scene; inland-sea marine environment with many islands of complicated feature. Particularly, at Katashioseto large growth in thick crowds of colorful Alcyonacea shows a great characteristic of this district. At Gotejima: Scleractinia like *Porites tenuis* and Acropora studeri. At Harunomendo: Splendid growth in crowds of Gorgonacea on wall-side.	2
Unzen-Amakusa National Park	Tomioka	Reihoku, Kumamoto Pref.	Site 1 7.6 Site 2 8.6 Total 16.2	1 July 1970	Especially seaweeds are abundant. *Martensia fragilis*, *Eckloniopsis radicosa*, *Corallina pilulifera* and *Amphiroa anceps* are growing thick and in crowds, and also Scleractinia can be seen abundantly. In shallow water, species of colorful Alcyonacea is abundant and groups of tropical fishes can be seen.	2
	Amakusa	Amakusa, Kumamoto Pref.	5.1	1 July 1970	Ogase is composed of 10 large and small groups of reefs; each reef has complicated topography of seabed. Scleractinia and tropical fishes are abundant, especially bright-colored Alcyonacea and *Anthoplexaura dimorpha* form an excellent underseascape.	2
	Ushibuka	Ushibuka, Kumamoto Pref.	Site 1 9.3 Site 2 7.5 Site 3 6.0 Site 4 7.6 Total 30.4	1 July 1970	Large gregariousness of Alcyonacea is characteristic, and on account of its abundance in kind and quantity form a beautiful flower zone. Growth in crowds of *Antipathes japonica*, *Entacmaea actinostoloides*, *Melithaea flabellifera* and *Lobophytum batarum* makes a splendid scene and also Scleractinia and tropical fishes are abundant.	2
Kirishima-Yaku National Park	Sakurajima	Sakurajima, Kagoshima Pref.	Site 1 6.5 Site 2 8.2 Total 14.7	1 July 1970	Hakamagoshi has a rugged topography of seabed formed by Taisho lava current. Growth in crowds of Alcyonacea and Scleractinia makes an excellent sight of underseascapes, whereas splendid seaweed scene of *Padina arborescens* can be seen. Also, at Okinokojima growth in crowds of *Entacmaea actinostoloides* shows a very beautiful scene.	2
	Sata Misaki	Sata, Kagoshima Pref.	Site 1 4.5 Site 2 7.3 Total 11.8	1 July 1970	Besides species of Scleractinia abundant in kind and quantity and making typical coral community scene, invertebrate like colorful *Melithaea flabellifera*, *Anthoplexaura dimorpha*, Sarcophyton and Alcyonacea live in crowds making an excellent underseascapes.	2
	Kurio	Yaku, Kagoshima Pref.	Site 1 84.8 Site 2 15.8 Site 3 13.8 Total 114.4	19. Feb.2002	The area has a distinctive undersea view with very high visibility, and holds highly diversified fish and hermatypic coral communities. The coexistance of the extratropical and the subtropical species is specially notable in this area. The area may be strongly affected by the black current, since some the southeast asian tropical species are seen.	2
Iriomote N.P	Taketomijima Takidonguchi	Taketomi, Okinawa Pref.	36.7	1 July 1977	Waters include outer reef-flat and patch reefs along the fringing reef extended from northwest Taketomijima, and contact to Takidonguchi Channel of the west side. At the reef-margin spurs and grooves develop, and its topography is Rugged. In shallow reef-flat, table-shaped and branch-shaped corals grow thickly and Scleractinia such as Acropora studeri, *Porites tenuis*, *Favia speciosa*, and Seriatopora hystrix, Alcyonacea and coral fishes such as Pomacentridae, Chaetodontidae and Labridae are seen abundantly.	1
	Taketomijima Shimobishi	Taketomi, Okinawa Pref.	83.1	1 July 1977	Waters include reef-margin and flat of Shimobishi Reef extended in the offing of southwest Taketomijima. Reef-margin develops with spurs and rugged topography. In shallow reef-flat, table-shaped and branch-shaped corals inhabit crowdedly on a large scale and Scleractinia such as *Acropora studeri*, *Favia speciosa* and *Porites tenuis*, and coral fishes such as Chaetodontidae, Pomacentridae and Acanthuridae are abundant. The area shows seascape of barrier reef, having specific character of outer reef.	1
	Kuroshima Kyanguchi	Taketomi, Okinawa Pref.	45.5	1 July 1977	Waters include a moat extended in the offing of Kyan of east Kuroshima. Its topography is rugged. The moat is 2 to 7 meter in depth, having a large scaled forest of stag-horn corals and also many fishes such as Pomacentridae and Chaetodontidae.	1
	Aragusukujima Maibishi	Taketomi, Okinawa Pref.	48.2	1 July 1977	The area includes Maibishi-reef extended off northwest Kamiji of Aragusukujima, composed by small patch reefs. In a lagoon of 1 to 3 meter in depth, large *Acropora pectinata* dominates, branch-shaped coral and Alcyonacea inhabit in crowds. Fishes such as Pomacentridae, Chaetodontidae, Acanthuridae and Labridae, Melithaea ocracea and Comatulida are living also abundantly.	1
Minamiboso Quasi-National Park	Katsuura	Katsuura, Chiba Pref.	14.5	7 Jun .1974	Algal flora, bearing a warm-sea element, shows a tendency to a cold-sea type. Growth in crowds of *Ecklonia cava* and *Eisenia bicyclis*, Fucales such as *Sargassum giganteifolium*, S. fulvellum and Myagrolpsis myagroides and *Serraticardia maxima* make underseascapes as a splended one. Fishes: Besides Chaetodon auripes and Chromis notatus notatus, *Prionurus scalprus*, *Calotomus japonicus*, *Girella punctata* and Labridae are abundant. Invertebrate: *Allopora boschmai*, Solanderia secunda, S. misakiensis, *Melithaea flabellifera* and Echinogorgia rigida are also taking parts in beautiful scenes.	3
Muroto-Anan Kaigan Quasi-National Park	Awa oshima	Mugi, Tokushima Pref.	Site 1 9.5 Site 2 4.0 Site 3 2.0 Total 15.5	22 Jan.1971	Seabed of sandstone is covered all over with benthonic organisms. Besides seaweed like *Padina arborescens*, reef-building coral like *Acropora studeri*, *Porites tenuis*, *Leptoria phrygia*, *Favia speciosa* and *Turbinaria rugosa* can be observed. Growth in large groups of *Entacmaea actinostoloides* is characteristic. Tropical fishes like *Amphiprion clarkii*, *Pomacentrus coelestis* and *Chaetodon auripes* are abundant.	2
	Awa takegashima	Shishikui, Tokushima Pref.	Site 1 5.3 Site 2 4.6 Total 9.9	16 Oct.1972	Topography with rather shallow seabed of sandstone. Scleractinia like *Acropora studeri*, *Pavona decussata* and *Favia speciosa* grow in community. Tropical fishes like *Pomacentrus coelestis*, *Abudefduf vaigiensis* and *Chaetodon auripes* are living, adding beautiful color to transparent sea.	2
Genkai Quasi-National Park	Genkai	Karatsu, Yobuko and Chinzei, Saga Pref.	Site 1 6.0 Site 2 12.4 Site 3 9.6 Site 4 10.5 Site 5 7.0 Total 45.5	1 July 1970	Sea caves and cliffs of basalt with pillar-shape joint, studded on Lias-style coast, and the feature of fauna and flora distributing to subtropical and temperate zone is characteristic. Underwater forest of seaweeds and undersea-scapes consisting of species of hermatypic corals growing almost at the northern-most are splended in particular.	2

Name of Park	Name of Marine Park Zone	Location	Area(ha)	Date Designated	Outstanding Characteristics *1 and Pertinent Data	Category *2
Iki-Tsushima Quasi-National Park	Iki-Tatsunoshima	Katsumoto, Ngasaki Pref.	8.6	16 June 1978	Flat rock beds, several tens of meters wide, stretch out stepwise over the seabed, where *Eisenia bicyclis*, *Ecklonia cava* and *Sargassum fulvellum* have grown densely. The dominant fish is Labridae. *Porites tenui*s, *Favites abdita* and other hermatypic coral species are seen. Exposed to the open sea, the area is characterized by clear sea water. With good natural land condition, the area has a harmonious overall environment.	2
	Iki-Tenagashima	Katsumoto, Ngasaki Pref.	9.7	16 June 1978	The sea contains a well-developed underwater forest consisting of large brown algae including *Eisenia bicyclis*, *Ecklonia cava*, *Sargassum ringgoldianum*, *Sargassum macrocarpum* and *Sargassum horneri*. In addition, Gorgonacea and Anthogorgia have also grown densely, forming a diversified undersea scape. Dominant coral species include *Alveopora japonica*, *Porites tenuis* and *Favia speciosa*. The dominant fish is Labridae while *Pomacentrus coelestis*, *Girella punctata*, *Prionurus scalprus* and *Oplegnathus fasciatus* are also seen.	2
	Iki-Tsumagashima	Ishida, Nagasaki Pref.	9.3	16 June 1978	The sea bottom topography is characterized by a sheer cliff that rise up vertically. The rock face is covered by densely-grown *Tubastrea faulkneri*, *Dendrophyllia arbuscula* and *Melithaea flabellifera*. Very large communities of Alcyonacea are seen in deeper parts. The area is rich in Sillaginidae as well as Labridae, Pomacentridae, *Parapristipoma trilineatum*, *Apogon semilineatus*, *Pagrus* major and *Chaetodontoplus septentrionalis*. Hermatypic coral Coscinaraea columna and soft coral are distributed.	2
	Tsushima-Asowan	Mitsushima, Nagasaki Pref.	9.5	16 June 1978	This area has typical undersea scape in the Aso Bay, characterized by masses of *Codium fragile* and coral communities of *Acropora squarrosa*.Very large community of *Entacmaea actinostoloides* is seen on the north of the island. The dominant fishes include *Pomacentrus coelestis*, *Halichoeres tenuispinnis*, *Apogon notatus*, *Parapercis snyderi*, *Spratelloides gracilis* and Pomacentridae.	2
	Tsushima-Kozaki	Izuhara, Nagasaki Pref.	10.4	16 June 1978	The area is characterized by a diversified three-dimensional undersea topography. The dominant algae include *Ecklonia cava*, *Sargassum fulvellum* and *Eisenia bicyclis*. The area also provides habitats for coelenterates including *Melithaea flabellifera*, *Anthoplexaura*, *Dendronephthya gigantea*, Dendronephthya sp., *Macrorhynchia phoenicea*, *Tubastrea faulkneri*, *Alveopora japonica* and sea anemones; echinoderms including sea urchins, *Diadema setosum*, *Tropiometra afra macrodiscus* and starfish; and fishes including *Chromis notatus notatus*, *Pomacentrus coelestis*, *Pempheridae*, *Girella punctata* and Labridae. Thus the area is abundant in a large variety of species.	2
Nippo Kaigan Quasi-National Park	Kamae	Kamae, Oita Pref.	Site 1 10.0 Site 2 10.0 Site 3 6.3 Site 4 7.2 Total 33.5	1974. 2.15 15 Feb.1974	*Acropora leptocyathus*, *Pavona decussata*, *Acropora studeri* and Alcyonacea grow widely and on a large scale. Tropical fishes such as *Chaetodon auripes*, Labridae, *Chromis notatus notatus* and *Amphiprion clarkii* are seen sailing here and there and making underseascape an excellent one.	2
	Minami Kitaura	Minami Kitaura	Site 1 13.5 Site 2 4.0 Site 3 3.4 Site 4 2.5 Site 5 10.5 Site 6 14.8 Total 48.7	15 Feb.1974 27 Jan. 1993 one area addition, two areas enlargement	Nice growth of large-sized *Acropora leptocyathus*, *Favia speciosa*, *Acropora studeri*, *Hydroides norvegicus* and Dendronephthya can be seen widely and on a large scale; tropical fishes like *Chaetodon auripes*, Labridae, *Chromis notatus notatus* and *Amphiprion clarkii* are sailing abundantly.	2
Nichinan Kaigan Quasi-National Park	Nichinan	Nango, Kushima and Nichinan, Miyazaki Pref.	Site 1 7.3 Site 2 11.3 Site 3 8.0 Site 4 10.4 Site 5 12.6 Site 6 6.3 Total 55.9	1 July 1970	On undulate reefs Alcyonacea, *Anthoplexaura dimorpha* and *Melithaea flabellifera* grow in groups, making underseascapes very beautiful. At Komenotoura, all over the bay large-sized stratiform *Acropora leptocyathus* grows in high density. Tropical fishes like *Chromis hollisi*, *Chaetodon auriga* and Labridae are sailing in groups and varied underseascapes can be seen.	2
Amami Gunto Quasi-National Park	Kasari Hanto-Higashi Kaigan	Kasari, Kagoshima Pref.	93.0	15 Feb.1974	Branch-shape corals such as *Acropora squarrosa*, *Porites tenuis*, *Stylophora pistillata*, and massive *Porites tenuis* are abundant. Besides, *Pocillopora damicornis* and leaf-shape Montipora can be seen. Fishes: *Chaetodon auripes*, *Chromis hollisi*, Labridae, *Zebrasoma flavescens*, and *Naso unicornis* are rich in color and make underseascapes very magnificent.	1
	Surikozaki	Naze, Kagoshima Pref.	70.0	15 Feb.1974	Fishes such as Chaetodontidae sail around among coral of Acropora and seaweed of Sargussum.	1
	Setouchi	Setouchi, Kagoshima Pref.	Site 1 18.0 Site 2 22.0 Site 3 18.0 Total 58.0	15 Feb.1974	Shore reef fronting on sand bottom and corals sticking vertically; transition in fauna distribution from open-sea kind to inland sea one mainly corals can be seen. Corals: *Pocillopora damicornis*, plate-shape *Acropora studeri*, *Platygyra lamellina*, *Favia speciosa*, *Montipora foliosa*, massive Porites tenuis, and branch-shape *Montipora cactus* can be seen. Fishes: *Chaetodon auripes*, *Chromis notatus notatus* and *Labroides dimidiatus* can be seen abundantly.	1
	Kametoku	Tokunoshima, Kagoshima Pref.	70.0	15 Feb.1974	*Acropora studeri*, *Favia speciosa*, *Goniopora planulata*, *Platygyra lamellina* and *Echinophyllia aspera* can be seen abundantly; fishes such as *Holacanthus semicirculatus*, *Chaetodon auriga*, *Chromis hollisi* and *Amphiprion clarkii* are also abundant.	1
	Yorontou	Yoron, Kagoshima Pref	Site 1 93.0 Site 2 4.0 Site 3 58.0 Total 155.0	15 Feb.1974	Corals in moat make a splendid scene; varying in kind like branch-shape Acropora, plate-shape Acropora, *Porites tenuis*, *Styllophora pistillata*, *Montipora cactus*, and *Favia speciosa*. Colorful fishes such as *Chaetodon auripes*, *Heniochus acuminatus*, *Holacanthus semicirculatus*, *Chromis hollisi*, *Amphiprion clarkii*, *Abudefduf sexfaxciatus*, *Prionurus microlepidotus*, *Balistes niger*, *Labridae* and *Leptoscarus japonicus* are abundant and full of variety.	1
Okinawa Kaigan Quasi-National Park	Okinawa Kaigan	Nago & Onna, Okinawa Pref.	140.0	15 May 1972 (3 Sept. 1971 by Ryukyu Government)	Typical coral reef with developed moat. Being moat area shallow and calm, *Acropora squarrosa*, species of Chaetodontidae and Pomacentridae make a delicate underseascape. And, at the reef margin it has a splendid underseascape with *Acropora leptocyathus* and large-sized tropical fishes like *Leptoscarus japonicus* sailing around.	1
	Tokashiki	Tokashiki, Okinawa Pref.	120.0	9 Dec. 1978	Hermatypic corals such as table-shaped, branch-shaped, massive and covering corals are distributed densely and colorful coral fishes such as Pomacentridae, Chaetodontidae and Labridae inhabit abundantly.	1
	Zamami	Zamami, Okinawa Pref.	233.0	9 Dec. 1978	Large fish of *Mobula japonica* are seen in addition to the same coral and fish species as above. The area has a distinctive undersea view.	1

Category 1	13 zones	23 sites	1,615.5 ha
Category 2	29 zones	78 sites	718.3 ha
Category 3	5 zones	6 sites	64.4 ha
Total	47zones	107 sites	2,398.2 ha

*1 : Description is mainly from results of survey carried for designation of proposed marine park areas.

*2 : Category; 1:Parks in coral reef area, 2:Parks in non-coral reef area, with hermatypic corals, 3:Parks possibly hermatypic corals exist though not confirmed yet.

Data source: Protecting Nature of the Sea- Roles and activities of marine parks- (Marine Park Center of Japan 2001). The information is partly added.

Other protected areas

Category of protection	Name of marine protected area	Location	Area (ha)	Date Designated	Outstanding Characteristics and Pertinent Data	Category*2
Nature Conservation Area	Sakiyamawan Nature Conservation Area	Sakiyama, Taketomi, Okinawa Pref.	128.0	28 June 1983	It is located on the coral reef in Sakiyama Inlet on the western coast of Iriomote Island. The area of the zone is 128 ha of the coral reef without land area. Large colony of *Galaxea fascicularis* and sea-grass beds manily *Enhalus acoroides*, are found this inlet.	1
Protected Water Surface	Kuroshima, Ushibuka	Kuroshima, Ushibuka,Kumamoto pref.	22.7	1979. 8.22 22 Aug.1979	Capturing aquatic animals and plants is strictly prohibited.	2
	Fukami, Ushibuka	Fukami, Ushibuka, Kumamoto pref.	32.0	1980. 7. 7 7 July 1980	Capturing aquatic animals and plants, excluding *Undaria pinnatifida* and *Monostoroma nitidum* is strictly prohibited.	
	Kabira Bay	Kabira, Ishigaki, Okinawa pref.	275.0	1974. 9.26 26 Sep.1974	Capturing *Pinactada margaritifera*, giant clam, *Panulirus versicolor*, *P. ornatus*, *Penaeus latisulcatus*, *Tripneustes gratilla* and *Betuphycus gelatinum* is prohibited.	1
	Nagura Bay	Sakieda-yarabu, Ishigaki, Okinawa pref.	68.0	1975. 9. 1 1 Sep.1975	Capturing aquatic animals and plants is strictly prohibited.	

*1：Description is mainly from results of survey carried for designation of proposed marine park areas.

*2：Category; 1:Parks in coral reef area, 2:Parks in non-coral reef area, with hermatypic corals, 3:Parks possibly hermatypic corals exist though not confirmed yet.

Data source: Protecting Nature of the Sea- Roles and activities of marine parks- (Marine Park Center of Japan 2001). The information is partly added.

Appendix 1-7 Additional information (6-1-5 Daito Islands)

Table 1. **Hermatypic corals recorded at 10-20m depths, at 6 sites in Daito Islands during October 2-4, 2001.**

Family	Species
Pocilloporidae	*Pocillopora eudoxii*
	Stylophora pistillata
Acroporidae	*Montipora undata*
	Montipora verrucosa
	Acropora gemmifera
	Acropora listeri
	Acropora florida
	Astreopora myriophthalma
	Astereopora gracilis
Poritidae	*Porites solida*
	Porites lutea
	Porites lobata
	Porites annea
	Porites cylindrica
	Porites lichen
	Porites rus
	Goniopora lobata
	Goniopora tenuidens
Siderastreidae	*Psammocora superficialis*
Agariciidae	*Gardineroseris planulata*
	Pavona duerdeni
	Pavona varians
	Pachyseris rugosa
	Leptoseris sp.
Oculinidae	*Galaxea fascicularis*
Pectiniidae	*Echinophyllia aspera*
	Echinophyllia orpheensis
	Pectinia paeonia
	Pectinia lactuca
Mussidae	*Acanthastrea echinata*
	Acanthastrea ishigakiensis
	Lobophyllia corymbosa
	Symphyllia recta
	Symphyllia radians
	Symphyllia agaricia
Merulinidae	*Hydonophora microconos*
	Merulina ampliata
	Scapophyllia cylindrica
Faviidae	*Caulastrea furcata*
	Favia stelligera
	Favia pallida
	Favia favus
	Barabattoia amicorum
	Favites abdita
	Favites halicora
	Favites pentagona
	Goniastrea retiformis
	Goniastrea edwardsi
	Goniastrea favulus
	Leptoria phrygia
	Leptoria irregularis
	Oulophyllia crispa
	Leptastrea purpurea
	Leptastrea pruinosa
	Montastrea curta
	Montastrea annuligera
	Cyphastrea agassizi
	Cyphastrea microphthalma
	Cyphastrea serailia
	Cyphastrea japonica
Dendrophylliidae	*Turbinaria mesenterina*
Milleporidae	*Millipora exaesa*
Total	62

Table 2. **Coral reef fish species recorded at 6 sites in Daito Islands during October 2-4, 2001.**

Date	Station	Depth (m)	Species	Remarks
2-Oct-01	St.3 Minamidaito Is.	40	*Chaetodon daedalma*	*1
		40	*Pseudanthias ventralis*	*1
		40	*Bodianus bilunulatus*	*1
		40	*Aphareus rutilans*	*2
		20	*Sphyraena barracuda*	*2
		20	*Xanthichthys mento*	*1
		15	*Pseudobalistes fuscus*	*2
	St.4 Minamidaito Is.	20	*Centropyge flavissima*	*1
		20	*Centropyge interrupta*	*1
		15	*Carcharhinus* sp.	*2
		15	*Girella leonian*	*1
		15	*Centropyge flavissima*	*1
		15	*Chaetodon daedalma*	*1
		15	*Centropyge heraldi*	*1
3-Oct-01	St.5 Minamidaito Is.	35	*Pseudochelinus sp.*	*1
		25	*Hamitaurichthys polylepis*	*2
		25	*Caesio teres*	*2
		25	*Hamitaurichthys thompsoni*	*1
		25	*Chaetodon daedalma*	*1
		25	*Genivanthus watanabei*	*2
		20	*Chaetodon unimaculatus*	*1
		20	*Gracila albomarginata*	*2
		20	*Macolor macularis*	*2
		20	*Acanthurus thompsoni*	*1
		20	*Pseudocoris yamashiroi*	*1
		15	*Belonoperca chabanaudi* (young)	*1
		10	*Melichthys vidua*	*1
		10	*Sufflamen fraenatum*	*1
		10	*Neocirrhites armatus*	*1
		10	*Chaetodon daedalma*	*1
	St.6 Minamidaito Is.	30	*Xanthichthys auromarginatus*	*1
		15	*Chaetodon punctatofasciatus*	*1
		15	*Parupeneus cyclostomus* (young)	*2
		15	*Bodianus bilunulatus* (var.)	*1
		15	*Bodianus bilunulatus*	*1
		15	*Caesio teres* (var.)	*1
		15	*Sargoxentron caudimaculatum*	*1
		15	*Thalassoma quinquevittatum*	*1
		10	*Plectroglyphidodon imparipennis*	*1
		10	*Chaetodon reticulatus*	*1
		10	*Pseudanthias cooperi*	*2
		10	*Acanthurus japonicus*	*1
4-Oct-01	St.1 Kitadaito Is.	25	*Hamitaurichthys thompsoni*	*1
		25	*Hamitaurichthys polylepis*	*2
		25	*Caesio teres*	*2
		25	*Gracila albomarginata*	*1
		20	*Xanthichthys caeruleolineatus*	*1
		20	*Zebrasoma flavescens*	*1
		20	*Bodianus anthioides*	*1
		20	*Sargoxentron caudimaculatum*	*1
		20	*Acanthurus japonicus*	*1
		15	*Neocirrhites armatus*	*2
		10	*Ptereleotris zebra*	*1
		10	*Chaetodon quadrimaculatus*	*2
		10	*Chaetodon daedalma*	*1
		10	*Thalassoma lutescens*	*1
	St.2 Kitadaito Is.	22	*Aphareus furca*	*1
		20	*Pterocaesio tile*	*2
		20	*Gnathodentex aureolineatus*	*1
		20	*Chaetodon punctatofasciatus*	*1
		20	*Xanthichthys auromarginatus*	*2
		20	*Epinephelus hexagonatus*	*1
		20	*Zebrasoma flavescens*	*1
		20	*Acanthurus pyroferus*	*1
		20	*Centropyge flavissima*	*1
		20	*Zebrasoma scopas*	*1
		20	*Naso tuberosus*	*1
		20	*Arothon meleagris*	*1
		20	*Pomacanthus imperator*	*1
		20	*Chlorurus microrhinos*	*2
		10	*Chromis vanderbilti*	*1
		10	*Chaetodon quadrimaculatus*	*1
		10	*Chromis atripes*	*1
		10	*Neocirrhites armatus*	*1
		10	*Sebastapistes mauritiana*	*1
		10	*Chromis vanderbilti*	*2
		10	*Chaetodon daedalma*	*1
		10	*Chaetodon auripes*	*1
		10	*Chaetodon lunula*	*1
		10	*Zebrasoma scopas*	*1
		10	*Parupeneus bifasciatus* (var.)	*1

*1:identification by photo *2:identification by observation

Appendix 1-7 Additional information (6-2-2 Sea of Japan)

Table 3. Observed coral species and their coverage (%) at the coral reef of Kurosaki in Iki Islands.

Distance from shore (m)	0	5	10	15	20	25	30	35	40	45	50
Depth (m)	-0.4	0.5	0.7	1.7	2.3	2.4	2.3	1.5	1.7	2.7	4.8
Lithophyllon undulatum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	5.8	13.3	22.8
Echinophyllia aspera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	8.8
Echinophyllia echinata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	6.7	31.5	29.5
Hydnophora exesa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
Caulastrea tumida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.0	0.0	0.0
Favia speciosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.8	64.5	42.4	10.8
Favia favus ?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Favia lizardensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8	5.5	2.0	0.0
Leptastrea pruinosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Cyphastrea japonica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.3	0.0	0.0
Coral coverage (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.4	84.8	89.1	72.6
Number of species	0	0	0	0	0	0	0	9	7	4	6

Table 4. Hermatypic corals recorded in Iki Islands.

Family	Species	Eguchi and Fukuda (1972)	This study
Acroporidae	*Montipora mollis*		+
	Acropora tumida	+	+
	Acropora pruinosa		+
Poritidae	*Porites australiensis*	+	
	Goniopora lobata	+	
	Goniopora stokes		+
	Goniopora sp.	+	
	Alveopora japonica	+	+
Siderastreidae	*Coscinaraea monile*	+	
Fungiidae	*Lithophyllon undulatum*	+	+
	Lithophyllon lobata		+
Pectiniidae	*Echinophyllia aspera*	+	+
	Echinophyllia echinata		+
	Echinophyllia patula		+
	Pectinia lactuca	+	+
	Pectinia (*Physophyllia*) *ayleni*		+
Mussidae	*Acanthasterea echinata*	+	+
	Acanthasterea hemprichii		+
	Cynarina lacrymalis	+	
Merulinidae	*Hydnophora exesa*	+	+
Faviidae	*Caulastrea tumida*	+	+
	Favia pallida		+
	Favia speciosa	+	+
	Favia favus		+
	Favia lizardensis ?		+
	Favia cf. *rotumana*		+
	Favia veroni		+
	Favites abdita	+	
	Favites russelli		+
	Platygyra lamellina	+	
	Platygyra contorta	+	+
	Goniastrea australensis		+
	Goniastrea pectinata	+	
	Oulastrea crispata		+
	Plesiastrea versipora	+	+
	Leptastrea pruinosa		+
	Cyphastrea serailia	+	+
	Cyphastrea japonica	+	+
Dendrophylliidae	*Turbinaria peltata*	+	+
	39species of 22genera	22species of 19genera	31species of 23genera

Appendix 1-7 Additional information (6-2-2 Sea of Japan)

Table 5. Hermatypic corals recorded in Tsushima Archipelago.

Family	Species	Eguchi (1973)	This study
Astrocoeniidae	*Stylocoeniella guentheri*	+	
Acroporidae	*Acropora tumida*	+	+
Poritidae	*Porites lichen*	+	
	Porites lutea	+	
	Porites lobata	+	
	Goniopora lobata	+	+
	Alveopora japonica	+	
	Alveopora verrilliana	+	
Siderastreidae	*Psamocora profundacella*	+	
	Coscinaraea sp.	+	
Fungiidae	*Lithophyllon undulatum*	+	+
Pectiniidae	*Echinophyllia aspera*	+	+
	Oxypora lacera		+
	Pectinia lactuca	+	+
Mussidae	*Cynarina lacrymaris*	+	
Merulinidae	*Hydnophora exesa*	+	+
Faviidae	*Caulastrea tumida*	+	+
	Favia pallida	+	+
	Favia speciosa	+	+
	Favia favus		+
	Favia veroni		+
	Favia lizardensis		+
	Favia sp.		+
	Favites abdita	+	+
	Favites russelli		+
	Platygyra lamellina	+	
	Platygyra contorta	+	+
	Goniastrea australensis		+
	Oulastrea crispata		+
	Plesiastrea versipora	+	+
	Leptastrea purpurea	+	+
	Leptastrea pruinosa		+
	Cyphastrea japonica		+
	Cyphastera microphthalma		+
	Cyphastrea chalcidicum		+
	Cyphastrea serailia	+	
Dendrophylliidae	*Turbinaria peltata*	+	
	Turbinaria mesenterina	+	
	38species of 23 genera	26species of 20 genera	25 species of 16 genera

Appendix 1-7 Additional information (6-2-2 Sea of Japan)

Table 6. Observed coral species and these coverage (%) at three sites Tsushima Archipelago.

[Senoura]

Distance from shore (m)	0	5	10	15	20	25	30
Depth (m)	0.4	0.9	2.3	1.3	1.5	4.5	6.2
Lithophyllon undulatum	0	0	9	0	6	0	0
Echinophyllia aspera	0	0	26	0	12	14	0
Pectinia lactuca	0	0	0	0	8	3	0
Caulastrea tumida	0	6	2	7	5	0	0
Favia specioisa	0	3	24	0	16	0	0
Favia favus	0	0	0	1	0	2	0
Favia sp.	0	0	0	0	2	0	0
Favites abdita	0	0	0	0	2	0	0
Oulastrea crispata	0	0	0	0	0	0	0
Cyphastera microphthalma	0	0	0	1	0	0	0
Coral coverage (%)	0	9	61	9	51	19	0
Number of species	0	2	4	4	7	3	0

[Kaseura east]

Distance from shore (m)	0	5	10	15	20	25	30
Depth (m)	0.6	1.2	2	2.7	3.6	5.1	7.1
Echinophyllia aspera	0	0	0	17	11	15	0
Favia pallida	0	0	0	0	14	0	0
Favia speciosa	0	0	34	22	8	0	0
Oulastrea crispata	0	0	0	0	0	0	0
Cyphastrea chalcidicum	0	0	0	5	0	0	0
Coral coverage (%)	0	0	34	44	33	15	0
Number of species	0	1	1	3	3	1	0

[Kaseura west]

Distance from shore (m)	0	5	10	15	20	25	30
Depth (m)	0.3	1	1.8	2.6	3.7	5.1	7.7
Echinophyllia aspera	0	0	3	5	30	0	0
Favia pallida	0	0	5	0	0	0	0
Favia speciosa	0	0	29	47	9	0	0
Favites abdita	0	0	3	0	0	0	0
Oulastrea crispata	0	1	0	0	0	0	0
Cyphastrea chalcidicum	0	5	0	0	0	0	0
Coral coverage (%)	0	6	40	52	39	0	0
Number of species	0	2	5	2	3	0	0

Appendix 2 5th National Survey on the Natural Environment by the Ministry of the Environment

The survey on coastal environment --- Distribution of coral reef ---

The information on the coral reef distribution described in chapter 6 is based on the results of the 4th National Survey on the Natural Environment. Following the 4th Survey, the 5th National Survey was carried out on coastal environment including coral reefs from 1996 to 1998, however, the results of both surveys, such as gross area of coral distribution, can not be directly compared, because in the 5th Survey, only the area shallower than 10-m was surveyed, while 4th survey result include deeper area. The summary of methods of both surveys is:

4th National Survey on the Natural Environment:
- Surrounding waters of Japanese archipelago was divided into two regions, which are coral reef region and non-coral reef region (The non-coral reef region was described as the northern area from Kodakara Island of Tokara Islands, while the coral reefs distribute in the southern area from the island),
- Ogasawara is exceptionally included in coral reef region.
- Only the coral communities with more than 0.1-ha in area and more than 5-% coral coverage were surveyed.
- The type of coral communities, coral coverage, distribution and area of corals were investigated by;
  - ・analysis of aerial photographs and manta tow survey in coral reef region,
  - ・literature citing and information gathering, manta tow and quadrate survey in non-coral reef region,

5th National Survey on the Natural Environment:
- Surrounding waters of Japanese archipelago was divided into two regions, which are coral reef region and non-coral reef region,
- Ogasawara was included in non-coral reef region as it is part of Tokyo metropolis.
- Only the shallow areas less than 10-m in depth were selected for the survey,
- When coral community in the shallow area, which is less than 10-m in depth, extended its distribution into the deeper water, whole community was counted including the part of the community more than 10-m in depth,
- The results of the 2nd and 4th National Survey were analyzed in each prefecture,
- Additional data were collected by literature citing and information gathering, and analyzed in each prefecture,

Summary of result of the 5th National Survey on the Natural Environment

1. Distribution of Hermatypic corals (in shallow area less than 10-m in depth)

① Distribution of corals in the regions

Total area of hermatypic corals of Japan is shown in Table 1 and Table 2.

[Non-coral reef region]

The total area of coral communities was 1,814.2-ha in the non-coral reef region. The communities without specific dominant corals described as type "Others", showed 825-ha and it was the largest portion of total area (45.50-%). Coral communities with dominant tabular corals were 728.2-ha and the second largest group in the non-coral region (40.14-%) (table 1).

Table 1. Area of hermatypic corals (non-coral reef region)

	Branching	Tabular	Massive	Encrusting	Foliose	Others	Unknown	Total
Area(ha)	53.0	728.2	172.3	29.7	1.8	825.4	3.8	1,814.2
%	2.92	40.14	9.50	1.64	0.10	45.50	0.21	100.0

*Others include the community with mixed species.
*The survey in Hyogo and Tokushima prefecture were not conducted.

[Coral reef region]

The total area of harmatypic corals was 33,531-ha in the coral reef region. Excluding the coral communities with uncertain dominant species, the group "Others" was the largest with 28,907-ha (8.62-% of the total area of coral), followed by the group of "tabular coral", which area was 1,222.8-ha (3.65-%)(table 2).

Table 2. Area of hermatypic corals (coral reef region)

	Branching	Tabular	Massive	Encrusting	Foliose	Others	Unknown	Total
Area(ha)	573.2	1,222.8	544.6	14.3	0.0	2,890.7	28,285.5	33,531.1
%	1.71	3.65	1.62	0.04	0.00	8.62	84.36	100.0

*Others include the community with mixed species.
*The survey in Hyogo and Tokushima prefecture were not conducted.

② Distribution of corals at each prefecture

[Non-coral reef region]
Figure 1 shows the area of coral distribution in each prefecture of non-coral reef region. Tokyo metropolis was the richest in hermatypic corals (527.0-ha, 29.05-% of total area of corals in the region), which including Ogasawara Islands (520.4-ha and 28.68-%). Miyazaki prefecture had the second largest coal area (378.8-ha, 20.88-%), followed by Kagoshima prefecture (294.8-ha, 16.25-%).

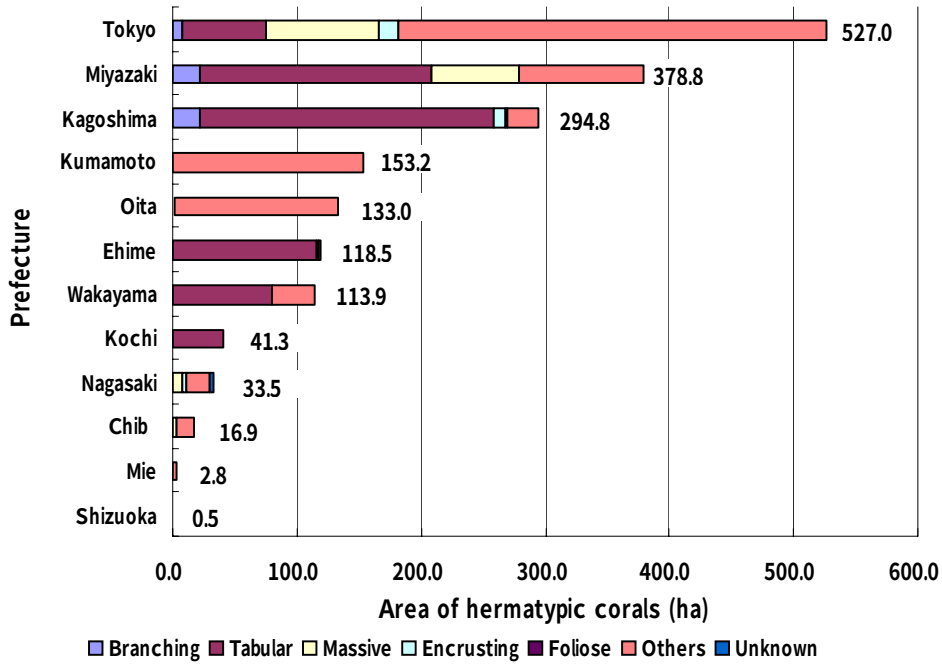


Fig. 1. Area of corals in each prefecture of non-coral region.

In Tokyo, several types of corals were mixed, while the tabular corals were dominant in Miyazaki and Kagoshima.

In this survey, Ogasawara islands were surveyed with the same method of the survey in non-coral region because of the low visibility of water and less developed reef systems, however, these islands actually belong to the coral reef region on geological location and their climate.

[Coral reef region]
Figure 2 show the area of corals in each prefecture of coral reef region. Okinawa prefecture was the richest in hermatypic corals (28,235.0-ha, 84.21-% of total area of corals), followed by Kagoshima prefecture (5,296.1-ha, 15.79-%).

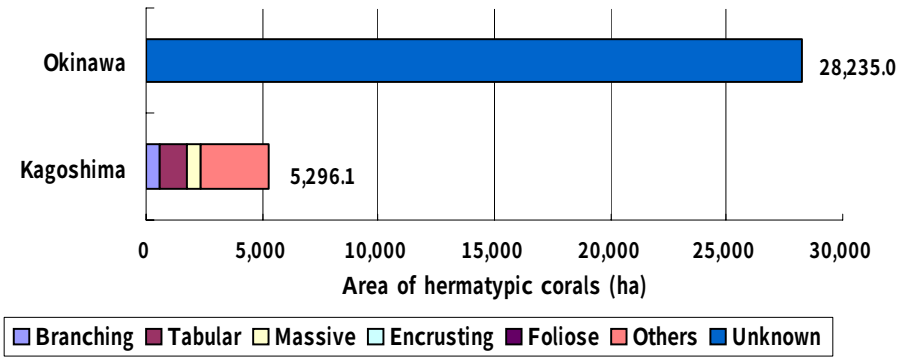


Fig. 2. Area of corals in each prefecture of coral reef region.

③ Distribution of corals at regional waters

[Non-coral reef region]
In non-coral reef regions the area was divided into 14 regional waters. Figure 3 show the area of hermatypic corals in the regional waters of non-coral reef region.

Surrounding waters of Ogasawara Islands had the largest coral area in the non-coral reef region (520.4-ha and 28.68-% of total coral area). The Hyuga open seawater had the second largest coral area (472.4-ha 26.04-%). The corals of these two waters occupied about a half of the total coral area in the region.

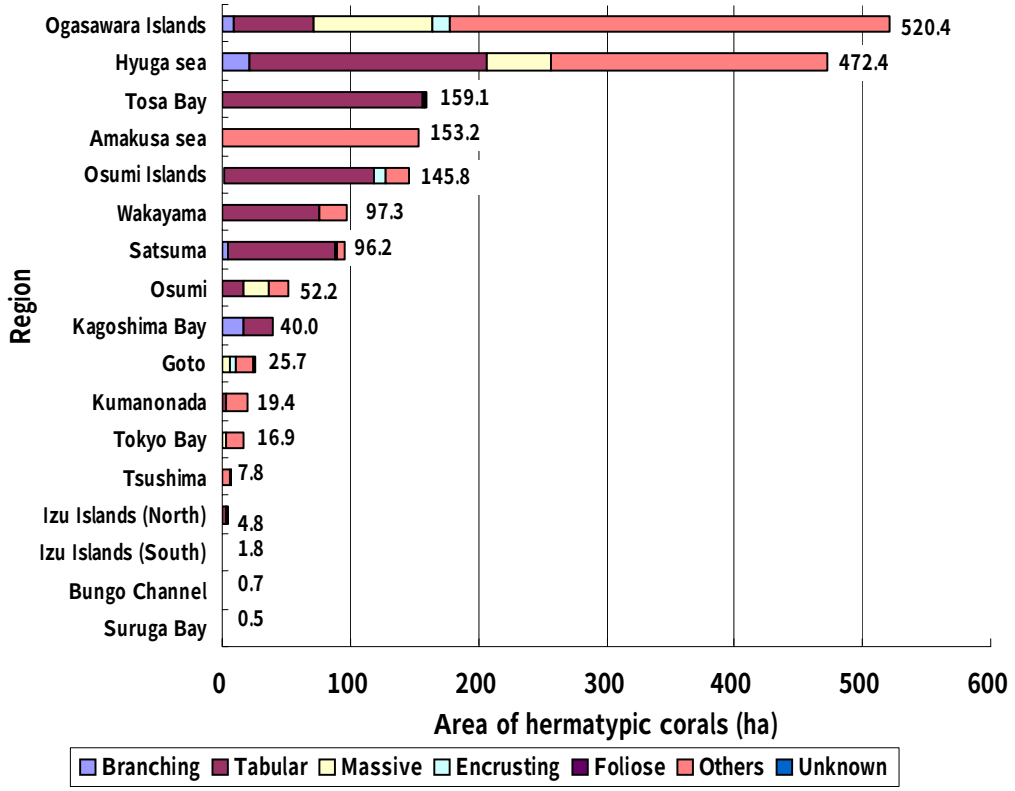


Fig. 3. Area of corals in regional waters of non-coral reef region.

The abundant type of corals of these waters was "Others", which included the coral communities with no dominant corals.

[Coral reef region]
In coral reef region the area was divided into 4 regional waters. Figure 4 show the area of corals in the regional waters of the coral reef region. Yaeyama islands water had the largest coral area among the regional waters. It was 19,231.5-ha and 57.35-% of total area of corals in the region. The most of the coral communities of this region had no specific dominant species.

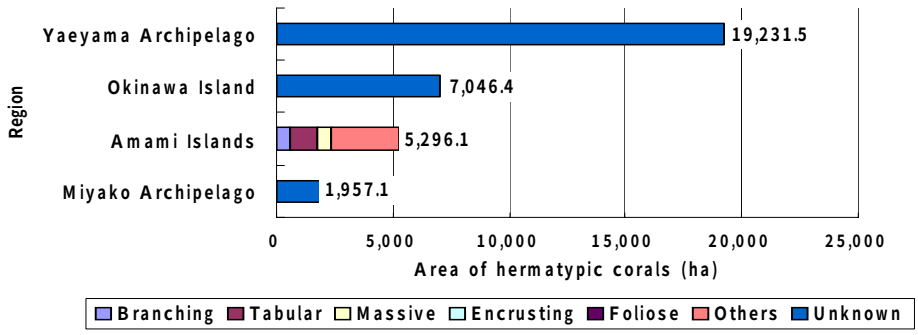


Fig 4. Area of corals in the regional waters of coral reef region.

Appendix 3 Spot Check Method for coral reef monitoring

INTRODUCTION

The Spot Check method is a monitoring method to evaluate the coral reef condition at a number of fixed sites by visual census during 15 minutes of snorkeling. The advantages of this method are; 1) requires only a few manpower (two observers at a time), 2) requires only a short time (15 minutes per each site, and compiling of the data is also easy), 3) does not require special qualification (e.g. scuba skills and knowledge on coral taxonomy), 4) can cover wide area (ca. 2500 m^2 per station), and 5) covers wide range of information (not only corals but also *Acanthaster*, *Drupellas* and other disturbances on coral reef). As this method uses visual assessment, some initial training is required for accurate assessment. Although the variance between experienced observers and beginners can be as much as 20% on coral coverage, this difference can be minimized through training with the skilled person. Averaging data of number of observers can also minimize the deviation. This manual has been developed based on the original procedure of the coral reef monitoring in Sekisei Lagoon (Marine Parks Center of Japan 2001) and introduced new parameters such as the number of juvenile coral colonies and the size range of *Acanthaster* (Okinawa Prefecture 2002).

BACKGROUND

Coral monitoring with spot check method has been developed by Yaeyama Marine Park Research Station, Marine Park Center in 1983 and conducted annually aimed to management of coral reefs in Sekisei Lagoon and effective control of *Acanthaster*. The Ministry of the Environment has had an initiative to continue the monitoring in Sekisei Lagoon since 2002. This method has been introduced to other monitoring programs such as, monitoring around Ishigaki Islands by the Ministry of the Environment since 1999 (Marine Parks Center of Japan 2001, International Coral Reef Research and Monitoring Center 2003), voluntary monitoring called "My Point Check" in Yaeyama waters by Yaeyama Coral Reef Conservation Committee since 1999 (Yaeyama Coral Reef Conservation Committee 1999, 2000, 2001）, rapid survey on *Acanthaster* by Okinawa Prefectural government since 2002 (Okinawa Prefecture 2002).

GENERAL PROCEDURE

The spot check method is used to evaluate annual changes of the coral reef condition in broad area using visual assessment of the site which are selected in a target broad area. Observers assess the reefs in the sites during snorkeling according to the monitoring parameters described below. In addition, bottom sediment can be collected during this survey for SPSS (content of Suspended Particles in Sea Sediment）measurement, which is a rapid assessment of sedimentation developed by the Okinawa Prefectural Institute of Health and Environment.

- The observers (two researchers) reach each site by the boat using GPS.
- At the site, each observer record data of the monitoring parameters using the snorkeling around the area covering approximately 2500 m^2 randomly for 15 minutes individually.
- Underwater photographs are taken as visual records.
- The data of both researchers are averaged or compiled, it is used for the analysis.

PERSONNEL AND EQUIPMENTS

- Two observers / researchers (requires snorkeling skills)
- A small boat with motor for the shallow waters
- Map or a hydrographic chart of the area
- A set of snorkeling equipment
- A GPS
- Data sheets: plastic clip board, underwater paper, and pencil (attached with the board with a string)
- Underwater camera (digital camera is convenient)
- A set of equipment for SPSS (= content of Suspended Particles in Sea Sediment) measurement: 250ml -500ml plastic container with seal (as much as number of points), sieve (ca. 4mm mesh), 2 and 5 ml measuring spoon (× 1, respectively), 500 ml plastic bottle with cap (× 1), a funnel, and 30 cm transparency meter.

MONITORING PARAMETERS TO BE RECORDED

The practical parameters for Spot Check method are listed below. A necessary minimum set of the parameters are; 1, 2, 3, 4 and 5 of biological parameters, 11, 12 and 13 of physical environmental parameters, and 15 and 16 of special remarks. Parameters 6, 7, 8, 9, 10 and 14 are more likely for experienced observers. These parameters can be selected depending on the purpose of the monitoring and the capacity of the observers.

(1) Biological parameters ●：***minimum*** ○：***options***

●	1. Live coral coverage (%)
●	2. Dominant lifeform categories
●	3. Number of *Acanthaster planci*
●	4. Dominant size of *A. planci*
●	5. Size range of *A. planci*
○	6. Rate of bleached corals (%)
○	7. Number of juvenile coral colonies (in categories)
○	8. Colonial size of large tabulate *Acropora*
○	9. Number of corallivous gastropods (in categories)
○	10. Number of large sized sessile fishes

(2) Physical environmental parameters

●	11. Geographic features
●	12. Benthic features
●	13. Depth range
○	14. Sedimentation level

(3) Special remarks

●	15. Other disturbances on corals
●	16. Peculiar phenomenon or organisms

Details of these parameters are described below.

(1) Biological parameters

(1)-1. Live coral coverage:

The live coral coverage is the percentage of visually estimated, projected area of live corals on a substrate (attachable substrate for corals, excluding mud and sandy bottom). When live coral cover does not reach 10 %, lesser digit (e.g. less than 10 % or less than 5 %) can be applied. Training using schematic representations of percent cover (fig. 1) is useful for accurate estimation. 15-minutes observation can be divided into 3 of 5-minutes observation to record more detailed information.

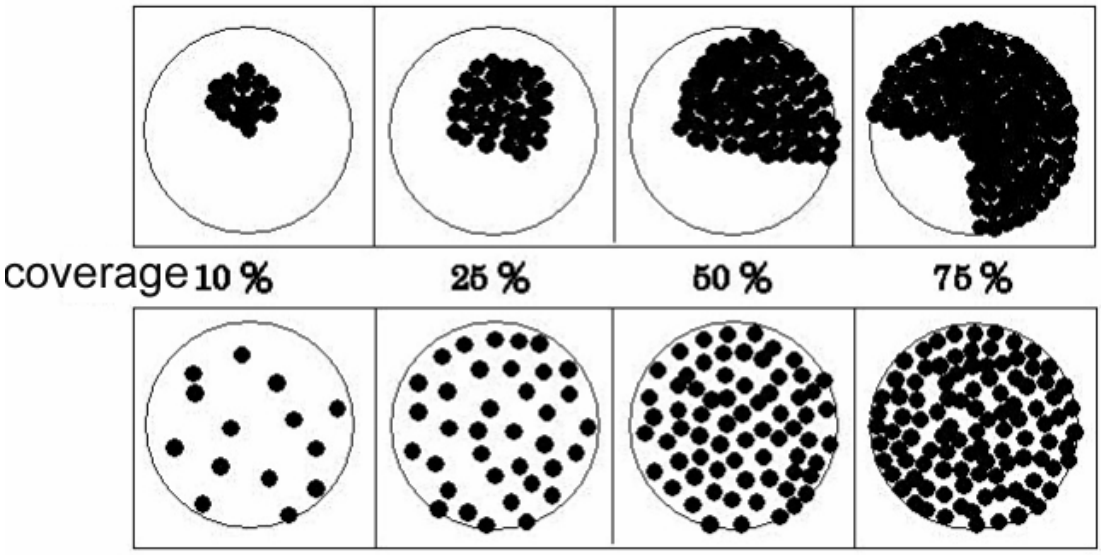


Fig.1 Schematic representations of percent cover. Both circle above and under the % shows same coverage with different patterns of black dots.

* This survey targets all hermatypic corals including Order Milleporina in Class Hydrozoa, Order Stolonifera and Helioporacea in Subclass Octocorallia, Class Anthozoa, and Subclass Hexacorallia in Class Anthozoa. Although soft corals are not included in the coral cover, when they are abundantly observed in the sites, it is recommended to estimate and record their coverage separately.

Table 1. Index of coral reefs' 'health' from the estimated coverage.

Coverage (%)	Evaluation
0-9	extremely poor
10-24	poor
25-49	rather poor
50-74	rich
75-100	especially rich

(1)-2. Types of coral community

Coral communities of the stations are identified into 6 categories focusing on dominant corals. The categories are; 1) branching *Acropora* dominant type, 2) tabulate *Acropora* (including corymbose) dominant type, 3) branching and tabulate *Acropora* mixed type, 4) specific species dominant type (record the dominant species, aside from *Acropora*), 5) multi-species mixed type (no dominant corals), and 6) soft coral dominant type. The term 'dominant' here means, coverage of which exceeds 60%. 'Soft coral' is defines as

all the species belonging to Order Stolonifera (excluding genus *Tubipora*) and Alcvonacea in Subclass Octocorallia. When the station is categorized as “soft coral dominant type”, coverage and dominant species of soft corals are recommended to be recorded.

(1)-3. Number of *Acanthaster planci*

The number of *A. planci* individuals are counted during 15 minutes snorkeling swim. When the starfish have a large population and too many to be counted (e.g., during intensive outbreak), the period of counting can be reduced. The data should be converted to the number per 15 minutes.

$$\text{Number of } A.\ planci \text{ / 15 minutes} = \frac{\text{Number of } A.\ planci \text{ observed x 15}}{\text{Observation time (minutes)}}$$

The number of starfish has to be counted from sea surface during snorkeling, but not to be searched under the corals or the niches. However, when scars of predation were found but not the starfish itself, observers can search for the starfish for affirmation. Table 3 shows the indication of the outbreak from the number of *A. planci* observed.

Table 3. Indication of *Acanthaster planci* outbreak from counted number of individuals during 15 minutes swim.

Count per 15 min.	State of outbreak
0-1	ordinary
2-4	abundant (warning)
5-9	pre-outbreak
< 10	outbreak

(1)-4. Dominant size of *Acanthaster planci*

The dominant size class of observed *A. planci* are recorded in three categories (< 20 cm, 20-30 cm, and 30 < cm). The approximate diameter (from the tip of the arm to another tip at opposite side) can be roughly estimated using a size of hand, or clipboard. When the size class ranges widely, it can be estimated from taking the average of first 10 encountered individuals.

The size estimation of the starfish will help to understand the approximate age of *A. planci* population. In general, *A. planci* reaches up to 20 cm in diameter in two years and start to be matured. The food consumption reaches to maximum after three years and becomes 30 cm or larger. The outbreak becomes obvious at a size class of 20-30 cm or more than 30 cm.

The forecast of *A. planchi* outbreak based on the distribution of juvenile starfish (Yokochi 1988) is tried in Okinawa, so it is recommended to record it as a special remarks, when numbers of juvenile starfish were observed.

(1)-5. Size range of *A. planci*

Record the minimum and maximum diameter of *A. planci* observed during 15 minutes snorkeling.

(1)-6. Rate of bleached corals

It is the rate of bleached and dead (which were considered to have died due to bleaching) colony among total live coral (including dead but which could be considered alive before bleaching) cover. This parameter is taken only when coral bleaching were observed. It is estimated with the formula below.

$$\text{Rate of bleached corals (\%)} = \frac{\text{bleached corals} + \text{dead corals due to bleaching}}{\text{Live coral} + \text{bleached corals} + \text{dead corals due to bleaching}}$$

(1)-7. Number of juvenile corals

The approximate number of juvenile colonies (5 cm or less in diameter) of *Acropora* species found within 1 m^2 on shallow reef flat or patch reefs will be recorded in a category of the followings: 1) non, 2) 1 or 2, and 3) 3 or more. The juvenile colony of 5 cm or less can be considered to have recruited within past two years. The abundance of *Acropora* recruitment will be useful for the foresight of recovery from the serious disturbance of coral communities.

(1)-8. Colonial size of large tabulate *Acropora*

The diameter of 5 largest colonies of tabulate *Acropora* (*Acropora hyacinthus*, *A. solitaryensis*, and *A. cytherea* etc.) will be recorded roughly and will be averaged. The size of tabulate *Acopora* can serve as an indicator on coral reef recovery. Table 2 shows the recovery phase and approximate age of coral community from the size of the largest *Acropora*.

Table 2. Approximate recovery phase and age of coral community from the largest size of tabulate *Acropora* in diameter

Size (cm)	Recovery phase	Approximate age
25 <	initial stage	0-5
25-99	prior stage	5-10
100-199	middle stage	10-15
< 200	later stage	< 15

(1)-9. Number of coral eating gastropods

The number of coral eating gastropod (Genus *Drupella*) will be recorded with the following category:

I) scars of predation are indistinctive,

II) Some small scars of predation can be observed on several corals,

III) Conspicuous scars of predation can be seen on many corals, but large mass of gastropods (more than 100 individuals) has not occurred,

IV) Many coral colonies are dead by the predation and large mass of gastropods can be seen.

The coral eating gastropods especially *Drupella fragum* and *D. concatenata* sometimes cause outbreak and disturbs coral communities considerably as *A. planci*. It occurs predominantly in subtropics areas in the mainland Japan (e.g., Nichinan in Kyushu, Uwakai and Ashizuri in Shikoku, and Kushimoto in Kii Peninsula). *Drupella* can be seen commonly in coral distributed region, but these two species forms a group and acquire mobility, and sometimes forms a mass of several thousands of individuals. When such a group were formed, coral coverage rapidly decreases (Nomura and Tominaga 2001).

(1)-10. Number of large sized sessile fishes

When large sized sessile fishes (e.g. grouper, gilthead, and parrotfish, but excluding migratory fish) of 30 cm or larger were observed, its species name and number of individuals were record. The number of these fishes will indicate fishing pressure around the sites.

(2) Physical environmental parameters

(2)-1. Topographic features

The topographic features of the survey site will be recorded with the following category: moat, patch reef, reef flat, and reef flat (see also Fig. 2). As for non-reefal region, the category can be either; inner bay, outer sea, and offing bank.

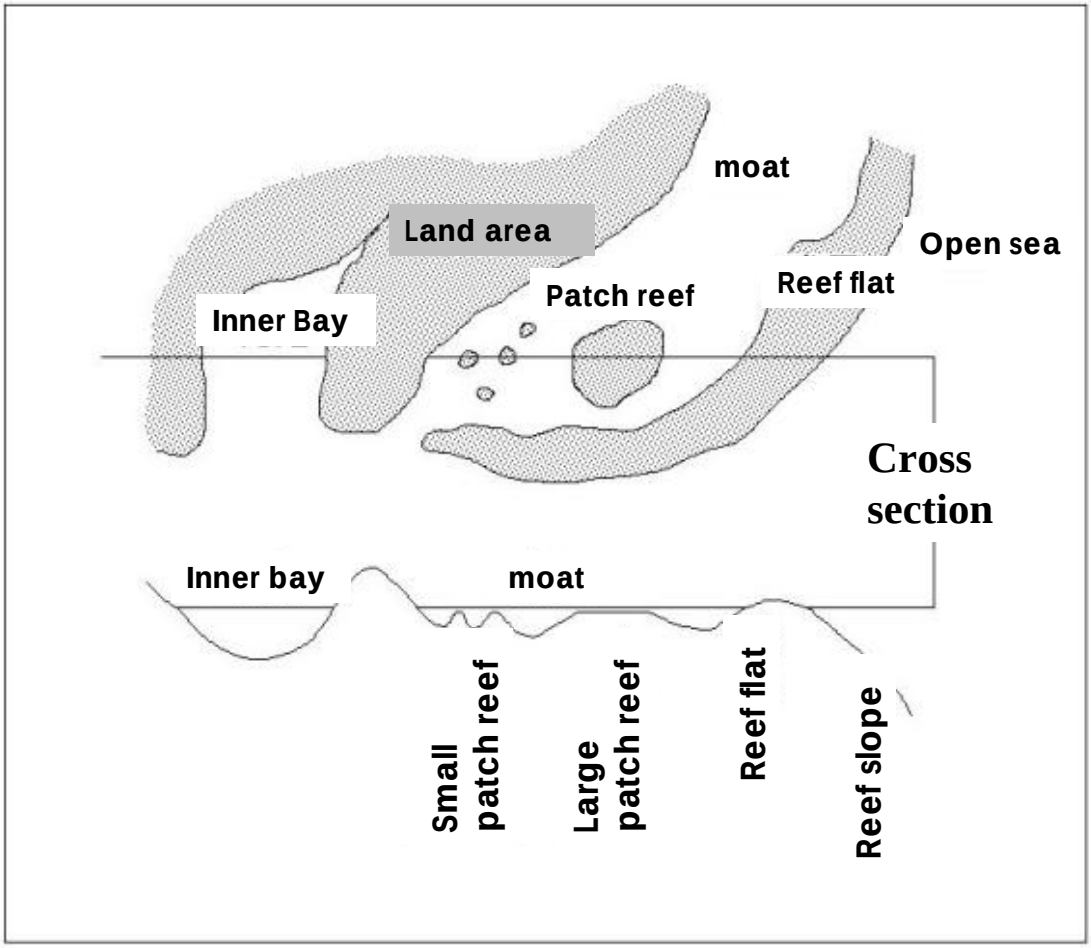


Fig. 2 Topography of the coral reef area

(2)-2. Substrate

The benthic features of the survey site will be recorded with the following category: carbonate, rubble, sand/rubble, sand, and mud.

(2)-3. Depth range

The approximate depth range of the surveyed sites by visual estimation will be recorded.

(2)-4. Level of sedimentation (SPSS measurement)**

Sediment samples is collected at the surface layer of sea bottom of the sites for SPSS. The method was developed by the Okinawa Prefectural Institute of Health and the Environment to monitor red soil pollution in 1985 (Omija 2001; Omija in press). It is also applicable to monitor the sedimentation level of terrestrial soil run-off in mainland as well.

(3) Special remarks

(3)-1. Other coral disturbing factors:

When other coral disturbing factors was recognized, record its factor and extent of the damage. The correspond factors are; eg., Coral bleaching event, *Acanthaster planci*, coral eating gastropods, accumulation of silts, drainage discharges, anchoring damages, and

typhoon destruction.

(3)-2. Peculiar phenomenon or organisms:

Record the encountered peculiar phenomenon (e.g. spawning behavior) or rare species when observed. Special remarks' column can be utilized for such personal notes. When large sized sessile fishes ((1)-10) were observed, record in this column.

COMMENTS

a. Site selection:

Sites are selected based on the fallowing information: A) where high coral coverage or important communities exist, B) where such communities had been recorded, C) where it had been utilized as study sites for other survey and their data are available, and D) where were considered important for long term monitoring. The sites should be selected for long term monitoring, but not a temporary show off the abundance of corals at the sites. Moreover, the location and the number of sites should be selected considering the repeatability for long term, meaning that it can be undertaken once a year without any difficulty. The minimum area is approximately 5 km^2 and less than 10 points per day.

b. Target Area:

The target of this monitoring is basically the area that can be observed during 15 minutes snorkeling and it is estimated about 50m × 50m (2,500 m^2). Although the area does not need to be a square shape, geographical features and approximate scale of the sites should be noted with GPS data to ensure monitoring of he same area. If specific colonies or communities are selected for the monitoring, the approximate area should be recorded every year to and Surrounding area of the target site can be selected as another monitoring site.

c. Timing of the survey:

It is recommended that the survey be conducted during late summer to fall to assess the impact of coral bleaching by high water temperature during the summer. Although the survey is possibly done in other season, it should be fixed in certain time annually to evaluate the change and trend

d. Period of observation:

Observation should be done in 15 minutes basically. To observe larger or smaller area, period of observation could be changed, but the number of *Acanthaster* counted should be calculated into 15 minutes to compare with other sites .

c. Visual record:

Underwater photograph is important data to overview the site and it provides more useful information if the photograph takes the same view of the site from fixed angle of the camera. It is recommended to select an area, which geographically or ecologically represents the site.

d. Use of SCUBA:

Spot check method has been developed for a snorkel survey. When the stations are deeper than 10 m in depth or in turbid water, it is difficult to observe the coral condition with snorkeling from the sea surface. SCUBA could be used for the survey in those conditions. However, there is a difference on the scope between snorkeling and SCUBA survey and the quality of the data also

possibly have difference between these two methods.　It should be noted on the data sheet which method was used for the survey.

e. Measurement of water temperature

Since coral bleaching has been occurred frequently, monitoring of water temperature is an important task for prediction of the impact. There are some reasonable automatic temperature measurement devices, called data logger, has been developed for underwater use. To detect the trend of water temperature, it is recommended to use these devices.

ACKNOWLEDGEMENT

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****PROCEDURE OF SPSS (content of Suspended Particles in Sea Sediment) MEASUREMENT.**

(cited from website of Okinawa Prefectural Institute of Health and the Environment in Japanese, http://www.eikanken-okinawa.jp/suiaka/akatuti/akahp/Spss.htm)

1: Collect the sediments from the surface layer of sandy bottom where it is though to represent the benthic feature of the target site. Fill up the 250 ml measurable container with the sediments, seal it tight, and bring up on the boat. The sediment samples will be collected by two divers respectively on each site, and brought back to the lab.

2: Leave the container still to precipitate fine particles and discard the supernatant water. Sieve the taken sediments through 4 mm mesh and exclude shells and pebbles. Each set of particles received after sieving and some mixture will serve as the analytical sample.

3: Measure out 5 ml of the analytical sample with the 5 ml measuring spoon (use the 2 ml one when it is abound with silts). Pour the sample with clean fresh water into the 500 ml plastic bottle with cap(commercially available 500 ml plastic bottle for drinking water) and mess-up to 500 ml. Shake the bottle intensely to extricate the sediments in water.

4: Leave the container still for one minute. The supernatant fluid will be the test water.

5: Pour the liquid into the 30 cm transparency meter and measure the transparency. When transparency was greater than 30 cm or less than 5 cm, adjustment is necessary.

6: Evaluate the rate of SPSS using below formula.

SPSS = (1.718 / transparency – 17.8) × dilution rate / amount of the sample

The required time for the above procedure is approximately 10 minutes for one sample. It can be done in about 5 minutes when skilled. An adjustment of dilution rate is often necessary when measuring with the transparency meter. The below table (Table 1) shows the correspondent state of the benthic feature with the SPSS level. It is considered that the area is under the red soil pollution caused by anthropogenic factor when the rank was greater than 6. SPSS often show seasonal fluctuations where it tends to be high during and after rainy season and adversely low during typhoon and monsoon seasons due to re-suspension of sediments by the waves. Therefore, such seasonality should be taken into consideration in order to understand the state of the red soil pollution.

Table 1. Relationship between SPSS value and visually observed benthic properties

Rank	SPSS (kg/m^3)	Benthic properties
1	0.0-0.4	Extremely clean and clear
2	0.4-1.0	Fine particles are not easily suspended even when bottom sediment is stirred.
3	1-5	Fine particles can be suspended by stirring the bottom sediment.
4	5-10	Water becomes little turbid when bottom sediment was stirred.
5	10-30	Fine particles can be observed on the surface of bottom sediment by careful observation.
6	30-50	Dust-like fine particles cover the sediment surface.
7	50-200	Sediments such as red soil can be seen at glance. Obvious pollution.
8	200-400	Sedimentation of red soil is remarkable, but sand can still be seen. Obvious pollution.
	400 <	Feet get bogged in mud. Sands can rarely be observed.

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Appendix 4 A list of hermatypic corals in Japan

① This list is based on a table in 'Hermatypic corals of Japan' (Nishihira and Veron 1995).

● Species reported by Veron (1993)
○ Species reported by the followings articles; Tribble and Randall (1986)(Miyakejima), Tachikawa (unpublished), and Tachikawa (1991)(Ogasawara) referenced by Veron (1992). Dai(1991) (Taiwan), Matsumoto (unpublished)(Miyakojima) and other observations.

② Japan Wildlife Research Center added the latest information from the distribution map of 'Corals of the World' (Veron 2000).

◎: Species added from Veron (2000)
×: Species deleted by Veron (2000)

The coral distribution of Miyake Island, Boso Peninsula and Izu Peninsula are not clearly distinguished from other areas on the map in Veron (2000). Therefore coral species for these areas are marked (△), and not counted in the total number of species.
In Veron(2000), the scientific names of some species are changed. This list includes both species name in Veron (2000) and Nishihira and Veron (1995) (＊ is marked in front of scientific name).

③ For reference, the species distributed in the Philippines and Taiwan are shown on the left column on the list.
This list dose not include all the species in those two countries.

Species name	Region															Remarks
	Philippines	Taiwan	Yaeyama Archipelago	Miyako Archipelago	Okinawa Islands	Amami Archipelago	Tanegashima (Osumi Islands)	Amakusa (Kyushu)	Tosashimizu (Shikoku)	Shirahama (Kii Peninsula)	Kushimoto (Kii Peninsula)	Izu Peninsula	Tateyama (Boso Peninsula)	Miyake Island (Izu Islands)	Ogasawara Islands	
【Scleractinia】																
＊ *Acanthastrea amakusensis*			●				●	●	●	●	●	●			○	In Veron(2000), *Micromussa amakusensis.*
Acanthastrea bowerbanki	◎	◎	●	◎	●		◎	●	●	◎	◎	△	△			
Acanthastrea brevis	◎														◎	
Acanthastrea echinata	●	○	●	○	●	●	●	●	●	●	●	△	●	○	○	
Acanthastrea hemprichii	◎	◎	●	○	●	●	●	●	●	●	●	△	△		○	
Acanthastrea hillae	●	○	●	○	●	●	●	●	◎	●	●	△	△			
Acanthastrea ishigakiensis	●	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△		○	
Acanthastrea lordhowensis	●	◎		◎	●	●	●	●	●	◎	●	●	△		×	
Acanthastrea regularis	◎														◎	New Species
Acanthastrea rotundoflora	●	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△	○	◎	
＊ *Acrhelia horrescens*	●	◎	●	○	×										◎	In Veron(2000), *Galaxea horrescens.*
Acropora abrolhosensis	◎	◎	●	◎	●	◎										
Acropora abrotanoides	◎	◎	◎	◎	◎	◎									◎	In Nishihira and Veron(1995), *A. danai.*
Acropora aculeus	●	◎	●	○	●										○	
Acropora acuminata	●	○	●	◎	●										○	In Wallace(1999), *A. sukamoi.*
Acropora akajimensis	●	◎	●	◎	●											In Wallace(1999), *A. donei.*
Acropora anthocercis	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		×	
Acropora aspera	●	○	●	○	●	●	◎	●	●	●	●	△	△		◎	
Acropora austera	●	○	●	◎	●	◎									×	
Acropora awi	◎	◎	◎	◎	◎	◎										
Acropora bifurcata	◎	◎													◎	It was thought the synonym of *A. hyacinthus.*
Acropora brueggemanni	●	◎	●	○	●											
Acropora carduus	●	◎	●	○	●	●									×	
Acropora caroliniana	◎														◎	
Acropora cerealis	●	○	●	○	●	●									×	
Acropora clathrata	●	○	●	◎	●											
Acropora cophodactyla	◎	◎													◎	
Acropora copiosa	●	◎	●	◎	●		●	◎	◎	◎	◎	△	△			
Acropora cuneata	●	○	●	◎	●		●	◎	◎	◎	◎	△	△		◎	
Acropora cytherea	●	○	●	○	●	●									×	
＊ *Acropora danai*	●	◎	●	○	●	●									○	In Veron(2000), *A. abrotanoides.*
Acropora dendrum	●	○	●	◎	◎	◎	◎	●	●	●	●	△	△		×	
Acropora digitifera	●	○	●	○	●	●	×	×							○	In Veron(2000), the mainland type is changed to *A. japonica.*
Acropora divaricata	●	○	●	○	●	●	●	●	●	◎	◎	△	△		○	
Acropora donei	◎	◎														In Wallace(1999), it is distributed southern from Okinawa Island and Ogasawara Islands.

Species name	Region															Remarks
	Philippines	Taiwan	Yaeyama Archipelago	Miyako Archipelago	Okinawa Islands	Amami Archipelago	Tanegashima (Osumi Islands)	Amakusa (Kyushu)	Tosashimizu (Shikoku)	Shirahama (Kii Peninsula)	Kushimoto (Kii Peninsula)	Izu Peninsula	Tateyama (Boso Peninsula)	Miyake Island (Izu Islands)	Ogasawara Islands	
Acropora echinata	●	◎	●	○	●	◎										
Acropora efflorescens	◎	◎	◎	◎	◎	◎										
Acropora elegans			×		×											
Acropora elseyi	●	◎	●	◎												
Acropora exquisita	●	◎	●	◎	●	●										
Acropora florida	●	○	●	○	●	●	●	●	●	●	●	△	△		○	
Acropora formosa	●	○	●	○	●	●									○	In Wallace(1999), *A. muricata.*
Acropora gemmifera	●	○	●	○	●	●									○	
Acropora glauca		○	◎	◎			●	●	●	◎	●	△	△			
Acropora globiceps	◎														◎	
Acropora grandis	●	○	●	○	●	●									○	
Acropora granulosa	●	○	●	◎	●	●									○	
Acropora horrida	●	◎	●	◎	●										×	
Acropora humilis	●	○	●	○	●										×	
Acropora hyacinthus	●	○	●	○	●	●	●	●	●	●	●	△	△		×	
Acropora inermis	◎	◎	◎	◎	◎											It is independent of *A. microphthalma.*
Acropora insignis	●	◎	●	◎	●	●	◎	◎	●	◎	◎	△	△			
Acropora irregularis	◎				◎	◎	◎									In Wallace (1999), *A. sukarnoi.*
Acropora japonica	◎						◎	◎	◎	◎	◎	△	△			The Japanese mainland type is independent of *A. digitifera.*
Acropora kimbeensis	◎	◎	◎	◎												
Acropora kirstyae	●	◎	●	◎	●	◎									×	
Acropora latistella	●	○	●	○	●	●	●	●	◎	◎	◎	△	△		×	
Acropora listeri	●	◎	●	◎	●		●	◎	◎	◎	◎	△	△		◎	
Acropora longicyathus	●	◎	●	○	●										×	
Acropora loripes	●	◎	●	○	●	●	●	●	●	◎	◎	△	△			
Acropora microclados	●	○	●	○	●										×	
Acropora microphthalma	●	○	●	○	●	●									◎	
Acropora millepora	●	○	●	○	●	●									◎	
Acropora mirabilis	●	◎	●	◎	×		×									
Acropora monticulosa	●	○	●	○	●										◎	
Acropora multiacuta	◎														◎	
Acropora nana	●	○	●	○	●	●									×	
Acropora nasuta	●	○	●	○	●	●	◎	◎	◎	◎	◎	△	△		◎	
Acropora nobilis	●	○	●	○	●	●									×	In Wallace(1999), *A.intermedia.*
Acropora palifera	●	○	●	○	●	●									○	
Acropora palmerae	◎	◎	◎	◎												
Acropora paniculata	●	◎	●	○	●	◎										
Acropora parilis	●	◎	●	◎	●	●										
Acropora pichoni	◎	◎	◎	◎	◎											
Acropora pruinosa		◎					◎	●	●	◎	◎	●	△			
Acropora pulchra	●	○	●	○	●	●									×	
Acropora rambleri	◎	◎													◎	
Acropora robusta	●	○	●	○	●	●									○	
Acropora rosaria	◎	◎	●	◎	●	●										
Acropora samoensis	●	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△		◎	
Acropora sarmentosa	●	◎	●	◎	●											
Acropora secale	●	○	●	◎	●	●									×	
Acropora sekiseiensis	◎	◎	●	◎	●	●										
Acropora selago	●	○	●	◎	●	●									×	
Acropora solitaryensis	●	◎	●	◎	●	●	●	●	●	●	●	●	△	○	×	
Acropora stoddarti	●						●	◎	◎	◎	◎	△	△			
Acropora striata	◎	◎	◎	◎	●	●	●	◎	◎	◎	◎	△	△			
Acropora subglabra	●	◎	●	○	●	◎									◎	
Acropora subulata	●	◎	●	◎	●	●	●	◎	●	◎	◎	△	△		×	
Acropora tanegashimensis							●									
Acropora tenella	●	◎	●	◎	◎	◎									◎	
Acropora tenuis	●	○	●	○	●	●									◎	
Acropora teres	●	◎		◎	●		◎	◎	◎	◎	◎	△	△		◎	
Acropora tumida	◎	◎	◎	◎	◎	◎	◎	◎	●	●	●	△	●			
Acropora valenciennesi	●	○	●	○	●	◎										
Acropora valida	●	○	●	○	●	●	●	●	●	●	●	△	△		◎	

Species name	Region															Remarks
	Philippines	Taiwan	Yaeyama Archipelago	Miyako Archipelago	Okinawa Islands	Amami Archipelago	Tanegashima (Osumi Islands)	Amakusa (Kyushu)	Tosashimizu (Shikoku)	Shirahama (Kii Peninsula)	Kushimoto (Kii Peninsula)	Izu Peninsula	Tateyama (Boso Peninsula)	Miyake Island (Izu Islands)	Ogasawara Islands	
Acropora vaughani	●	◎	●	○	●										○	
Acropora verweyi	◎	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△		◎	
Acropora wallaceae	●	◎	●	◎	●	◎										
Acropora willisae	●	◎	●	◎	●	●	◎	◎	●	◎	◎	△	△		○	
Acropora yongei	●	◎	●	◎	●										×	
Acropora sp.1			●													
Acropora sp.2							●									
Alveopora allingi	●	◎	●	○	●											
Alveopora catalai	●	◎	●	◎												
Alveopora excelsa	●	◎	●	◎	●	●	●	◎	◎	●	●	△	△			
Alveopora fenestrata	◎	◎	◎	◎											◎	
Alveopora japonica							●	●	●	●	●	●	●			
Alveopora spongiosa	●	○	●	○	●	●	◎	●	◎	●	◎	△	△		○	
Alveopora tizardi	●	◎	●	○												
Alveopora verrilliana	●	○	●	○	●	●									×	
Anacropora forbesi	●	◎	●	○	●											
Anacropora matthaii	●	○	●		●											
Anacropora puertogalerae	●	◎	●	◎	●	◎									◎	
Anacropora reticulata	●	◎	●	◎												
Anacropora spinosa	●	◎	●	◎											◎	
Anacropora sp.	●		●													
Astreopora cucullata	◎	◎	◎	◎												
Astreopora expansa	◎	◎	◎	◎			◎	◎	◎	◎	◎	△	△			In Nishihira and Veron(1995), *Astreopora explanata.*
* *Astreopora explanata*	●	◎	●	◎			●	◎	◎	◎	◎	△	△		×	In Veron(2000), *A. expansa.*
Astreopora gracilis	●	○	●	○	●	●	◎	◎	●	◎	●	△	△		○	
Astreopora incrustans	●	◎	●	◎	●	●	●	◎	●	●	●	△	△		×	
Astreopora listeri	●	○	●	○	●	●									◎	
Astreopora macrostoma	◎			◎	●		●	◎	◎	◎	◎	△	△			
Astreopora myriophthalma	●	○	●	○	●	●	●	●	●	◎	◎	△	△		○	
Astreopora ocellata	●	◎	●	◎	◎	◎									×	
Astreopora randalli	◎														◎	
Astreopora scabra															◎	
Astreopora suggesta	●	○	●	◎	◎	◎										
Australomussa rowleyensis	●	◎	●	○	●	●										
Barabattoia amicorum	●	○	●	○	●	●	●	●	●	●	●	△	△		○	
Barabattoia laddi	◎														◎	
Blastomussa merleti	●	◎	●	○	●	●										
Blastomussa wellsi	●	◎	●	○	●	●	●	●	●	◎	●	△	●			
Boninastrea boninensis	◎														○	
Cantharellus jebbi	◎														◎	
Catalaphyllia jardanei	●	◎					◎	◎	◎	●	●	△	△			
Caulastrea curvata	●			◎	●											
Caulastrea echinulata	●	◎	●	◎	●	●										
Caulastrea furcata	●	○	●	○	●	●									×	
Caulastrea tumida	●	◎	●	○	●	●	●	●	●	●	●	△	●	○	×	
Coeloseris mayeri	●	○	●	○	●	◎									◎	
Coscinaraea columna	●	○	●	○	●	●	●	●	●	●	●	●	△		○	
Coscinaraea crassa	●			◎	●	●	●	◎	◎	●	◎	△	△			
Coscinaraea exesa	●	◎		◎	●											

Species name	Region															Remarks
	Philippines	Taiwan	Yaeyama Archipelago	Miyako Archipelago	Okinawa Islands	Amami Archipelago	Tanegashima (Osumi Islands)	Amakusa (Kyushu)	Tosashimizu (Shikoku)	Shirahama (Kii Peninsula)	Kushimoto (Kii Peninsula)	Izu Peninsula	Tateyama (Boso Peninsula)	Miyake Island (Izu Islands)	Ogasawara Islands	
Coscinaraea hahazimaensis							●		×		×	×				
Coscinaraea monile	◎	◎	◎	◎	●	◎	●	◎	●	◎	◎	●	△			
Coscinaraea wellsi	●			○	●		◎	◎	●	◎	◎	△	△			
Ctenactis albitentaculata	◎	◎	◎	◎	◎	◎										
Ctenactis crassa	●	○	●	○	●	●										
Ctenactis echinata	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△		◎	
Cycloseris costulata	●	○	●	○	●										◎	
Cycloseris curvata	●	◎	●	◎	●											
Cycloseris cyclolites	●	○	◎	○	●	●	◎	●	◎	●	●	●	●		×	
Cycloseris hexagonalis	●	◎	●	○	◎	◎										
Cycloseris patelliformis	●	◎	●	◎	●		●	◎	◎	●	◎	△	△		×	
Cycloseris sinensis	●	○	●	◎	×											
Cycloseris tenuis															◎	
Cycloseris vaughani	●	○	●	○	●	●	◎	●	◎	◎	◎	△	△		○	
Cycloseris sp.	●						●									
Cynarina lacrymalis	●	◎	●	○	●		●	●	●	●	●	△	△	○		
Cyphastrea agassizi	●	◎	●	◎	●	●									◎	
Cyphastrea chalicidicum	●	○	●	○	●	●	●	●	●	●	●	●	●		○	
Cyphastrea decadia	●	◎	●	○	●	◎										
Cyphastrea japonica	●	◎	●	◎	●	●	●	●	●	●	●	●	△		×	
Cyphastrea microphthalma	●	○	●	○	●	●	●	●	●	◎	●	△	●		○	
Cyphastrea ocellina	●	◎	●	◎												
Cyphastrea serailia	●	○	●	○	●	●	●	●	●	●	●	●	●	○	○	
Diaseris distorta	●	◎	●	◎	●	◎				×					×	
Diaseris fragilis	●	○	●	○	●	◎									◎	
Diploastrea heliopora	●	○	●	○	●										◎	
Echinomorpha nishihirai	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△			In Nishihira and Veron(1995), *Echinophyllia nishihirai.*
Echinophyllia aspera	●	○	●	○	●	●	●	●	●	●	●	●	●	○	○	
Echinophyllia echinata	●	◎	●	○	●	●	◎	●	●	◎	◎	△	△		×	
Echinophyllia echinoporoides	●	◎	●	○	●	●										
* *Echinophyllia nishihirai*	◎	◎	●	○	●	◎	◎	◎	●	◎	◎	△	△			In Veron(2000), *Echinomorpha nishihirai.*
Echinophyllia orpheensis	●	◎	●	○	●										×	
Echinophyllia patula	●	◎	●	◎	●	◎	●	◎	◎	◎	◎	△	△			
Echinopora gemmacea	●	◎	●	○	●	●									×	
Echinopora lamellosa	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Echinopora mammiformis	●	◎	●	○												
Echinopora pacificus	●	◎	●	◎	●	●	◎	◎	◎	◎	◎	△	△			
Euphyllia ancora	●	○	●	○	●	●	●	●	●	●	●		●		○	
Euphyllia cristata	●	○	●	◎	●										◎	
Euphyllia divisa	●		●	○												
Euphyllia glabrescens	●	○	●	○	●	●								○	○	
Euphyllia paraancora	◎														◎	
Euphyllia paraglabrescens							●									
Euphyllia yaeyamaensis	●	◎	●	◎	●	●										
Favia danae	●	◎	●	◎	●		●	◎	●	◎	◎	△	△		◎	
Favia favus	●	○	●	○	●	●	●	●	●	●	●	△	△	○	○	
Favia helianthoides	●	◎	●	◎	●		◎	●	●	◎	●	△	△			
Favia laxa	●	○	●	○	●		●	●	●	◎	●	△	△			
Favia lizardensis	●	◎	●	○	●	●	●	●	●	◎	●	●	△		×	
Favia maritima	●	○	●	◎	●	●									○	

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Favia matthaii	●	◎	●	○	●	●								○	○	
Favia maxima	●	○	●	○	●	●	●	◎	●	●	◎	△	△		○	
Favia pallida	●	○	●	○	●	●	●	●	●	◎	●	△	△		○	
Favia rotumana	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Favia rotundata	●	◎	●	○	●	◎	●	◎	◎	◎	●	△	△		×	
Favia speciosa	●	○	●	○	●	●	●	●	●	●	●	●	●	○	×	
Favia stelligera	●	○	●	○	●	●										
Favia veroni	●	◎	●	○	●	●	●	●	●	●	●	△	△		×	
Favia marshae	◎														◎	New species
Favia truncatus	◎	◎			◎	◎									◎	New species
Favia vietnamensis	◎	◎					◎	◎	◎	◎	◎	△	△			New species
Favia sp.	●				●											
Favites abdita	●	○	●	○	●	●	●	●	●	●	●	●	△		○	
Favites acuticollis	◎	◎	◎	◎	◎	◎										
Favites chinensis	●	○	●	○	●	●	●	●	●	◎	◎	△	△			
Favites complanata	●	○	●	◎	●	●	●	●	●	●	●	●	△		×	
Favites flexuosa	●	○	●	○	●	●	●	●	●	●	●	●	△	○	○	
Favites halicora	●	○	●	○	●									○	○	
Favites micropentagona	◎	◎	◎	◎	◎	◎										New species
Favites pentagona	●	○	●	○	●	●	●	●	●	●	●	●	△	○	○	
Favites russelli	●	○	●	○	●	●	●	●	●	●	●	△	△		○	
Favites stylifera	◎	◎	●	◎	●	●										
Fungia concinna	●	○	●	○	●	●									◎	
Fungia danai	●	◎	●	○	●										◎	
Fungia fungites	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△		◎	
Fungia granulosa	●	○	●	○	●	●										
Fungia horrida	◎	◎	◎	◎											◎	
Fungia moluccensis	●	○	●	○	●											
Fungia paumotensis	●	○	●	○	●	●									◎	
Fungia repanda	●	○	●	○	●	●									×	
Fungia scabra	●	◎	●	○	●											
Fungia scruposa	●	○	●	◎	●	●										
Fungia scutaria	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Fungia spinifer	●			○	●											
Fungia valida			●	○	●	●										
Fungia sp.				○	○											
Galaxea astreata	●	○	●	○	●		◎	◎	●	◎	◎	△	△		○	
Galaxea fascicularis	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Galaxea horrescens	◎	◎	◎	◎											◎	In Nishihira and Veron(1995), *Acrhelia horrescens.*
Galaxea longisepta	◎	◎	◎	◎	◎	◎										New species
Galaxea paucisepta	◎	◎	◎	◎	◎	◎									◎	
Gardineroseris planulata	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Goniastrea aspera	●	○	●	○	●	●	●	◎	●	◎	●	●	△		○	
Goniastrea australiensis	●	○	●	◎	●	●	●	●	●	●	●	●	△	○	○	
Goniastrea deformis							●	●	●	●	●	●	●			
Goniastrea edwardsi	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△		◎	
Goniastrea favulus	●	◎	●	○	●	●	●	●	●	●	●	●	△	○		
Goniastrea palauensis	◎	◎													◎	
Goniastrea pectinata	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Goniastrea retiformis	●	○	●	○	●	●	●	●	●	◎	●	△	△		○	
Goniopora burgosi	●	◎	●	◎	●	◎										
Goniopora cellulosa						●	●	◎	●	◎	◎	△	△			
Goniopora columna	●	○	●	○	●	●	◎	◎	◎	◎	◎	●	●		◎	
Goniopora djiboutiensis	●	○	●	○	◎	●	●	◎	◎	◎	◎	△		○	○	
Goniopora fruticosa	●	◎	●	○	●	◎									○	
Goniopora lobata	●	○	●	○	●	◎	●	●	●	●	●	●	●		○	

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Goniopora minor	●	○	●	○	●	●									◎	
Goniopora norfolkensis	◎	◎		◎	◎											
Goniopora pandoraensis	●	◎	●	○												
Goniopora pendulus	×						●	●	◎	◎	●	△	△		×	
Goniopora polyformis	●							●								
Goniopora somaliensis	●	◎	●	○	●	●	●	◎	◎	◎	◎	△	△	○	◎	
Goniopora stokesi	●	◎	●	◎	●		●	●	●	◎	◎	△	△	○		
Goniopora stutchburyi	◎	○	●	◎	●		◎	◎	●	●	●	△	△			
Goniopora tenuidens	●	◎	●	○	●										◎	
Goniopora sp.			●		●					●						
Gyrosmilia interrupta			×													
Halomitra clavator	◎														◎	
Halomitra pileus	●	◎	●	◎	●	◎									◎	
Heliofungia actiniformis	●	◎	●	○											◎	
Herpolitha limax	●	○	●	○	●	●									◎	
Herpolitha weberi	●		×	×											◎	
Heteropsammia cochlea	●	◎		◎	●											
Hydnophora bonsai		◎	◎	◎	◎	◎	◎	●	●	●	●	●	△			
Hydnophora exesa	●	◎	●	○	●	●	●	●	●	●	●	●	●	○	○	
Hydnophora grandis	◎														◎	
Hydnophora microconos	●	◎	●	○	●	●									◎	
Hydnophora rigida	●	◎	●	○	●	●									◎	
Leptastrea bewickensis	◎	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△		×	
Leptastrea bottae	◎														◎	
Leptastrea inaequalis	●	◎	●	◎	●										×	
Leptastrea pruinosa	●	○	●	○	●	●	◎	◎	●	◎	◎	●	△	○	×	
Leptastrea purpurea	●	○	●	○	●	●	●	●	●	●	●	●	●	○	○	
Leptastrea transversa	●	○	●	○	●	●									○	
Leptoria irregularis	●	◎	●	○	●	●									◎	
Leptoria phrygia	●	○	●	○	●	●									○	
Leptoseris amitoriensis	◎	◎	●	◎	◎	◎										
Leptoseris explanata	●	○	●	○	●	●								○	○	
Leptoseris foliosa	●	◎	●	○	●	●									◎	
Leptoseris gardineri	●	◎	●	○											◎	
Leptoseris hawaiiensis	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△	○	○	
Leptoseris incrustans	●	○	●	◎												
Leptoseris mycetoseroides	●	◎	●	○	●	●	●	●	●	●	●	●	●	○	○	
Leptoseris papyracea	●	◎	●	○	●										◎	
Leptoseris scabra	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△	○	○	
Leptoseris solida	●	◎	●	◎	●		●	◎	◎	◎	◎	△	△		◎	
Leptoseris yabei	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		×	
Lithophyllon lobata	●	◎	●	○	●	●										
Lithophyllon mokai	◎	◎	◎	◎												
Lithophyllon undulatum	●	○	●	◎	●		●	●	●	●	●	△	△			
Lobophyllia corymbosa	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Lobophyllia flabelliformis	◎	◎	◎	◎	◎	◎										New species
Lobophyllia hataii	●	○	●	○	●	●	●	●	◎	◎	●	△	△	○	○	
Lobophyllia hemprichii	●	○	●	○	●	●	●	●	◎	●	●	△	△	○	○	
Lobophyllia pachysepta	●	◎	●	○	●											
Lobophyllia robusta	●	◎	●	◎	●	●	●	●	◎	◎	●	△	△		◎	

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Madracis asanoi							◎	◎	◎	◎	●	○	△			Because it doesn't have the zooxanthella, it is excluded from the hermatypic coral.
Merulina ampliata	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Merulina scabricula	●	◎	●	○	●	●	●	◎	◎	◎	◎	△	△		◎	
Micromussa amakusensis	◎	◎	◎	◎	◎		◎	◎	◎	◎	◎	△	△			In Nishihira and Veron(1995), *Acanthastrea amakusensis*.
Montastrea annuligera	●	◎	●	◎	●											
Montastrea colemani	◎	◎													◎	New species
Montastrea curta	●	○	●	○	●	●	●	●	●	●	●	△	△	○	○	
Montastrea magnistellata	●	◎	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Montastrea multipunctata	●	◎	●	◎	●		●	◎	◎	◎	◎	△	△			
Montastrea salebrosa	◎	◎	◎	◎	◎											
Montastrea valenciennesi	●	○	●	○	●	●	●	●	●	◎	●	△	△		◎	
Montipora aequituberculata	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Montipora altasepta	●	◎	●	◎	◎	◎										
Montipora angulata	●	○	●	◎	●	●	◎	◎	●	◎	◎	△	△		×	
Montipora australiensis	◎	◎	◎	◎												
Montipora cactus	●	◎	●	◎	●	◎										
Montipora caliculata	●	◎	●	○											○	
Montipora capitata	●	◎	●	◎	◎	◎										
Montipora cebuensis	●	◎	●	◎												
Montipora danae	●	○	●	○	●	●	●	◎	●	◎	●	△	△	○		
Montipora digitata	●	○	●	○	●	●									×	
Montipora efflorescens	●	○	●	○	●		◎	◎	◎	◎	◎	●			○	
Montipora effusa	●	◎	●	◎	●	●	◎	●	●	◎	●	△	△			
Montipora foliosa	●	○	●	○	●	●									×	
Montipora foveolata	●	○	●	○	●	●									◎	
Montipora friabilis	●	◎	●	◎	●		●	◎	◎	◎	◎	△	△			
Montipora gaimardi	●	◎	●	◎	●	◎										
Montipora grisea	●	○	●	○	●										◎	
Montipora hirsuta	●	◎	●	◎	●											
Montipora hispida	●	○	●	○	●	●	●	●	●	●	●	△	△		×	
Montipora hoffmeisteri	●	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△		○	
Montipora incrassata	◎	○	●	◎	●	●	●	◎	◎	◎	◎	△	△			
Montipora informis	●	○	●	○	●		●	●	●	●	●	△	△		◎	
Montipora mactanensis	●	◎	●	◎												
Montipora malampaya	●	◎	●	◎												
Montipora millepora	●	◎	●	○	●		◎	●	●	●	●	△	△		×	
Montipora mollis	●	◎	●	○	●	●	●	●	●	●	●	△	△		×	
Montipora monasteriata	●	○	●	○	●		●	◎	●	◎	◎	△	△		○	
Montipora niugini	◎	◎	◎	◎												New species
Montipora nodosa	◎	◎	◎	◎												
Montipora peltiformis	●	○	●	◎	●	◎										
Montipora porties	◎	◎	◎	◎	◎	◎										New species
Montipora samarensis	●	◎	●	◎	●	◎										
Montipora spongodes	●	◎	●	◎			●	●	●	●	●	△	△		○	
Montipora spumosa	●	○	●	◎	●	●	●	◎	◎	◎	●	△	△			
Montipora stellata	●	○	●	○	●	●									×	
Montipora taiwanensis	◎	◎	◎	◎												New species
Montipora tuberculosa	●	○	●	○	●										◎	
Montipora turgescens	●	○	●	○	●	●	●	●	●	●	●	●	△	○	×	
Montipora undata	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Montipora venosa	●	○	●	◎	●	●									×	
Montipora verrucosa	●	○	●	○	●	●									○	
Montipora sp.	●		●		●	●										
Mycedium elephantotus	●	○	●	○	●	●	●	●	●	●	●	●	△		○	
Mycedium mancaoi	◎	◎	◎	◎												
Mycedium robokaki	●		×												×	

Species name	Region															Remarks
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Oulastrea crispata	●	◎	●	◎	●	●	●	●	●	●	●	●	●		×	
Oulophyllia bennettae	●	◎	●	○	●	●										
Oulophyllia crispa	●	○	●	○	●	●	●	●	●	●	●	△	△	○	○	
Oulophyllia levis	◎	◎	◎	◎	◎	◎									◎	It was thought the synonym of *O. crispa.*
Oxypora crassispinosa	◎														◎	
Oxypora glabra	●	○	●	○											◎	
Oxypora lacera	●	○	●	○	●	●	●	●	●	●	●	●	△		×	
Pachyseris gemmae	●		×		×											
Pachyseris rugosa	●	○	●	○	●	●									○	
Pachyseris speciosa	●	○	●	○	●	●	●	◎	●	◎	◎	△	△	○	×	
Palauastrea ramosa	●	◎	●	○	●	◎										
Pavona bipartita	●	◎	●	◎	●										◎	
Pavona cactus	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Pavona clavus	●	○	●	◎	●	◎									○	
Pavona danai	●	◎	●	◎	●	◎										
Pavona decussata	●	○	●	○	●	●	●	●	●	◎	●	△	△	○	○	
Pavona duerdeni	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△		◎	In Nishihira and Veron(1995), *P. minuta.*
Pavona explanulata	●	◎	●	○	●	●	●	●	●	◎	◎	●	△		○	
Pavona frondifera	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		◎	
Pavona maldivensis	●	○	◎	◎	●	●	●	◎	◎	◎	◎	△	△		○	
* *Pavona minuta*	●		×	×	×	×	×	×							○	In Veron(2000), *Pavona duerdeni*
Pavona varians	●	○	●	○	●	●	●	◎	◎	◎	◎	△	●		○	
Pavona venosa	●	○	●	○	●	●									○	
Pectinia alcicornis	●	◎	●	○	●	◎									◎	
Pectinia ayleni	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△			In Nishihira and Veron(1995), *Physophyllia ayleni.*
Pectinia lactuca	●	○	●	○	●	●	◎	●	●	●	●	△	△			
Pectinia paeonia	●	○	●	○	●	●	◎	●	◎	●	●	△	△		◎	
Pectinia teres	●	◎	●	◎												
Physogyra lichtensteini	●	○	●	○	●	◎									◎	
* *Physophyllia ayleni*	●	◎	●	◎	◎	◎	◎	●	●	●	●	△	△		○	In Veron(2000), *Pectinia ayleni.*
Platygyra contorta	●	◎	●	○	●	●	●	●	●	●	●	●	△			
Platygyra daedalea	●	○	●	○	●	●	●	●	●	●	●	●	△	○	○	
Platygyra lamellina	●	○	●	○	●											
Platygyra pini	●	○	●	○	●	●	◎	●	●	◎	◎	△	△		○	
Platygyra ryukyuensis	●	◎	●	○	●	●									○	
Platygyra sinensis	●	○	●	○	●	●	●	◎	◎	◎	●	△	△			
Platygyra verweyi	●	◎	●	◎	●	●	●	◎	◎	◎	◎	△	△			
Platygyra yaeyamaensis	◎	◎	●	◎	●	◎										
* *Plerogyra eurysepta*	●	◎	◎	◎	◎	●									◎	In Veron(2000), *Plerogyra sinuosa.*
Plerogyra simplex	◎	◎													◎	
Plerogyra sinuosa	●	○	●	○	●	●									◎	
Plesiastrea versipora	●	○	●	○	●	●	●	●	●	●	●	●	●	○	○	
Pocillopora damicornis	●	○	●	○	●	●	●	●	●	●	●	△	△	○	○	
Pocillopora elegans	◎														◎	
Pocillopora eydouxi	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△		○	
Pocillopora kelleheri	◎	◎			◎	◎	◎									New species
Pocillopora meandrina	●	○	●	◎	●										◎	
Pocillopora verrucosa	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	

Species name	Region															Remarks
	Philippines	Taiwan	Yaeyama Archipelago	Miyako Archipelago	Okinawa Islands	Amami Archipelago	Tanegashima (Osumi Islands)	Amakusa (Kyushu)	Tosashimizu (Shikoku)	Shirahama (Kii Peninsula)	Kushimoto (Kii Peninsula)	Izu Peninsula	Tateyama (Boso Peninsula)	Miyake Island (Izu Islands)	Ogasawara Islands	
Pocillopora woodjonesi	●	○	●	○											◎	
Podabacia crustacea	●	○	●	○	●	●									◎	
Podabacia motuporensis	●	◎	●	×												
Polyphyllia talpina	●	○	●	○	●	●									◎	
Porites annae	●	○	●	○	●										○	
Porites aranetai	●	◎	●	◎	●											
Porites attenuata	●	◎	●	◎	●	●										
Porites australiensis	●	○	●	○	●										◎	
Porites cocosensis	◎	◎	◎	◎												
Porites cylindrica	●	○	●	○	●	◎	◎	◎	●	◎	◎	△	△		◎	
Porites deformis	●	◎	●	○												
Porites densa	◎	◎													◎	
Porites evermanni	●		●		●											
Porites heronensis				◎	●	●	●	●	●	●	●	●	●		×	
Porites horizontalata	●	◎	●	○	●	◎									◎	
Porites latistella	●	◎	●	◎	●											
Porites lichen	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Porites lobata	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△			
Porites lutea	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△		○	
Porites mayeri	●	◎	●	○												
Porites murrayensis	●	○	●	◎	●										○	
Porites napopora	◎	◎	◎	◎	◎	◎									◎	New species
Porites negrosensis	●	◎	●	◎	◎	◎										
Porites nigrescens	●	○	●	○	●	●									◎	
Porites okinawensis				◎	●		◎	◎	◎	◎	◎	●	△			
Porites rus	●	○	●	○	●	●									◎	
Porites sillimaniani	●	◎	×		●	◎										
Porites solida	●	○	●	○	●											
Porites stephensoni	●	○	●	○	●											
Porites vaughani	●	◎	●	◎	●										◎	
Psammocora contigua	●	○	●	○	●	●	●	◎	◎	◎	◎	△	△		○	
Psammocora decussata			◎	◎	●	●										
Psammocora digitata	●	○	●	○	●	●									○	
Psammocora haimeana	●	◎	●	◎	●										○	
Psammocora nierstraszi	●	◎	●	◎	●		●	◎	◎	◎	◎	△	△			
Psammocora obtusangula	◎														◎	
Psammocora profundacella	●	○	●	○	●	●	●	●	●	●	●	●	●	○	×	
Psammocora stellata															◎	
Psammocora superficialis	●		●	○	●	●	●	●	●	●	●	●	●	○	×	
Psammocora vaughani		◎	●	◎	●	◎	◎	◎	◎	◎	◎	△	△	○	○	
Pseudosiderastrea tayamai	●	◎	●	◎	●											
Sandalolitha dentata	◎	◎													◎	
Sandalolitha robusta	●	○	●	○	●	●									◎	
Scapophyllia cylindrica	●	○	●	◎	●	●									○	
Scolymia australis	◎						◎	◎	◎	◎	◎	△	△		◎	The distribution of Ogasawara Islands is uncertain.
Scolymia vitiensis	●	○	●	○	●										×	
Seriatopora aculeata															◎	

Species name	Region															Remarks
	Philippines	Taiwan	Yaeyama Archipelago	Miyako Archipelago	Okinawa Islands	Amami Archipelago	Tanegashima (Osumi Islands)	Amakusa (Kyushu)	Tosashimizu (Shikoku)	Shirahama (Kii Peninsula)	Kushimoto (Kii Peninsula)	Izu Peninsula	Tateyama (Boso Peninsula)	Miyake Island (Izu Islands)	Ogasawara Islands	
Seriatopora caliendrum	●	○	●	○	●	●									◎	
Seriatopora hystrix	●	○	●	○	●	●									◎	
Seriatopora stellata	◎	◎	◎	◎											◎	
Stylaraea punctata															◎	
Stylocoeniella armata	●	○	●	○	●			◎	●	●	●	●	△		◎	
Stylocoeniella cocosensis		◎	●	◎												
Stylocoeniella guentheri	●	○	●	○	●	●	●	●	●	●	●	△	△	○	◎	
Stylophora pistillata	●	○	●	○	●	●	●	●	●	◎	◎	△	△		◎	
Stylophora sp.	●				●											
Symphyllia agaricia	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Symphyllia radians	●	○	●	○	●	●	●	◎	●	◎	◎	△	△	○	×	
Symphyllia recta	●	○	●	○	●	●	◎	◎	●	◎	◎	△	△		×	
Symphyllia valenciennesii	●	○	●	○	●	●	◎	●	●	●	●	△	△		○	
Trachyphyllia geoffroyi	●	◎	●	◎	●		●	●	●	●	●	△	△		×	
Turbinaria bifrons	◎	◎	◎	◎	◎	◎										
Turbinaria frondens	●	○	●	○	●	●	●	●	●	●	◎	△	△		×	
Turbinaria irregularis	●	◎	●	◎	●	●	●	●	●	●	●	△	△		○	
Turbinaria mesenterina	●	○	●	○	●	●	●	◎	●	◎	◎	△	△	○	○	
Turbinaria peltata	●	○	◎	○	●	●	●	●	●	○	●	△	△		×	
Turbinaria reniformis	●	○	●	○	●	●	●	◎	●	◎	◎	△	△		○	
Turbinaria stellulata	●	◎	●	○	●	●	●	◎	●	●	●	△	△		○	
Zoopilus echinatus	●	◎	●	◎	◎	◎										
【None Scleractinia】																
Heliopora coerulea	○	○	○	○	○	○									○	
Tubipora musica	○	○	○	○	○	○									○	
Millepora dichotoma	○	○	○	○	○											
Millepora exaesa	○		○	○	○											
Millepora intricata	○	○	○	○	○	○										
Millepora murrayi	○	○	○	○	○	○										
Millepora platyphylla	○	○	○	○	○	○									○	
Millepora tenella	○	○	○	○	○											
Number of specieses in Nishihira and Veron(1995)	369	203	371	248	348	225	151	98	127	79	95	45	24	43	181	410 species of 77 genera
Number of specieses after new information is added	453	418	409	414	381	291	203	198	197	198	197	44	24	43	231	477 species of 80 genera
(numbers of species except synonym)	446	412	402	408	377	287	199	194	193	194	193	44	24	43	225	469 species of 79 genera

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Appendix 5 Japanese organizations related to coral reef study and conservation

Akajima Marine Science Laboratory

179 Aka, Zamami-son, Shimajiri-gun, Okinawa 901-3311, Japan

http://www.amsl.or.jp/

The major research and studies are focused on the ecology and genetics on hermatypic corals, coral reef conservation, the breeding biology of the tropical and subtropical invertebrates, and submarine mapping.

Amakusa Marine Biological Laboratory, Kyushu University

2231 Tomioka, Reihoku-machi, Amakusa-gun, Kumamoto 863-2507, Japan

http://sciencescc.kyushu-u.ac.jp/ambl/

The organization is focusing on the study of shallow sea ecology and community ecology of marine life. Using the sea in Amakusa area, the studies of coral reefs are conducted on their settlement, growth, distribution and breeding ecology. Experimental laboratory studies are also carried to reinforce the research. The characteristics of non-coral reef are studied by comparing with the coral reefs in Okinawa area. The laboratory is also studying about the diversity and structure of coral communities in Indonesia.

Banda Research Training Station, Tokyo University of Mercantile Marine

Aza miyashiyo, Banda, Tateyama, 294-0308 Chiba, Japan

http://www.tokyo-u-fish.ac.jp/Japanese/University-Outline/research-training-station.html

The station is studying about physiology, ecology, and culturing of hermatypic corals, abalones and seaweeds. Ecological studies of fish, experimental and practical study on fishery, marine environment are also conducted.

Institute of Boninology

Miyanohamamichi, Chichijima, Ogasawara-mura, Tokyo 110-2101, Japan

http://www.ogasawara.or.jp/

The institute is studying about the nature, history, culture of Ogasawara area, as well as their sustainable conservation and use. On the studies of corals, the dispersion of planula larvae of hermatypic corals, and carbon-fixation by zooxanthella are focused on.

International Coral Reef Research and Monitoring Center

Yashima-cho, Ishigaki-shi, Okinawa 907-0011, Japan

http://www.coremoc.go.jp/

As a base station of GCRMN in Japan and in East Asia, the major roles and functions of this center are collecting and providing information of coral reefs. The database holds the information about the reference on coral reef related scientific and management studies, related organizations, and coral reef monitoring data in the covered area. The center also conducts monitoring survey of coral reefs.

Institute of Oceanic Research and Development, Tokai University

3-20-1, Shimizu-Orido, Shizuoka 424-8610, Japan

http://www.iord.u-tokai.ac.jp/

The institute is studying about the lifecycle and ecology of shallow-water fish and their taxonomy.

Ishigaki Tropical Station ／ Seikai National Fisheries Research Institute

148-446,Fukai-Ohta, Ishigaki-shi Okinawa 907-0451, Japan
1551-8 Taira-machi, Nagasaki-shi, Nagasaki 851-2213 Japan
http://www.snf.affrc.go.jp/

The monitoring of the physical environment of coral reef area, fish catch, fishery and other marine life ecology are studied. The research on coral is inquiring about the relation of gene discovery between red soil pollution and coral, and spawning induction of hermatypic corals.

Japan Wildlife Research Center

3-10-10 Iriya, Taito-ku, Tokyo 110-8676, Japan
http://www.jwrc.or.jp/

The center is conducting and coordinating coral reef monitoring in Sekisei lagoon area ,"Monitoring Site 1000" project, and exchanging coral reef related information with neighboring countries as assigned by the Ministry of the Environment. The center also coordinate JICA' s "Conservation and sustainable Management of Coral Reefs", a group training course for developing countries.

Kuroshio Biological Research Foundation

560-I Nishidomari, Otuki-cho, Hata-gun, Kochi 788-0333, Japan
http://www.kuroshio.or.jp/

An inclusive study on propagation of corals is focused in. The study includes practical aquarium for the breeding and keeping corals in several generations, practical collecting and transferring methods of coral spawns in the field, and their releasing method to the sea.

Kushimoto Marine Park Center

1157 Arida, Kushimoto-cho, Nishimuro-gun, Wakayama 649-3514, Japan
http://www.kushimoto.co.jp/

Ecological investigations on the marine life, as well as awareness program on their conservation are conducted in the center. Long-term monitoring for Acropora is also going on.

National Institute for Environmental Studies

16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
http://www.nies.go.jp/

Social and Environmental Systems Division and Water and Soil Environment Division are conducting on remote sensing and ecological researches on coral reefs, respectively, in collaboration with universities and other research institutes (e.g., Japan Aerospace Exploration Agency and Seikai National Fisheries Research Institute).

Ocean Research Institute, University of Tokyo

1-15-1 Minamidai, Nakano-ku, Tokyo 164-8639, Japan
http://www.ori.u-tokyo.ac.jp/

The institute is studying oceanography, biological oceanography, marine-resources study, and physical oceanography.

Okinawa Prefectural Institute of Health and Environment

2085 Ozato, Ozato-son, Shimajiri-gun, Okinawa 901-1202, Japan
http://www.eikanken-okinawa.jp/suiaka/suiaka.htm

The Water pollution & Soil Run off section of the institute is researching about red soil erosion and its effect to coral reefs. Using the research data, the provision of their negative effect to coral reefs is also studied.

Okinawa Regional Research Center, Tokai University

870-277 Uehara, Taketomi-cho, Yaeyama-gun, Okinawa 907-1541, Japan

http://www.iord.u-tokai.ac.jp/

The center is conducting long-term monitoring of dynamics of coral communities.

Research Institute for Subtropics

1 Asahimachi, Naha-shi, Okinawa 900-0029, Japan

http://www.subtropics.or.jp/

The major research and studies are focused on mangrove, present status of coral reefs, bleaching, restoration of coral reefs, and negative impact for coral reefs from terrestrial human activities.

Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus

3422 Sesoko, Motobu-cho kunigami-gun, Okinawa 905-0227, Japan

http://www.cc.u-ryukyu.ac.jp/~tilapia/

The center is conducting physiological and ecological studies on coral reefs and other animals inhabiting in mangrove area.

Shimoda Marine Research Center, University of Tsukuba

10-1, 5-chome, Shimoda-shi, Shizuoka 415-0025, Japan

http://www.shimoda.tsukuba.ac.jp/

The center is focusing on physiological ecology of seaweeds, Acropora corals, lobsters, and the embryology and taxonomy of sea squirt community.

WWF Coral Reef Conservation and Research Centre

3-1-14 Shiba, Minato-ku, Tokyo 105-0014, Japan

http://www.wwf.or.jp/shiraho35vil/index.htm

The center is studying about the present conditions of coral reef environment in Shiraho, Ishigaki area. Continuous monitoring of the red soil specifically accumulated on their study field are conducted.

Yaeyama Marine Park Research Station

136 Kuroshima, Taketomi-cho, Yaeyama-gun, Okinawa 907-1311, Japan

http://www.umigame.net/ymprs.htm

The station is conducting and research and awareness program on the conservation of coral reefs and sea turtles. Coral reef monitoring in Sekisei lagoon, restoration study of coral reefs, and ecological studies of sea turtles.

※ The information is retrieved from the homepages of the organization.

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Note that the Japanese literature marked with * at the end of the reference represents it was translated to English by the JWRC (Japan Wildlife Research Center)

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	SEINO, Satoko	College of Arts and Sciences, University of Tokyo address: 3-8-1 Komaba, Meguro-ku, Tokyo 153-8902, Japan	Column: Toward the revival of Miyakejima after the latest volcanic eruption
	SHIMAZAKI, Hiroto	Social and Environmental Systems Division, National Institute for Environmental Studies address: 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan	Map inside front cover Index map for Chapter 6
*	SHIMOIKE, Kazuyuki	Japan Wildlife Research Center address: 3-10-10 Iriya, Taito-ku, Tokyo 110-8676, Japan	6-1-4-c Other Islands around Okinawa Island 6-1-7-b Sekisei lagoon 6-2-1-a Boso Peninsula
	SUGIHARA, Kaoru	Department of Earth System Science, Fukuoka University address: 8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan	6-2-2-a Iki Islands 6-2-2-b Tsushima Archipelago
*	TAKAHASHI, Keisuke	Biodiversity Policy Division, Ministry of the Environment address: 1-2-2 Kasumigaseki, Chiyoda-ku, Tokyo 100-8975, Japan	4-2 Legal systems 4-3 Environmental education related to coral reefs 4-6 International cooperation 5-2 Approaches for restoring coral reef ecosystems
**	TSUCHIYA, Makoto	Department of Biology, Chemistry and Marine Science, University of the Ryukyus address: 1 Senbaru, Nishihara, Okinawa 903-0213, Japan e-mail: tsuchiya@sci.u-ryukyu.ac.jp	1-3 Distribution of coral reef communities Column: Coral reef development near cities
	UENO, Shinpei	Department of Marine Civilizations, Tokai University address: 3-20-1 Shimizuorido, Shizuoka, Shizuoka 424-8610, Japan	6-2-1-b Izu Peninsula
	YAMAGAWA, Osamu	Iki City Office address: 682 Gonoura-cho-Motomurafure, Iki, Nagasaki 811-5193, Japan	6-2-2-a Iki Islands
**	YAMANO, Hiroya	Social and Environmental Systems Division, National Institute for Environmental Studies address: 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan e-mail: hyamano@nies.go.jp	1-2 Coral reef landforms in Japan 3-2 Remote sensing of coral reefs in Japan 6-1-7-a Ishigaki Island 6-2-2-a Iki Islands 6-2-2-b Tsushima Archipelago 6-2-2-c Oki Islands and Goto Archipelago Figure inside back cover
	YAMASHIRO, Hideyuki	Department of Tourism, Meio University address: 1220-1 Biimata, Nago, Okinawa 905-8585, Japan	2-3 Coral diseases
	YAMAZATO, Kiyoshi	University of the Ryukyus (Professor emeritus) address: 1 Senbaru, Nishihara, Okinawa 903-0213, Japan	Preface

Author name	Affiliciation and address	Chapter / Section /Column
YOKOCHI, Hiroyuki	Institute of Oceanic Research and Development, Tokai University address: 3-20-1, Shimizu-Orido, Shizuoka 424-8610, Japan	2-2 Predation damage to corals 6-1-7-c Iriomote Island and neighboring islands

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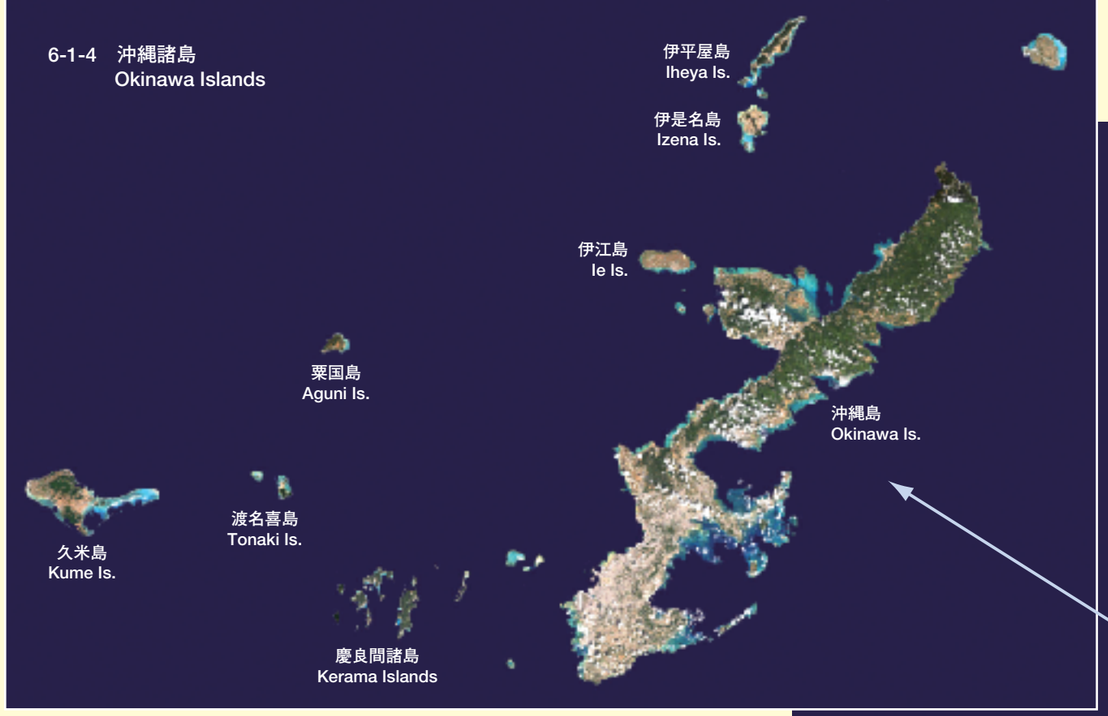
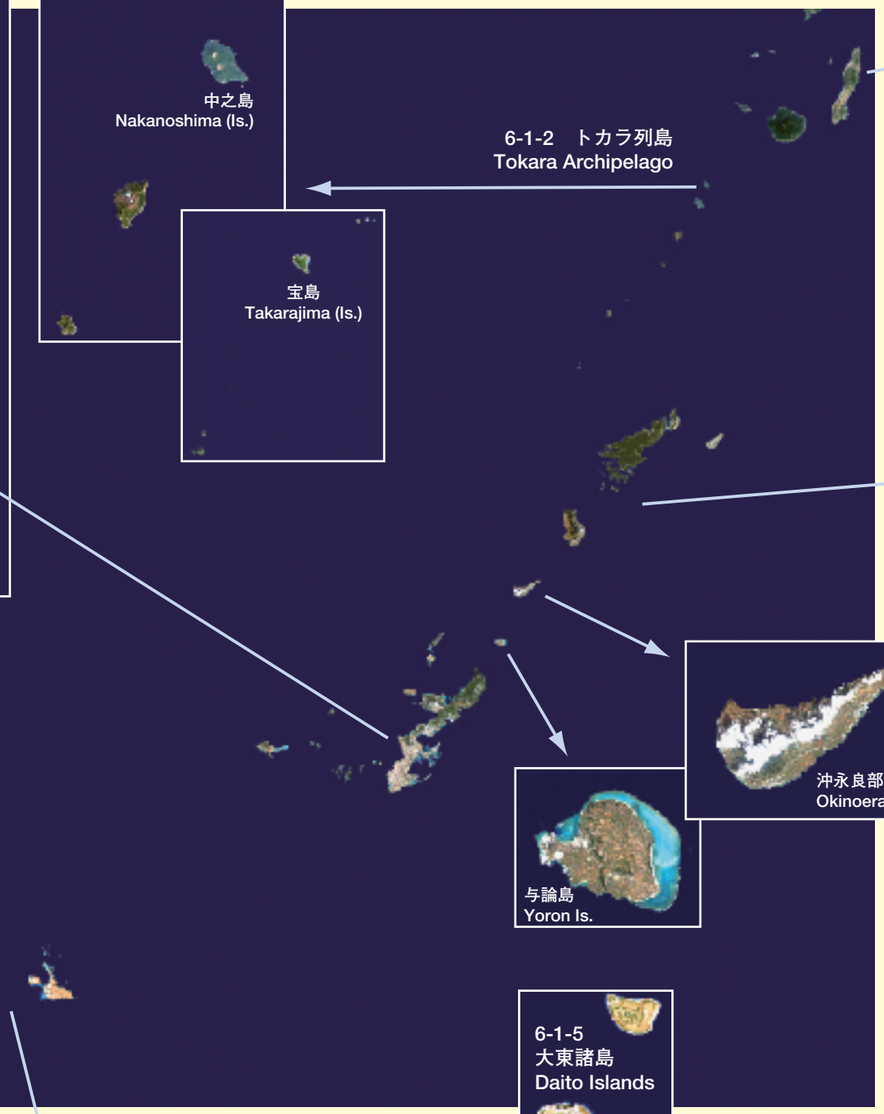
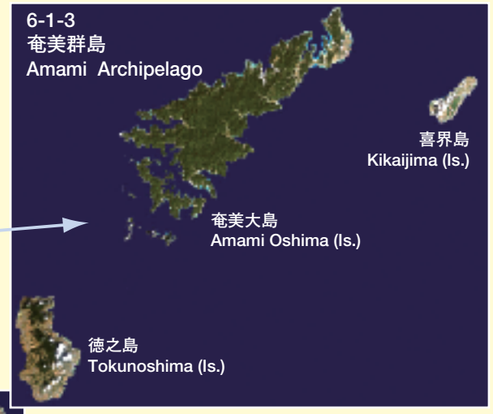
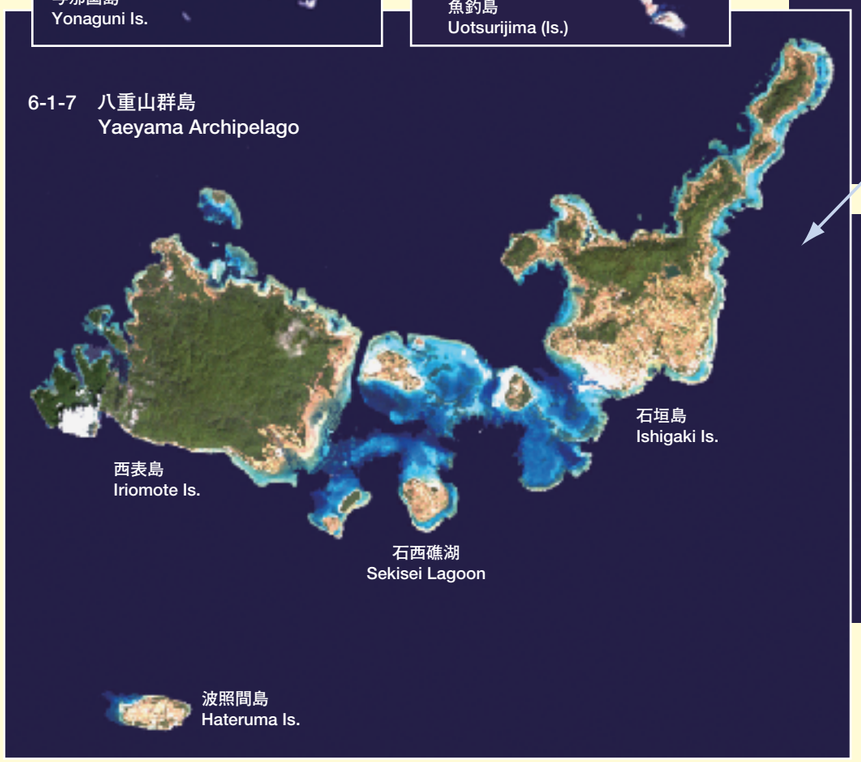
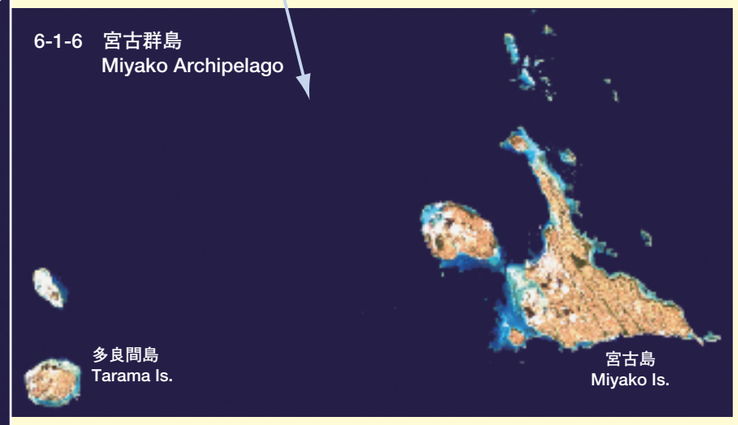


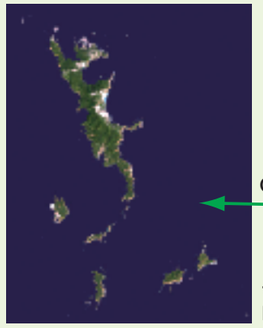


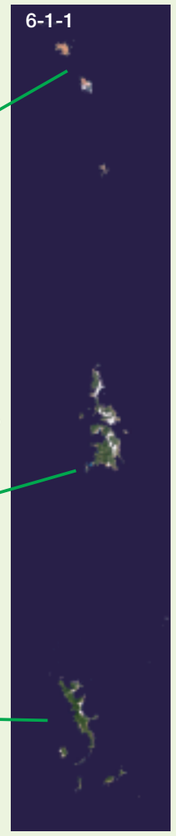






小笠原諸島 Ogasawara Islands





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