

F-5 Study on the Disturbance and Restoration of Coral Reefs
(Abstract of the Final Report)

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1. Introduction

Coral reefs, which have high productivity and biodiversity, are often called "Tropical forests of the Ocean". They contribute much to us as fishery and recreation area. However, the coral reefs of the world are largely in decline by both natural events (*e.g.* severe storms, outbreaks of crown-of-thorns starfish) and human activities (*e.g.* eutrophication, marine pollution, destructive fishing)^{1), 2)}. In the face of such conditions, preservation of the coral reefs has been recognized as an issue of international gravity.

2. Research Objective

For conservation and management of the coral reefs, we need to scientifically find the data for the coral reefs. Therefore, we carried out studies, which included ecology, chemistry, molecular biology, engineering and physical oceanography, to understand status of disturbed coral reef ecosystems and to accelerate the recovery of coral reefs.

3. Results

1. Evaluation and management of coral reefs

1-1. Evaluation of coral reefs based on sessile organisms

The ecological survey of hermatypic corals and marine plants was carried out at 16 areas along the eastern to southern moat on the Ishigaki Island (24° 25' N, 124° 14' E), the Ryukyus (southwestern Japan), during September of 2000 and 2001. Three 50 m belt transects were laid parallel to the shore (inshore-side, mid-moat and offshore-side) and 1 m² quadrat method was used to investigate the species richness and abundance. A total of 123 hermatypic coral species, belonging to 43 genera and 14 families, and 135 species of marine plants, in which 46 was chlorophytes, 21 phaeophytes, 58 rhodophytes, 6 cyanophytes and 4 seagrasses, were recorded in the moat throughout the present. The number of species and the percent cover of the hermatypic corals are lesser at the inshore-side than at the center and the offshore-side of the

moat. Four taxa of *Montipora*, *Acropora*, *Porites* and Faviidae were predominated in the most survey areas. Coral communities, especially *Acropora* ones, within the moat of the southeastern Ishigaki Island might be continuously destroyed over the past dozen years or so, and marine algae covered luxuriantly on the dead coral fragments and framework. While the species composition of marine plants exhibited the tropical features in which the chlorophytes was abundant and the phaeophytes was rare. Small prostrated algae such as *Dictyota friabilis*, *Lobophora variegata*, Melobesioideae species and *Peyssonnelia* spp. were considered as an biological indicator which could evaluate the recovery process of the hermatypic coral communities and the early stage of the secondary succession of coral reefs. By using the multivariate analysis, some biological indicators of distribution patterns were also recognized along the transverse section of the moat. Monitoring results over the past several years at Urasoko Bay suggested that the coral communities exhibited a remarkable self-sustaining resilience under the good environmental conditions for corals.

1-2. Development of indicators using mobile animals for management of the coral reef ecosystem

A manipulative experiment using small-scale artificial reefs was conducted to quantify the relationship between the degree of degradation of branching corals (i.e., the extent of deterioration of coral reef ecosystems) and fish density at Urasoko Bay, Ishigaki Island. Four types of small-scale, structurally different artificial reefs, including (1) vertical bars with three layers of horizontal bars (type A), (2) vertical bars with a single layer of horizontal bars (type B), (3) vertical bars only (type C), and (4) no bars (type D), were employed for the experiment. The mean number of individuals of damselfishes (Pomacentridae) per replicate varied depending on the reef type. The mean number of individuals on type A was significantly greater than those on the other types, whereas no difference between types B and C was found, and only a few fish were observed on type D.

Practical methods using PVC panels, which were suspended 9-month in the reef of Urasoko Bay, and coral rubble traps, which were placed in the reef of eastern part of Ishigaki Island, were examined to select indicator species of benthic invertebrates. In addition, traps were transplanted between two sites with different turbidity regimes to investigate the sensitivity of species to the environmental variation. Coverage of algae and settlement of mobile invertebrates on the PVC panels were highly variable between the panels. Settlement patterns of mobile invertebrates on the coral rubble traps showed that 2 - 4 week period was sufficient to detect the community structure, and that the abundant species were classified into three groups. The transplant experiment of traps showed that the change of the community structure could be detected by specific responses of several species to the short-term environmental variation. Multivariate analysis on benthic community in the traps at 14 points in the reef of eastern part of the Island showed several clusters and respective indicator species. Some indicator species had good correlations to salinity or turbidity of seawater.

1-3. Study on the environmental management of the coral reef by analyzing the growth and deterioration of individual colonies

As a tool of environmental management of the coral reef, growth and deterioration of individual colonies of two categories, fast growing *Acropora* and slowly growing massive corals, are monitored and modeled. Concerning the former corals we construct an underwater image archives by taking stereo photographs along two transects with permanent quadrat at Kuroshima, Yaeyama Islands, Okinawa, Japan. Inter-annual growth of their outer edges was measured using a PC software to process the stereo images to be as fast as or faster than 5cm/year.

Concerning the latter corals we collected a skeletal specimens of *Porites* sp. at Urasoko Bay, Ishigaki and measured the distribution of Ca/Sr ratio in the line of skeleton using an X-ray fluorescence. The growth speed around 1cm per year was obtained but the water temperature was not accurately evaluated because of the porous structure of the skeleton.

Based on these data, we developed a simplified computer model to simulate the competitive growth of two categories of corals, the fast growing tabular coral and the slowly growing massive coral, assuming the latter is stronger in the inter-colony struggle. The results accounted for the qualitative characteristics in the archives.

1-4. Development of monitoring method on coral stress condition using gene expression

All experiments were performed on the coral *Pocillopora damicornis*. To isolate the red soil responsive genes, the fragments of the coral were exposed to 0 ppm (control) or 500 ppm of red soil, and the gene expression profiles were compared between the two treatments using mRNA differential display technique. Apparent differences were observed in the gene expression profile between the control and the red soil treatment. We cloned thirty-one candidate DNA fragments derived from specifically expressed genes. One of the clones showed significant homology to a member of Hsp70 (heat shock protein) gene family. Reverse transcription-mediated PCR exhibited that the expression of this gene was also increased by elevated temperature, but not by reduced salinity. Full length cDNA cloning revealed that the gene consisted of 2484 bp, comprising open reading frame (2007 bp), which encoded 669 amino acid residues. The deduced amino acid sequence contained RDEL (ER retention signal) in its C-terminus.

2. Restoration of coral communities

2-1. Studies on regeneration of coral community

In order to categorize coral communities using aerial photographs, analysis between coral coverage and images was carried out. Weighed each 50 fragments of *Acropora nobilis*, *A. tenuis*, *A. cytherea* and *A. formosa* have been transplanted for a year at five places where sediment condition was different for researching coral tolerance on sedimentation. Gray value of each RGB band between duplicated images of same coral community on overlapped aerial photographs was analyzed in some coral reefs.

2-2. Study on coral recruitment by larval settlement for reef recovery

The results of observations on larval settlement and metamorphosis under various conditions of temperature and salinity shows coral larvae have ability to settle under wide-ranged conditions of temperature and salinity (18-32°C, 21-51PSU on one species). But the process of skeletal development occurred sequently after settlement as a part of metamorphosis did not

make progress normally under too high/low temperature and salinity. It presumed that the suitable temperature and salinity for coral recruitment are around 26°C/34PSU. The deposition of red soil, even if a little quantity, reduces the percentage of larval settlement, because it reduce the opportunities of contact to inducer and substrata for settlement by covering over the bottom of reef. Some benthic organisms (crustose coralline algae and *Peyssonnelia* species) play efficient for larval recruitment, but others (some sponges) play against. Both efficient organisms have ability to induce for larval settlement, crustose coralline algae is available also for settlement substrata, but *Peyssonnelia* species is not preferred as substrata. The result of the experiment assumed natural bottom revealed that low larval recruitment were expected on area covered with the luxuriance of *Dictyota* and *Lobophora* species.

2-3. Study on environmental factors controlling recovery of coral communities based on the analysis of interaction between circulation and water properties

We chose seven coral reef areas around Ishigaki Island including Hirakubo, Yasurazaki, Urasoko, Shiraho, Miyara, Isobe, and Ohama from north to south. Relatively good condition is reported for coral reefs in the northern part of Ishigaki Island (Hirakubo and Yasurazaki) while coral reefs in the southern part of the island appear to be subject of terrestrial influences (Miyara and Shiraho). In FY 2001-2002, we conducted research on the following topics: 1) water properties of rivers around coral reef, 2) differences in reef water properties among coral reef areas, 3) reef water exchange, and 4) occurrence of relatively high sea-surface temperature (SST) during the summer of 2001.

Major rivers along the eastern coast of Ishigaki Island exhibited high nitrate and phosphate contents, indicating riverine input as a major source of nutrients for coral reefs. Although differences in nitrate and phosphate concentrations in reef water among seven reef sites were not evident, north - south contrast can be seen in silicate and suspended solid (SS) concentrations in reef water. Relatively high SS concentrations were found in the reefs in southern part of the island while low values were observed in the northern reef sites.

We examined capability of a portable turbidity meter for evaluating red soil content in reef sediments as well as suspended solids in reef water. A portable turbidity meter is also applicable for quick measurements of reef waters and the pattern of turbidity was observed in Miyara coral reef area of Ishigaki Island. Positive relationship between salinity and water turbidity can be seen, together with high turbidity in the most inner part of the bay, probably caused by resuspension of terrigenous sediments (red soil). The technique provides a quick method for evaluating reef environment.

3. Discussion

In the ecological survey of hermatypic corals and marine plants, it was evident that the luxuriant growth of marine plants followed a course of decline of the hermatypic coral communities, especially acroporid ones, at the moat of Ishigaki Island. Judging from the distribution patterns of the hermatypic corals and the marine plants, the size of coral colonies, the number of the newly recruited young coral colonies, luxuriant growth of small prostrated

algae, and the high percent cover of dead coral frameworks, in addition to the previous reports, it was considered that the disturbance of the hermatypic coral communities in the moat continued over the past dozen years or so. This suggests that the moat biotope has remained in a permanent state of early succession.

The results of manipulative experiments demonstrated that damselfish density is a reliable indicator of the degree of deterioration of coral reef ecosystems. In addition, the experiment indicated that, to increase fish density by establishing artificial reefs on degraded coral reefs, the structural complexity of artificial reefs, rather than its area, should be considered as a successful ingredient.

Long-term experiment of the PVC panels was not appropriate to detect any indicators because of the high variability. On the other hand, short-term experiment of the coral rubble traps could classify the benthic invertebrates into 3 groups and suggested candidates for indicator species. Application to the east coast of Ishigaki Island showed that indicator species of reef environment could be selected by using the benthic community composition of the traps.

Multivariate analyses were carried out to detect indicator species and environmental gradients by using presence-absence data of 296 species (122 species of corals, 136 species of seaweeds and seagrasses, and 38 species of pomacentrid fishes) at 46 points on the coral lagoon of Ishigaki Island. Cluster analyses revealed five major clusters depending on the variation of species composition and a subsequent analysis detected indicator species of respective clusters. Ordination analyses (MDS and PCA) showed a clear relationship between the major change of species composition and the inshore-offshore gradient of environment. The presence-absence data of each species were regressed against the PCA coordinates of the points. These regression functions can be used to predict the presence (or absence) of species from the coordinate value, and vice versa. Because this method summarizes a multi-species community data into several values, it can be applied to set a numerical goal of a multi-species management in coral reef environment and to evaluate the effects of the management.

Other than the quantitative results, observation of the image archive qualitatively implied that the water movement of the local scale is important in that the sedimentation of the silts on the colonies depends on the stagnation of waters, although it has been pointed out hitherto that the water movements across reef affects the health of the reef. The way coral colonies grow, deteriorate and compete each other is diverse and therefore could not fully described by the macroscopic indicators by the usual census methods but more effectively recorded by the long-term image archiving such as the one in this study.

The result of mRNA differential display showed that red soil affects the gene expression of the coral. One of the genes induced by red soil is assumed to be a member of Hsp70. This gene was induced by elevated temperature but not by low-salinity, which indicates that the set of genes expressed under a stressor is different from that expressed under another stressor, and that it may be possible to distinguish stressors by analyzing stress-responsive genes in corals.

In the aerial photograph analysis, correlation between change ratio of the gray value of each RGB band on duplicated images and coral coverage suggested that high coral coverage

induced low change ratio of the gray value. Relationship between growth of transplanted corals and sediment quantity suggested that sediment influenced coral growth. In the four coral species, *A. nobilis* showed higher tolerance with the lowest mortality and highest growth.

It appears that coral polyps could not always metamorphose on certain temperature/salinity condition that allows larvae to settle. In other words, the suitable condition on metamorphosis is more important for coral recruitment. The deposition of red soil reduces the larval settlement, because it brings down the opportunities of contact to inducer and substrata for settlement by covering over the bottom of reef. Benthic organisms have various influences to larval settlement by each taxon. Thus, the composition of benthic organisms affect significantly to coral recruitment.

The north - south contrast seen in silicate and suspended solid (SS) concentrations in reef water of Ishigaki Island is probably attributed to the difference in land use pattern between southern and northern parts of Ishigaki Island. This trend suggests the possibility of reef water SS content as an indicator of coral reef health. Reef water Chl-*a* concentration, another candidate for a reef health indicator, showed complicated relationships with other reef water constituents and it may not be a good indicator of reef health at least in coral reefs around Ishigaki Island.

Results of multi-station SST monitoring in a unit of coral reef can provide qualitative or semi-quantitative information on water exchange between reefs and the offshore. High SST condition and coral bleaching was also reported from the Okinawa Island area in the summer of 2001. We also observed high SSTs at two stations in Ishigaki Island showing daily mean SST >30°C until the middle of September, 2001

Reference

- 1) Wilkinson, C. (eds.) 1998. *Status of Coral Reefs of the World: 1998*. Aust. Inst. Mar. Sci. 184 pp.
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