F-5 **Study on the selection of biodiversity conservation area of the coral reef (Abstract of the Final Report)**

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Total Budget for FY2003-FY2005 75,695,000Yen (**FY2005**; 19,145,000Yen)

Key Words Coral Reefs, Biodiversity, Conservation area, Management, Restoration

1. Introduction

Coral reefs, which have high productivity and biodiversity, are often depicted as "Oases in the Ocean." They contribute much to us as fishery and recreation area. In recent years, however, the coral reefs of the world are largely in decline by both natural events (*e.g.* severe storms and outbreaks of the crown-of-thorns starfish *Acanthaster planci*) and human-related activities (*e.g.* eutrophication, marine pollution and destructive fishing)[1]. In the face of such conditions, preservation of the coral reefs has been recognized as an issue of international gravity. The effective coral reef management and conservation of coral reef biodiversity is urgently required.

2. Research Objective

We conducted a series of studies on the coral reefs in the Sekisei Lagoon, southern Japan (24° 21' N, 124° 12' E). Initially, we investigated relationships between community structures of coral reef organisms (*i.e.* hermatypic corals, algae and fishes) and physical environment among three typical reefs, Miyara Bay, Shimobishi Reef and Katagwa Reef, in order to evaluate effective biodiversity conservation areas of coral reefs. Secondly, we developed mathematical models to project future individual number of *Acanthaster planci* in the Sekisei Lagoon, aiming to formulate strategy for the adaptive management of Crown-of-Thorns starfish protecting coral communities from devastating damage by *A. planci* predation. Moreover, a numerical simulation of the water flow in the Sekisei Lagoon was performed to predict major source areas of coral eggs and dispersion areas of coral eggs and larvae. Finally, we discussed synthetically strategy to maintain high biodiversity on coral reefs for establishment of marine protected areas.

3. Results and Discussion

1. The evaluation of biodiversity on coral reef communities for the establishment

of marine protected area.

The ecological surveys of hermatypic corals, marine plants and fishes were carried out at 223 survey points on Miyara Bay and on Shimobishi and Katagwa reefs. Miyara Bay has a variety of marine biotopes including a reef slope, reef flat and shallow (2m) moat with branching coral areas and seagrass beds within one kilometer from the shoreline. Shimobishi Reef, one of the lagoon patch reefs inside the Sekisei Lagoon, has a reef slope and reef flat. Katagwa Reef, located at the outer edge of the Sekisei Lagoon, has also many marine biotopes including a reef slope, reef flat and deeper (7-10m) lagoon with branching coral areas and patches.

A total of 297 hermatypic coral species, belonging to 54 genera of 15 families were recorded in this study. Total numbers of species in Miyara Bay and on Shimobishi and Katagwa reefs were 156, 198 and 232, respectively. The percentage coral cover increased at shallower rocky areas, while coral species numbers and Shannon-Wiener index values increased at deeper areas. The distinctive zonation pattern of hermatypic corals was found at both Miyara Bay and Katagwa Reef, while such pattern was not observed on Shimobishi Reef. Areas with high coral diversity and/or cover would be selected as preservation areas of coral communities. Although the species diversity of branching *Acropora* corals is relatively lower in the rubble bottom, these corals may provide living space and/or food for other biota. Therefore, such branching *Acropora* coral areas also may be important as conservation areas.

In Miyara Bay, many fish species were distributed according to diverse environmental characteristics of the reef. Among these species, Pomacentridae was most abundant and inhabited mainly shallow branching coral areas. Most of common species in Miyara Bay were found on the entire Shimobishi Reef. The greatest numbers of fish species and individuals were recorded on Katagwa Reef, which has a variety of marine biotopes. The fish community structure of branching coral areas on the lagoon bottom of Katagwa Reef differed considerably from that n the moat of Miyara Bay, likely because the water depth of the sand bottom of Katagwa Reef was greater than that of Miyara Bay. It seems to be important to conserve the shallow branching coral areas, which provide shelter or food resources for juvenile reef fishes, for the management of coral reef fisheries.

The endemic species of marine plants in Miyara Bay, where had various biotopes, was the most abundant of three survey areas as well as the total species number. In Shimobishi Reef, where the branching corals dominated, many marine algae were growing on and among the branches of branching corals and on the debris derived from dead branching corals. Katagwa Reef had wide and deeper lagoon, so that the species diversity of marine plants was low. It was recognized that marine plants were distributed corresponding to the hermatypic coral community and environmental gradients: the kind and stability of substrata, the exposure of wave action, the emergence and depth. The kind and stability of substrata influenced considerably on the distribution of marine plants and the fact was supported by the multiple analyses of existence and absence data of marine plants. Branching coral community and sandy bottom developed in shallow moat and lagoon, where small organisms like marine algae and various invertebrates used the middle and lower parts of coral branches as the substrata. It was considered that the branching coral community was one of the important conservation areas in the coral reef ecosystem though there was low species diversity of hermatypic corals.

In order to show a priority of area for marine protected areas, the Irreplaceability was estimated among the 223 points in Miyara Bay, Shimobishi Reef and Katagwa Reef. The number of points of the minimum representative combination was 38 points for corals, while 43 points for algae and 59 points for fishes. The distribution pattern of these selected points was different among corals, algae, and fishes. Major relationships between communities of reef organisms and physical environmental variables were analyzed by multivariate methods using the presence -absence data of 242species of corals, 194 species of algae, and 290 species of fishes. Classification of the 223 points showed 12 major communities (corals, algae, and fishes combined). Indicator species for these 12 communities were selected by IndVal method. A distance-based redundancy analysis revealed that relationships between the 12 communities and the four environmental variables (depth, SPSS, sand and rock coverage). Providing the each community is a unit of conservation targets, evaluation of designs of protected areas become possible by the numerical solution of the Irreplaceability values.

The mean numbers of fish species and individuals per transect (40 m^2) did not differ significantly among the four sites in coastal bay and open oceanic areas, the fish assemblage at each comprising seagrass bed residents and coral reef species. A cluster analysis, based on the abundance of each species, showed that the similarity of fish assemblages between the coastal bay and open oceanic areas was relatively high, with 15 dominant species contributing over 80% of the total individual number. These findings indicate that either seagrass beds in coastal bay or open oceanic areas should be preserved for maintaining high levels of fish species diversity of coral reefs.

Six combinations of the seagrass beds in the Sekisei Lagoon covered all of the seagrass-specific species, with the partial exception of the wrasse *Halichoeres melanurus*. However, preservation of coral areas, where both juveniles and adults of that species are abundant, should suffice, thereby making each of the combinations tenable. However, the combinations including the seagrass bed north of Kuro Island supported relatively fewer fish individuals, therefore being less cost effective than the other combinations. In conclusion, in the case that not all of the seagrass beds are able to be preserved for some reason, a combination of those east of Iriomote Island, east and west of Kohama Island and west of Taketomi Island, or the alternative combination of those beds plus that east of Taketomi Island, should be preserved, in order to provide permanent habitats for the overall seagrass fish assemblage.

2. Some fundamental parameters for regulating the environment of protected areas of coral-reef biodiversity

2-1. Water quality and underwater light environment

We conducted a spatial survey on marine CO_2- and nutrient-related parameters on the following three coral reefs of different settings around Ishigaki Island: Miyara Bay, Shimobishi, and Katagwa reefs. In Miyara Bay, high nutrient values were found inshore suggesting the DIN species (NH_4+NO_3+NO_2) and PO_4 were terrestrial in origin. Threshold values for coral reef eutrophication have been proposed based on studies in Kaneohe Bay, Hawaii and Barbados. The threshold concentrations are about 1 μM for DIN and 0.1–0.2 μM for PO_4, and the corresponding chlorophyll *a* concentration range is 0.3–0.5 μg L^{-1} [2]. Observed DIN, PO_4 and chlorophyll *a* concentrations in Shimobishi, and Katagwa Reefs, together with the outer part of Miyara Bay, were lower than the threshold values. However, the chlorophyll *a* concentration measured in the inshore area of Miyara Bay was in the proposed threshold-value range for coral reef eutrophication. Coral reefs examined could be listed in descending order in terms of terrestrial influence as follows: Miyara Bay, Shimobishi, and Katagwa reefs. This order reflects the proximity to the land. We also conducted a preliminary survey on nutrient levels in the Sekisei Lagoon. During the observation period, nutrient levels were slightly higher in the lagoon compared with offshore waters. Because the high chlorophyll *a* content was observed in some parts of the lagoon, we should carefully watch subsequent developments by using an adequate monitoring method.

2-2 Currents and suspended materials in coral reefs

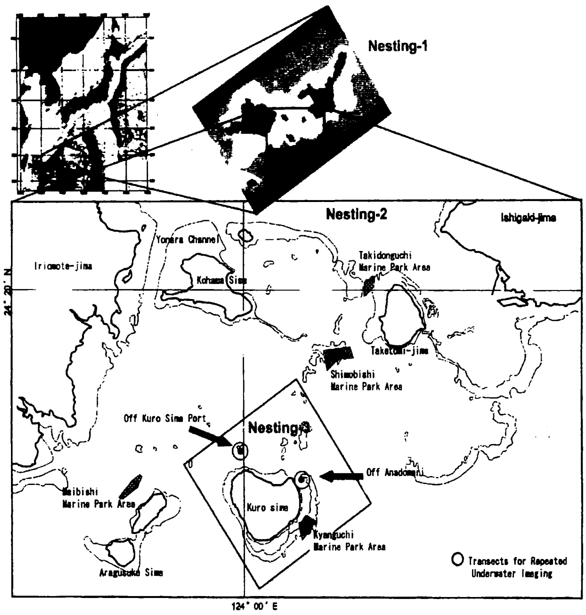
The distributions of sediments and its relation to reef water turbidities were investigated in three fringing reefs along the east coast of Ishigaki Island (Miyara Bay, Shiraho and Yasura) and a patch reef named "Shimobishi" in the lagoon of Sekisei Reef. In order to quantify fine particles in sediments, we employed "SPSS (content of suspended particles in sea sediments) method", which was originally proposed by Ohmija[3] for quick assessment of land-derived soil distribution in reef sediments. We found highest SPSS values in a moat and channel bottom of the Miyara Bay and along the northern coast of the Todoroki River mouth in the north of Shiraho. In contrast, SPSS values were low in other three reefs including Yasura, Shiraho and Shimobishi areas. Reef water turbidities showed significant correlation with SPSS values, which suggests that the major cause of reef water turbidities is resuspension of fine particles in the sediments. Accuracy and precision of the measurements can be increased by using a portable turbidimeter in the original SPSS method that has the potential for applying to a study of underwater light environment, which may influence coral-algal competitions in degrading reef conditions. Principle Component Analysis (PCA) and cluster analysis are available to detect difference or similarity between coastal and offshore coral reefs, after trial use of these methods for analysis for environment dataset of Miyara Bay and Shimobishi. Long-term observation result of water quality for almost one and a half year in the lagoon of Sekisei Reef shows that this reef is currently not in a stage of eutrophication, however, successive monitoring must be needed especially in its northern enclosed sea area.

3. The prediction of coral reef trends

3-1. A coverage dynamic model for coral reefs

Using bootstrap method and observed data, the number of starfish in 2004 was between 217,796 and 21,027. Even using the lower limit of 95%CI, the increasing number of starfish is definitely larger than the number of catch in 2003 (4437 starfish). The population of the Crown-of-Thorns starfish is consistently increasing during 2000-2004. The total effort of culling starfish in 2004 is definitely short for preventing further increase of starfish. The nature restoration project in the Sekisei Lagoon[4] is well designed under the guideline by the Ecological Society of Japan[5].

3-2. Numerical simulation on the trajectory of coral egg and larvae based on the time series of underwater images



We developed the configuration of the model using the nesting technique, where the Nesting-1, 2, and 3 represent the whole Yaeyama area, the Sekisei Coral Lagoon, and the area around the Kuroshima, respectively. The tidal force mainly caused the reciprocating motion whereas the wind force mainly caused directed motion. The latter force was proved to be crucial to the transport of coral larvae. We also simulated the trajectories of particles assuming various spawning area. Considering the wind direction depends on the year, in the case where the particles were released from the central part of the Sekisei Lagoon would generate the highest possibility of particles' residence in the Lagoon. Therefore, the central part of this lagoon would be one of the choices of the prioritized MPA.

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