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, Okinawa 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
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