B-15 **Research on Sustainable Land Management in Atoll Island Countires**
(Abstract of the Final Report)

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Total Budget for FY2003-FY2007 137,206,000 Yen (**FY2006**; 26,913,000 Yen)

Abstract

An atoll island consists of a storm ridge and a beach ridge divided by a central depression with an elevation less than 1m. The island sediment is composed of coral debris and foraminifera sand and others. Foraminifera live on a reef flat and produce a large amount of sand to form island landform. However, they are now strongly degraded by human stresses leading to degradation of sand production potential. Laura Island in Majuro Atoll was formed 2000 years ago triggered by a sea level fall, which was immediately followed by human settlement. People have continuously lived on the island with management efforts of land and vegetation, which has also been collapsed by urbanization.

Wave field simulation and in situ current measurement showed that a long shore current with sedimentation and erosion areas along the inner lagoon coast of the atoll. Remote sensing and GIS are both most effective tools to map time-series change in coastal landform, vegetation and human settlement pattern, and thus they provide most basic information for diagnostics of atoll islands. We constructed a zoning map and a hazard map to assist management plan of the island.

Present problems of the atoll islands are mostly resulted from local issues of population increase and change in economic situation and life style. However, these local stresses has increased vulnerability of the island against the future global changes.

Key Words Atoll, Atoll Island, Sea Level Rise, Landform, Human-nature interaction

1. Introduction

Atoll islands are low-flatted land with a maximum altitude of several meters, which bear limited amount of resources. Thus, their vulnerability to environmental changes is extremely high. Intensive international concern has been gathered and research on possible responses of atoll islands to future sea level rise has been conducted mainly from engineering points of view. However, ecological processes of coral reefs, which form a natural breakwater and provide bioclastic materials as sand to the islands, operate on atoll islands, and maintenance of vegetation by inhabitants also contribute to formation and maintenance process of the islands. On the other hand, modernization and urbanization of atoll islands lead to collapse of these processes in recent years.

For sustainable utilization and development of atoll islands, it is fundamental to evaluate the interaction between natural and human processes by interdisciplinary research among geomorphology, anthropology and coastal engineering. We will establish diagnosis of the present states and future response of atoll islands to environmental changes and propose appropriate adaptation strategy against global changes on the basis of the evaluation. Remote sensing and GIS would provide effective tools to extend the results obtained at model fields to other atoll islands in general.

2. Objective

This research has targeted the following four themes.

(1) **Landform-ecosystem processes** and factors determining land formation.

(2) **Land-human interaction,** a role of human management of island landforms and vegetation, in effective utilization of resources and land.

(3) Present **coastal processes**.

(4) **Remote sensing and GIS** for monitoring and diagnosis.

The scientific results should be **adapted** to local coastal management/conservation plan in view of reducing vulnerability of the islands against sea level rise and environmental changes.

For field surveys, we classified atoll islands in relation to determining factors to atoll island formation and selected representative atolls from this classification. Majuro Atoll in the Marshall Islands, Funafuti Atoll in the Tuvalu Islands (Fig. 1).

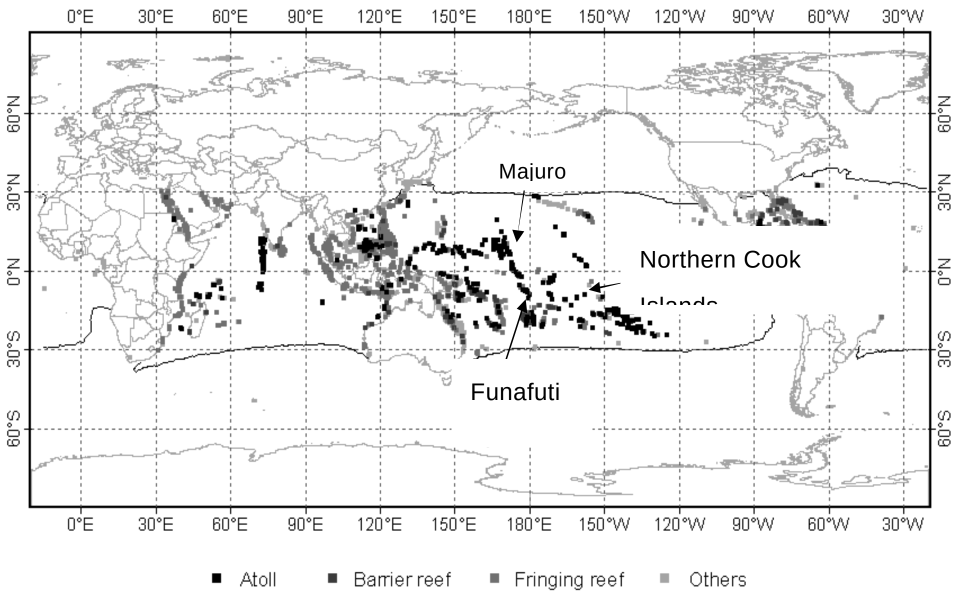

Fig. 1 Study sites.

3. Results and Discussion

(1) Landform-ecosystem processes

Atoll island landform consists of coral reef flat, storm ridge, central depression and beach ridge from ocean to lagoon (Fig. 2). The sediment is composed of coral debris, foraminifera sand and others. The central body of the island was formed to expose its surface above high water level at 2000 years B.P. The formation of the island occurred within 100 years, which was triggered by the eustatic fall of sea level. The island was colonized by a people almost at once its exposure at 2000 years B.P., and continuously has been settled since then. The coincidence of the island formation and people colonization means that the pioneering people migrated to colonize on the almost bare island without dense vegetation just after the exposure above the sea.

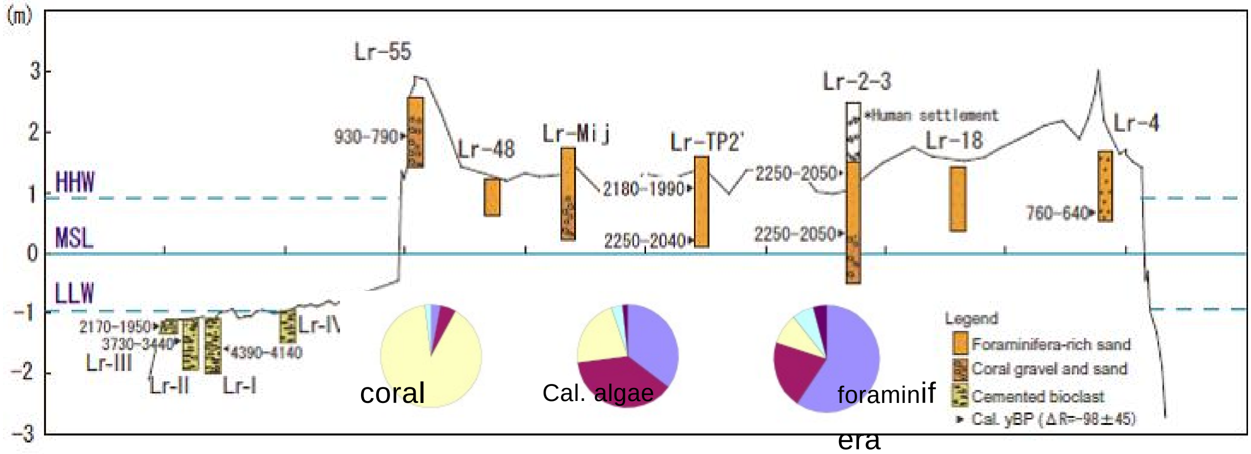

Fig. 2 Geomorphic section with sediment contents of Laura Island, Majuro Atoll.

Tests of large benthic foraminifera are one of the major components of bioclastic sediments in reef islands on many Pacific atolls. However, sources and rates of sediment production by large foraminifera on atolls are not fully understood. In addition, previous studies reported that large benthic foraminifera have recently been absent on reef flats near densely populated atoll islands. However, causality between the decline of living foraminifera and anthropogenic influences is poorly known. We investigated (1) the distribution and annual sediment production of large benthic foraminifera on reef flats of Majuro Atoll, and (2) the present status and causes of population declines of large benthic foraminifera on ocean reef flats from sparsely populated islands through densely populated islands on Majuro Atoll.

Dominant large benthic foraminifers were *Calcarina gaudichaudii* and *Amphistegina lobifera*. Both species were found mainly attached to macrophytes, particularly to turf–forming algae. The population density varied with substratum types and locations. Different distribution patterns were shown by species. Both species were particularly abundant on ocean reef flats and in inter-island channels near windward, sparsely populated islands. However, they were rare or absent in nearshore zones around reef islands, and on ocean reef flats near windward, densely populated islands. Sediment production rates by these foraminifera were highest on ocean reef flats and in inter-island channels near windward, sparsely populated islands (ca. 1 m^3/yr/100 m^2). These results suggest that a combination of physical factors (water motions and water depth/elevation relative to a low-tide level) and the distribution of suitable substratum mainly affect foraminiferal distribution and production.

The population density of large benthic foraminifers declined from reef flats near sparsely populated islands to those near densely populated islands. *Calcarina*, the most dominant foraminifers in the study area, was absent on reef flats near densely populated islands. The decline of foraminiferal density is inversely proportional to the increase in human population on ocean reef flats of NE Majuro. Increasing human populations and activities have resulted in high nutrient loading in groundwater and possibly into nearshore water. Increasing nutrient concentrations may have direct and indirect negative effects on foraminifera, which may result in the decline of foraminiferal density in populated area.

(2) Land-human interaction

1) Human settlement in the context of landform and vegetation history

Atoll islets are most dynamic of earth landforms. They begin as a product of catastrophic storms and remain precariously balanced between the destructive forces of waves, currents, erosion and the constructive efforts of island produced sediments. Five types of islets are recognized based on their morphology, sediments and archaeological evidences. Type A or a fish-hook shaped islet and type C or a saw-toothed islet are more supportable of permanent human settlement among them. The first type of islet is formed on sharp bend of atoll rim at northern end. The recurved sand spits are having been added successively after earlier spits by high wave energy of storms. The second type of islet occurs along the windward atoll rim near reef channels. They grow and shrink but sometimes grow dramatically into habitable land. The first type of islets tend to more stable, if compare with them, and have a significant fresh water lens under ground than that of the second. There are evidences in plenty to show that well developed village life have been established after 1000 years ago in the northern Cook atolls. The vegetation pattern has remarkably changed after human settlement started. The salt-tolerant beach species have been replaced with the non-tolerant species transported by human hands at the considerable portion. In the prehistoric time, people moved into the south-pacific brought with them seeds and saplings of many plants, including taro, pulaka, banana roots, bread-fruits, coconut, pandanus and other useful plants for architecture and medicine. At least 25 species, almost a half of 52 vascular plant species confirmed on Pukapuka atoll, are introduced.

People have elaborately managed useful plants and protected the local wild-life which includes many species of sea-birds, sea-turtles and coconut crabs along with domesticated animals based on that sustainable agro-forestry. And we should know people put their force to special protection and management for the beach vegetations that protect the coastal line and prevent its erosion. It can be said a big environmental change have occurred after the copra industry collapsed and the agro-forestry management has ended in 1980’.

2) Case study at Laura Island, Majuro Atoll

In the mid-Holocene period, the paleoreef had grown up to the highstand sea level over the bedrock of Pleistocene limestone. It has been generally agreed that the Holocene reef started to emerge sometime after around 2000 yr BP (Tracey and Ladd 1974; Buddemeier et al. 1975) and was fully exposed when the subsequent decline of sea level first carried its high-tide level below the mid-Holocene low-tide level. This “crossover” date is estimated to be around 1100 AD for the Marshall Islands (Dickinson 2003). Our geoarchaeological evidence, however, indicates that wave buildup sediment rapidly formed the subaerial core of Laura on Majuro Atoll, on which the earliest islanders colonized and established habitations around 2000 yr BP. Monocotyledonous trees such as *cocos* and *pandanus* had probably already grown on even the emergent land. The people, who appear to have moved northward from Melanesia, may have cultivated wet taro, probably *Cyrtosperma*, in low-lying natural swamps on the basis of their own knowledge brought from the late Lapita cultural tradition. Some centuries later, they deliberately excavated agricultural pits to exploit the freshwater resource, and probably planted on the spoil banks tall trees of Pacific rosewood (*Cordia* spp.) and Chinese lantern (*Hernandia* spp.) as well as pandanus and coconut trees, the organic matter of which would have been also used as green fertilizers. However, there is no evidence that breadfruit trees existed there in this period.

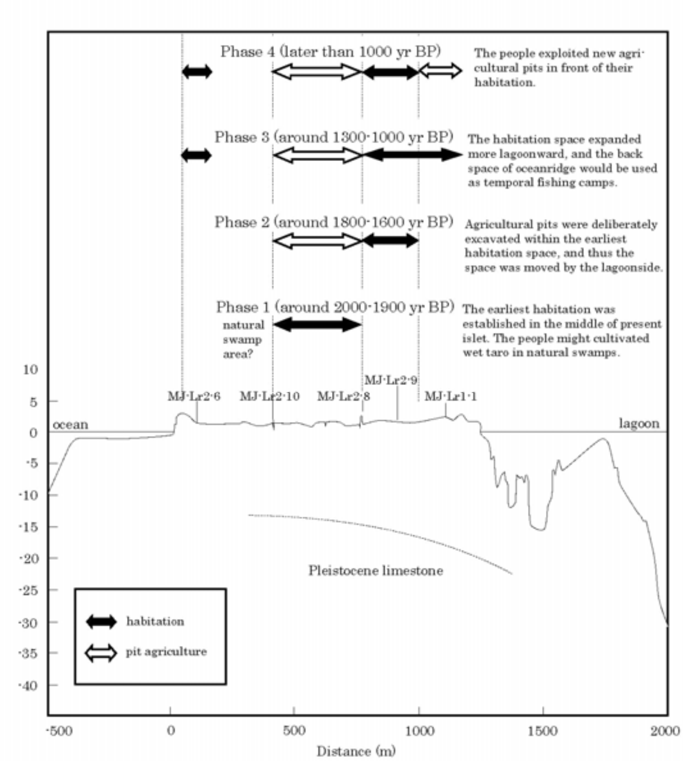

Fig. 3 Landscape history of Laura Island , Majuro Atoll.

The subsequent sea-level fall in the late Holocene probably enlarged the foraminiferal sediment and thus the islet extended its landform both oceanward and lagoonward as well as along the north–south axis. The land accretion caused its inhabitants to increasingly extend their activity space and caused the reallocation of habitations. It would also have enlarged the volume of the freshwater lens, and thus its thickest portion moved lagoonward. The enlargement of the freshwater lens enabled more construction of agricultural pits even in the area just behind the lagoonside beach ridge. The present landscape of Laura would have been formed by around 1000 yr BP. Detailed geoarchaeological synthesis can more precisely elucidate the chronological relationship between islet accretion and expansion of human activities.

In general Oceanic atolls have been stereotyped in both natural and anthropological sciences as the most precarious landform and the severe environment for any human settlement. Recent archaeological investigations in Marshall Islands, Eastern Micronesia, however, have revealed that some atoll islets possessed long-term human settlement history dating back to ca. 2000 yr. BP. The historical interaction of human agency with atoll environment should be scrutinized to properly comprehend the local diversity of atoll conditions and of the present and future influences cause by global warming.

(3) Present coastal processes

Coastal areas, which are quite important for the land maintenance processes, are affected by both of the external forces due to waves and currents and the land cover changes due to human settlement impacts. The purposes of the sub-theme 3-2 were 1) to investigate the flow fields on the coasts of atolls, and the beach topographic changes of atoll islets, and to simulate the coastal changes due to waves and currents affected by the climate change and the sea-level rise by using a numerical model, and 2) to make a zoning map incorporating coastal vegetation and land use characteristics toward sustainable coastal land management, and to analyze the coastal vegetation environments.

1) Beach topographic surveys and current measurements

In order to assess the ratio of beach erosion and deposition around Laura islet, we selected nine survey lines to survey beach profiles. Comparing the profiles surveyed by SOPAC in 1997 and 1998, we detected the ratio of erosion and deposition at the survey lines for 1997-2006. These results of erosion and deposition along the Laura coasts were almost consistent with the results of sand budgets calculated by the wave field simulations around Majuro atoll in 2005. There were, however, still gaps between the calculated sand budget and the surveyed profile. The effects of tidal currents on waves should be included in the wave field simulation.

2) Zoning map and land cover changes

A zoning map of Laura islet were proposed based on the ground levels and land covers surveyed in the field investigations in 2006. Geographical features and land cover of the coastal zone was able to be divided by using ground truth data acquired in filed investigation, GPS-image, satellite image (IKONOS). The map highlighted the characteristics of Laura coasts, and suggested that countermeasures to beach erosion should be most important at the tip of Laura, and that around the tip coastal vegetations should be cultivated, in order to preserve the natural and human environments on Laura coasts.

(4) Remote sensing and GIS

In order to understand the maintenance mechanism of atoll reef islands and to evaluate the vulnerability to global warming, four topics were examined by using remote sensing and GIS: 1) generation of geographic information, 2) typology of environment and reef-island structure, 3) vulnerability assessment, and 4) prediction and application to adaptive measure. For the topic 1), GIS database for natural (climate) and human environments was generated. In addition, the ability of remote sensing techniques for mapping atoll reef-islands was evaluated. For the topic 2), typology of marine environment surrounding the islands was presented to select the fieldwork sites. Typology of atoll reef islands by satellite sensor data was also present. As a result, a framework to apply adaptive measures examined in the fieldwork sites to atoll reef islands worldwide was set up. For the topic 3), we used data spanning 108 years to reconstruct changes in topography, land use/cover, population, and the distribution of buildings at Fongafale Islet, Tuvalu, which suffered flooding during high tides. The results indicate that the vulnerability of Fongafale Islet relates to its original landform characteristics. Our results clearly demonstrate that present-day vulnerability of atoll islands is caused by combination of global-scale and local-scale factors. For the topic 4), we developed a statistical model that quantitatively relates island area of 213 individual atolls in the Indian and Pacific oceans with physical climate and local-scale variables, including the biological productivity of sediments. We highlighted the importance of proper local-scale management strategies, including conservation of coral reefs to maintain carbonate sediment production, in order to help maintaining islands in an era of global warming. Based on the importance of local management and historical images, we have generated a hazard map to help local people's adaptive measure to global warming (Fig. 4).

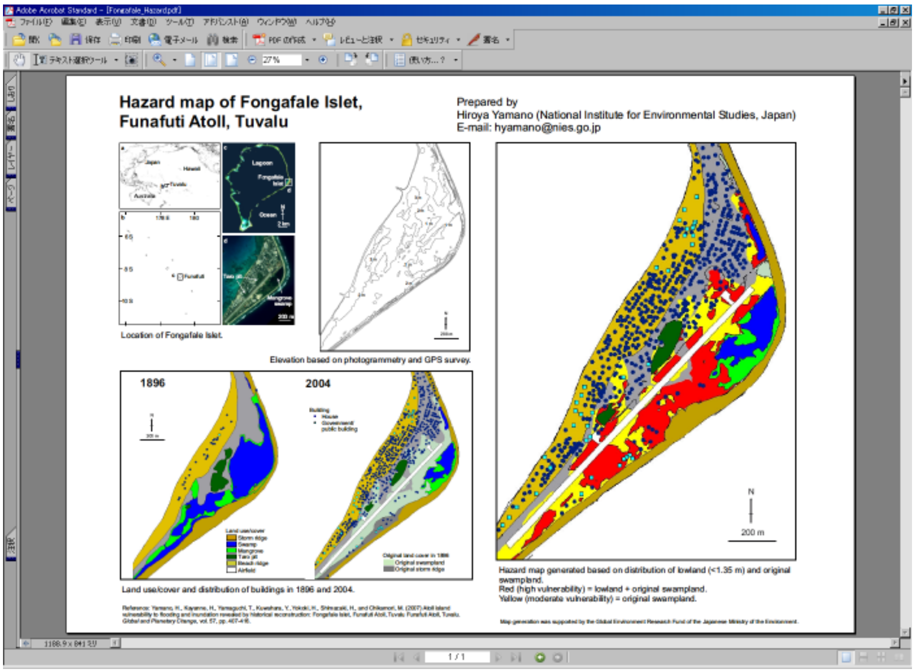

Fig. 4　A hazard map prepared for Fongafale Islet, Tuvalu, indicating the vulnerable areas for sea-level rise. This map was generated based on historical data for original swampland and present-day distribution of lowlands.

4. Recommendation for Sustainable land management of atoll islands

At the end of this project, we held an international workshop on "Sustainable land management of atoll islands" to exchange information and to ask for international review. The participants of workshop agreed to declare a recommendation for sustainable land management of atoll islands as follows.

Atoll islands are threatened by climate changes (not only sea level rise but also changes in storm intensity and frequency, sea surface temperature rise, ocean acidity, rain fall and so on) and human impacts. Atoll islands are low-lying with small areas and limited resources. Our scientific studies have found that they support considerable physical and cultural diversity.

A better understanding of the geographical variation in geomorphological and ecological processes offers the potential to increase the adaptive capacity of atoll island systems and the communities that depend upon them. There is a need for research on unresolved issues on modeling island landform, land-human interactions, sediment budget as well as water resources, pollution and garbage problems.

We need to recognize that present landscapes and many existing environmental challenges are a historical product of interaction between humans and the environment. We also need to recognize that environmental stresses and necessary adaptive responses will be significantly different in rural (low human population) and urban (high impact) settings. Estimation of carrying capacity of islands based on the above factors is helpful to estimate the vulnerability of the islands. We need to enhance public awareness both from top-down and from bottom-up directions.

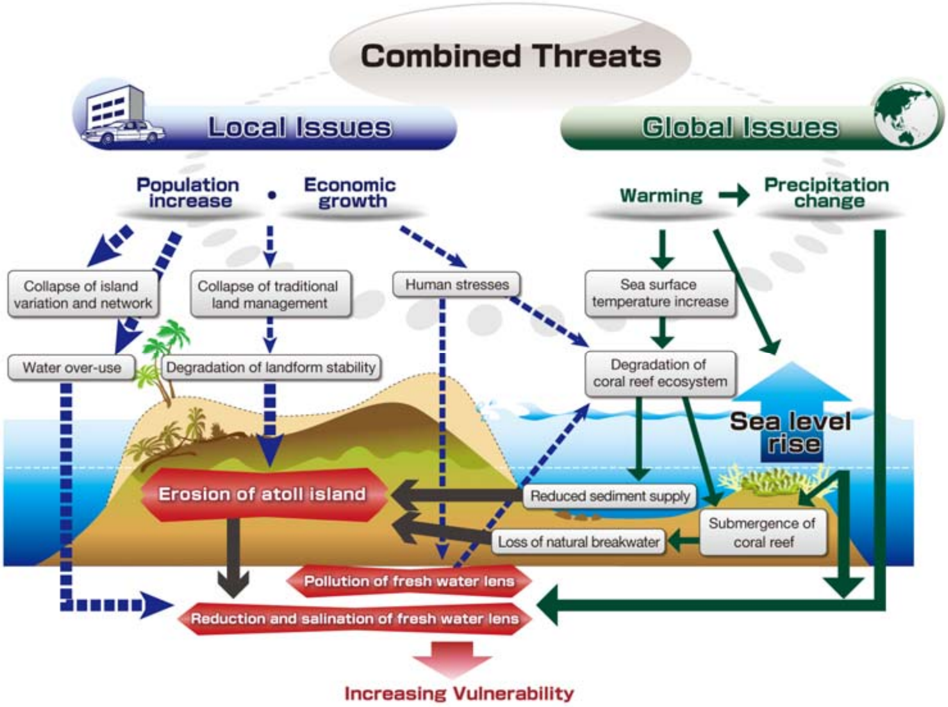

Fig. 5 Global and local combined threats upon atoll islands.

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