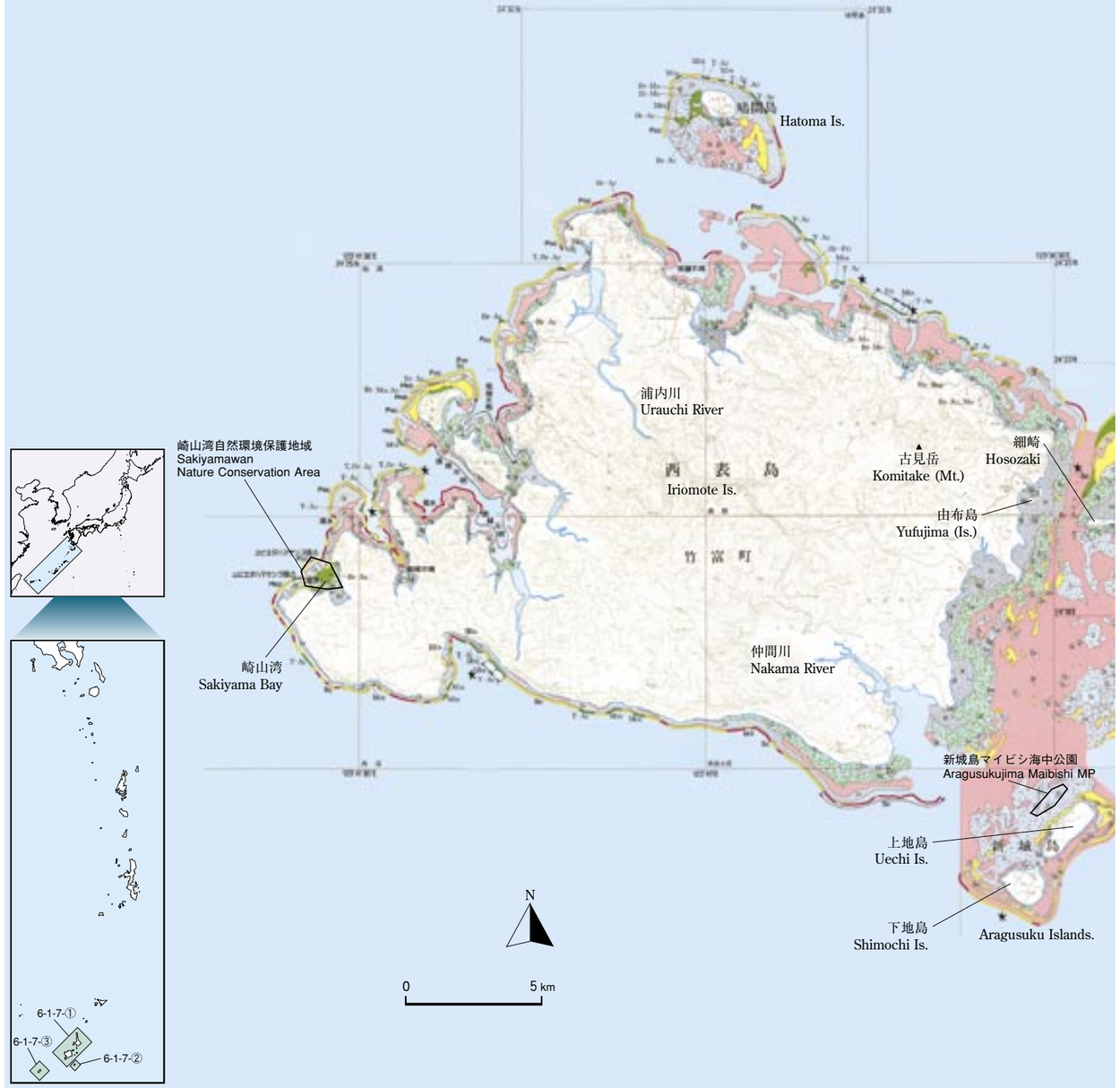
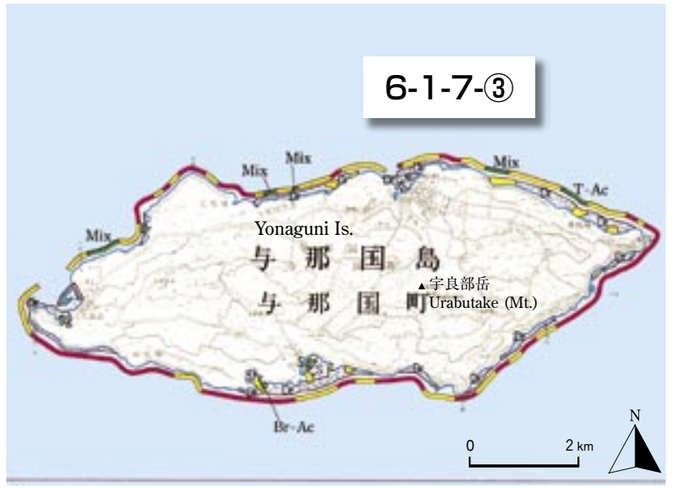
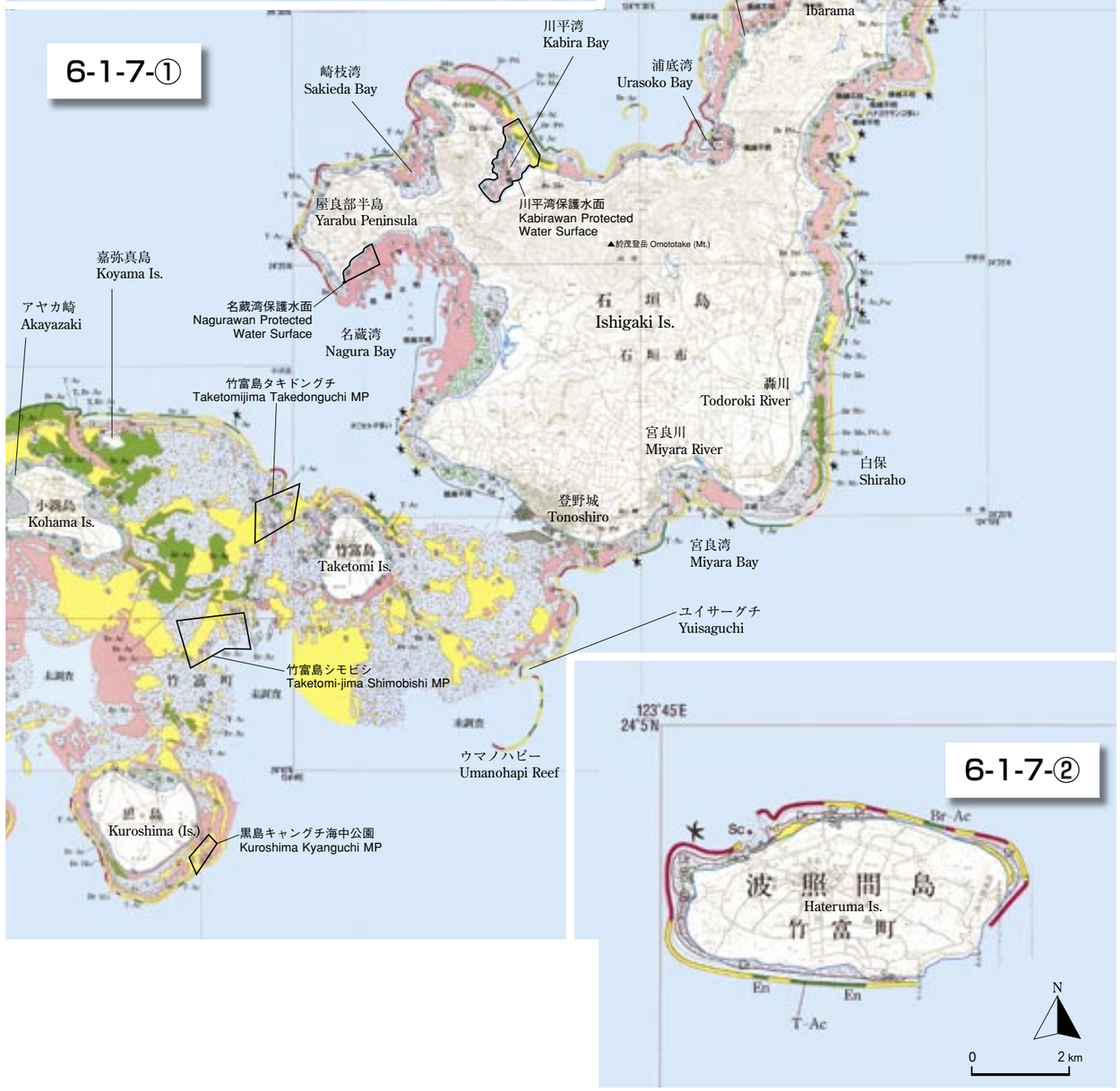
6-1-7 Yaeyama Archipelago
(Map 6-1-7)

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)

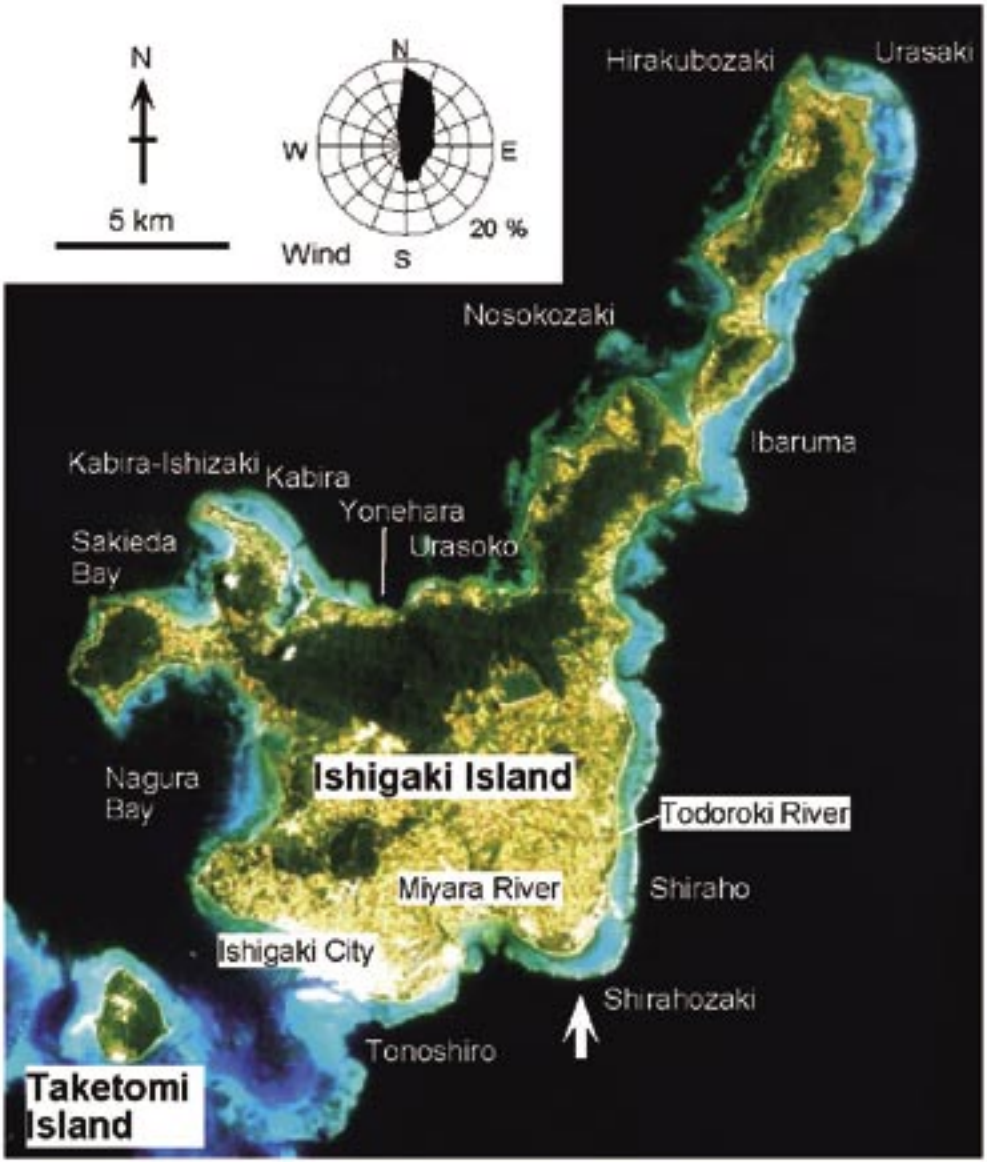


Fig. 1. Landsat TM image of Ishigaki Island (16 May 1994) including wind rose. The arrow indicates the direction in which Photo. 1 was taken.

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 south in summer, and towards the north 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.

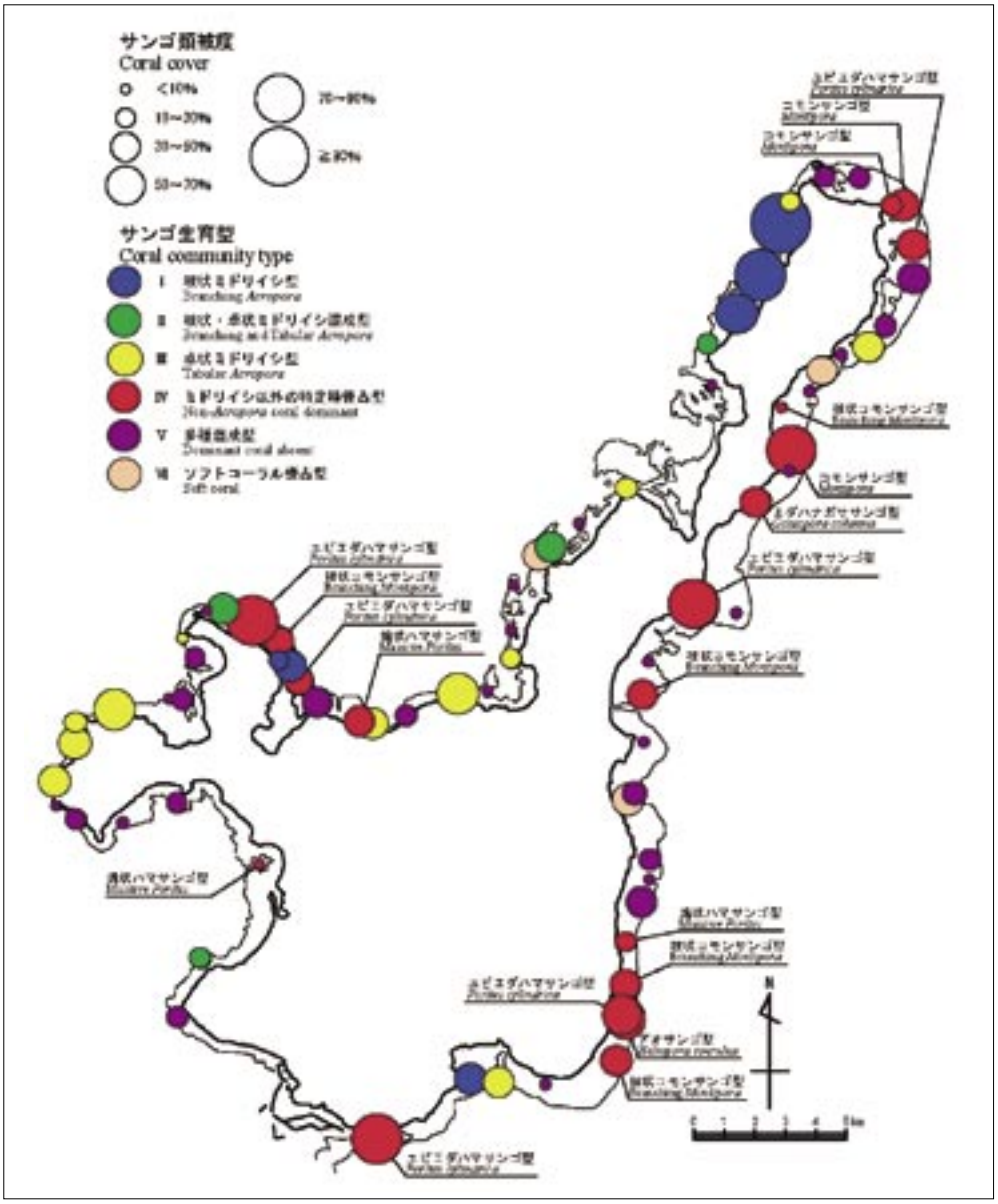


Fig. 2. Area coverage and lifeform of hermatypic corals and soft corals in Ishigaki Island in 2002 (from Nature Conservation Bureau, Ministry of the Environment 2002).

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: thhp://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

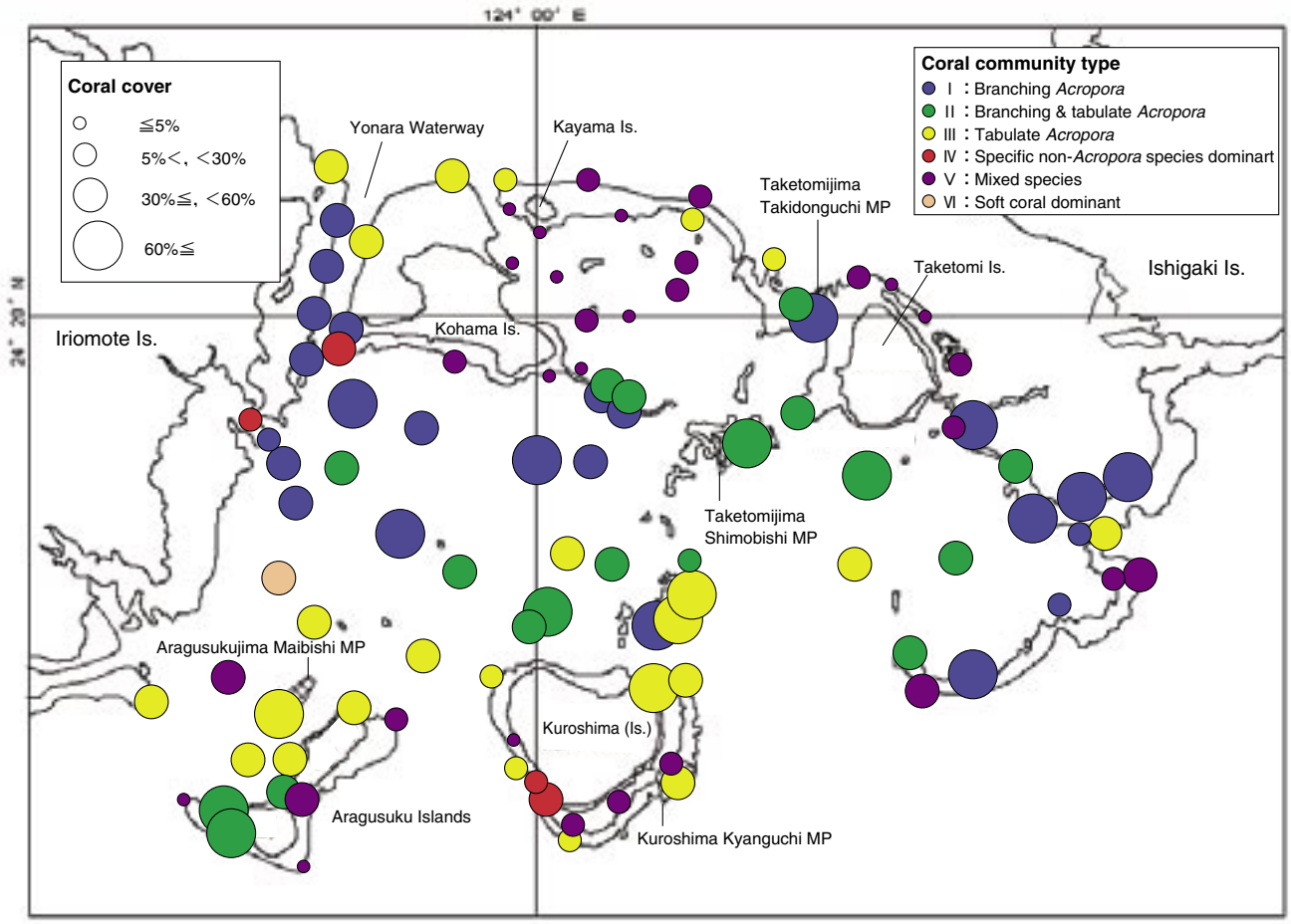


Fig. 1. Hermatypic corals in Sekisei Lagoon in 2002 (from Nature Conservation Bureau, Ministry of the Environment 2003b).

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 2003b).

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 tabulate *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

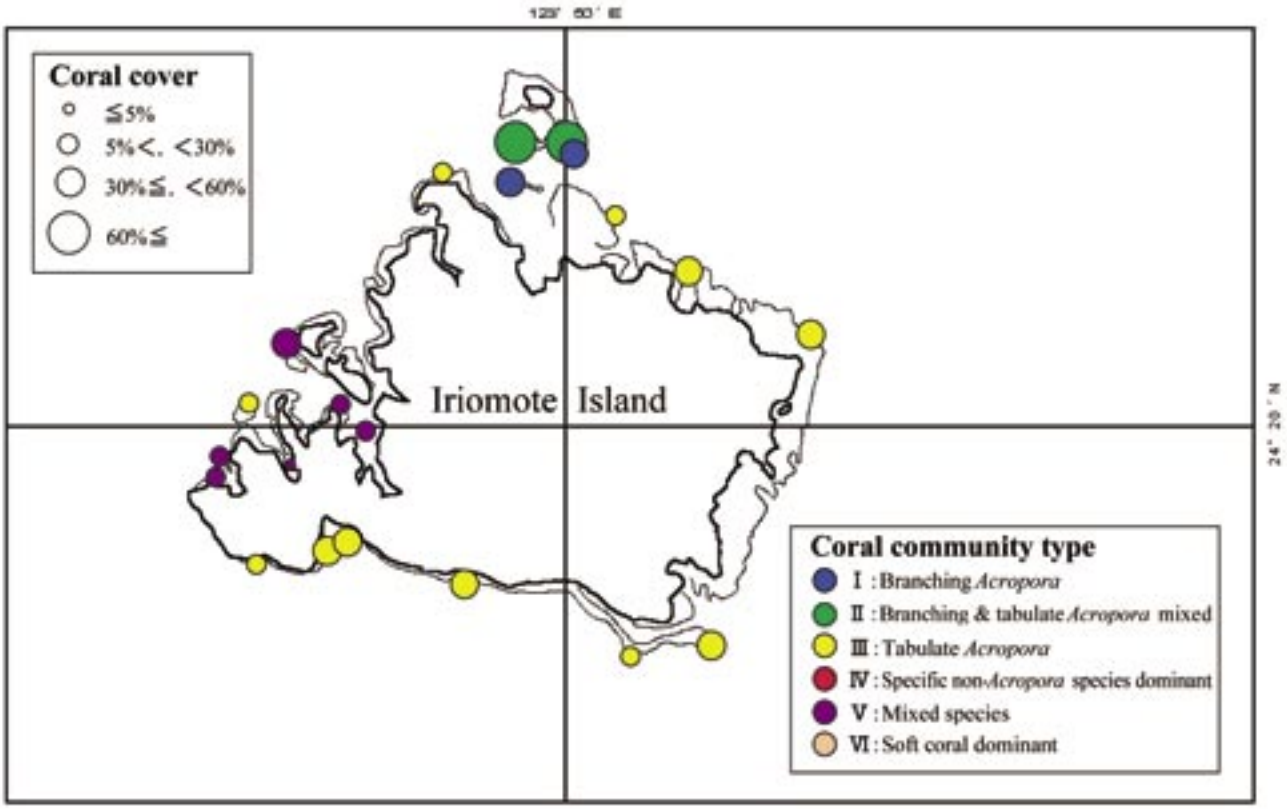


Fig. 1. Area coverage and lifeform of hermatypic corals and soft corals on Iriomote reefs in 2002 (from the Nature Conservation Bureau, Ministry of the Environment 2003b).

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, tabulate 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 (Marine Parks Center of Japan 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 tabulate *Acropora*, occur at some places off the northern coast (Nature Conservation Bureau, Environment 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 (Natural Conservation Bureau, Ministry of the Environment 2002c).

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 (Department of Planning and Development, Okinawa Prefecture 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 (Department of Planning and Development, Okinawa Prefecture 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 2002a; 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, Environment Agency 2000).

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 (Marine Parks Center of Japan 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 2003).

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 between 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 western 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 extermination program. Continuous monitoring of COTS populations is also essential for adequate conservation.