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Interdisciplinary Approach for Sustainable Land Management of Atoll Islands

Hajime KAYANNE,¹ Masashi CHIKAMORI,² Hiroya YAMANO,^{3,4} Toru YAMAGUCHI,⁵
Hiromune YOKOKI⁶ and Hiroto SHIMAZAKI³

¹*Department of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan
e-mail: kayanne@eps.s.u-tokyo.ac.jp*

²*Faculty of Informatics, Teikyo Heisei University,
Ichihara, Chiba 290-0171, Japan*

³*Social and Environmental Systems Division, National Institute for Environmental Studies,
Tsukuba, Ibaraki 305-8506, Japan*

⁴*Institute de Recherche pour le Développement, BP A5 Nouméa Cedex, New Caledonia*

⁵*Department of Ethnology and Archaeology, Keio University, Mita, Tokyo 108-8345, Japan*

⁶*Center for Water Environmental Studies, Ibaraki University, Hitachi, Ibaraki 316-8511, Japan*

Abstract

Atoll islands are low, flat land on atolls with a maximum elevation of one to two meters. They are under crisis of submergence due to rising sea levels in this century. The formation and maintenance of atoll island landforms are regulated not only by physical but also by ecological processes. The source of sand constituting the islands is calcifying organisms, and coral reefs on the ocean side of the islands act as a natural breakwater and provide bioclastic materials. Bleaching induced by global warming degrades the ecological process of island formation. Moreover, the traditional vegetation management system acts to stabilize landforms, but urbanization of atoll islands disrupted this human process, thereby increasing the vulnerability of these islands to environmental stresses. For sustainable utilization and development of atoll islands, it is fundamental to evaluate the interaction between natural and human processes through interdisciplinary research among geomorphology, anthropology and coastal engineering. The ultimate goal of the research is to establish a diagnosis of the present status and future response of atoll islands to environmental changes, and to establish an 'atoll island model' to predict their landform changes in response to future sea levels. Another objective is to re-evaluate traditional human management systems of island landforms and vegetation in effective utilization of resources and land. Remote sensing and GIS would provide effective tools to extend the results obtained in model fields to other atoll islands in general.

Key words: atoll, atoll Island, landform, land management, sea level rise

1. Atolls and Atoll Islands

The atoll is one of the three major types of coral reef landforms: a ring-shaped reef enclosing a shallow lagoon. The diameter of the ring may be as large as several tens of kilometers (Fig.1) to as small as a few kilometers (Fig. 2). The width of the reef, which forms the ring, is generally one to two kilometers at maximum, and the depth of the lagoon is several tens of meters. If a coral reef forms a circular or elliptical flat without a lagoon, it is called a table reef.

Approximately 500 atolls are distributed worldwide: approximately 400 in the Pacific Ocean, 70 in the Indian Ocean, and 30 in the Caribbean Sea (blue dots in Fig. 3). Most of the atolls exist in the Pacific

Ocean. Some small-island countries and regions (the Republic of the Marshall Islands, the Federated States of Micronesia, Tuvalu, the Republic of Kiribati, and French Polynesia in the Pacific, and the Republic of Maldives in the Indian Ocean) consist fully or mostly of atolls. Many atolls are also distributed around Southeast Asia and in the South China Sea (e.g., the Spratly Islands), yet we have little information on them.

Islands distributed on atolls are called atoll islands (other terminologies for them are reef islands, atoll-reef islands, motu and cays). Since the surface of reef flats only reaches low tide level, islands above high tide level are formed from bioclastic sand thrown up onto the reef flats, from

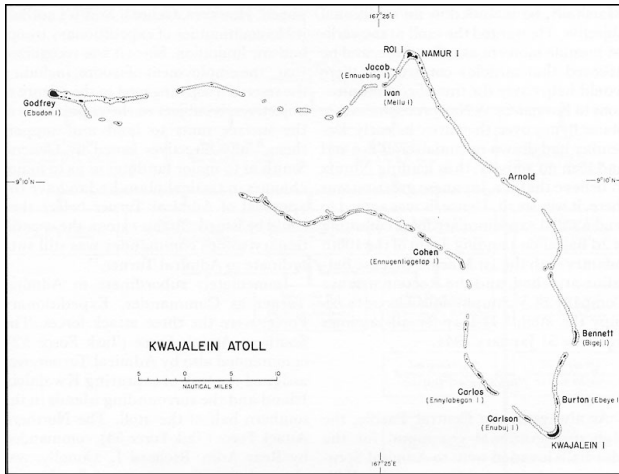


Fig. 1 Map of Kwajalein Atoll.

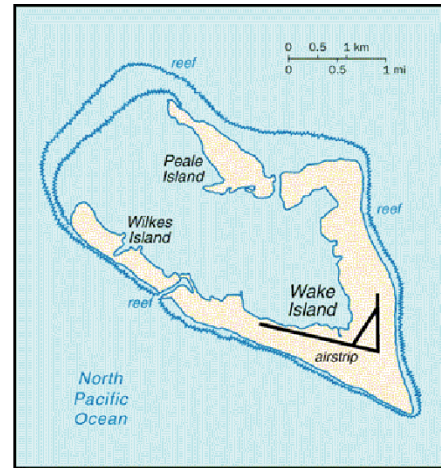


Fig. 2 Map of Wake Island.

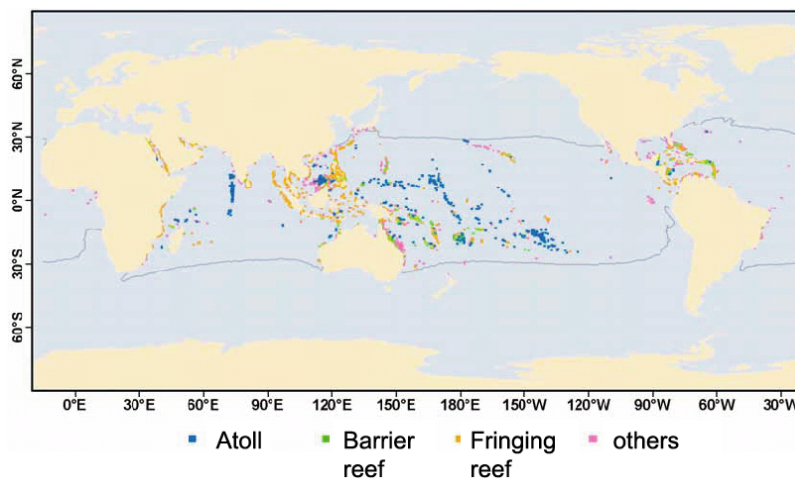


Fig. 3 World distribution of coral reefs with major categories of reef landforms. Blue dots show atolls. Prepared by H. Shimazaki from ReefBase.

remnants of an emerged reef, or by a composite process of both. The elevation of most of the islands is one to two meters. More than 500 thousand people live on atoll islands. Some atoll islands (*e.g.*, Majuro Atoll in the Republic of the Marshall Islands and Funafuti Atoll in Tuvalu) are densely populated and urbanized (Fig. 4). Residences and infrastructure extend across these small, low islands.

2. Geomorphology of Atoll Islands and Their Submergence due to Rising Sea Levels

Since atoll islands are low, flat lands with a maximum altitude of one to two meters, they bear a limited amount of resources. Therefore, their vulnerability to environmental stresses is extremely high. Among various threats to atoll islands, submergence due to rising sea levels induced by global warming is the most serious, as it leads to loss of national land. The predicted rise in sea levels in the 21st century ranges from 10 to 90 cm with a median

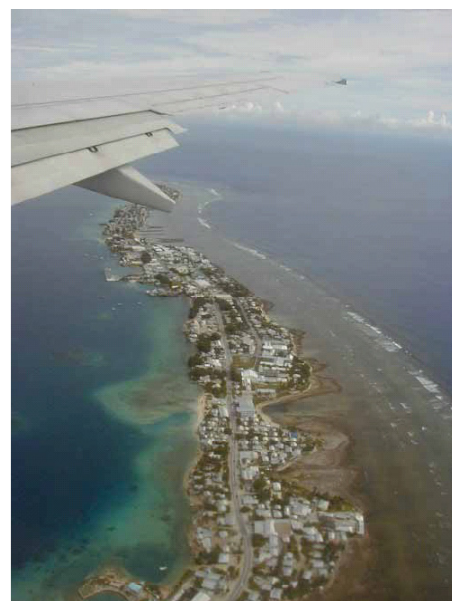


Fig. 4 Aerial view of Uliga Island, eastern side of Majuro Atoll. Photo by H. Yamano.

estimate of 40 cm (Fig. 5). The amount of this rise is crucial with regard to maintenance of island landforms. At present, high-energy ocean swells break mainly at the algal ridge, the seaward rise on the reef flat (Fig. 6; Uliga Island in Majuro Atoll). However, a 65 cm rise in sea level (upper level of prediction) will raise the mean sea level to the present high water level, and ocean swells will break directly onto the shore.

Against the backdrop of submergence, intensive international concern has been elicited, and research on possible responses of atoll islands to future sea

level rises has been conducted mainly from an engineering point of view. However, formation of atoll islands is regulated not only by physical but also by ecological processes (Fig. 7). Yamano *et al.* (2005a) reviewed the role of ecological process in detail. In this introduction, we will raise two points.

Firstly, the source of sand constituting the islands is calcifying organisms. Corals and foraminifera are two major contributors of sand together with associated creatures, including calcareous algae, mollusks, echinoderms, and others. At Laura Island in Majuro Atoll, the atoll island landform is divided into coral

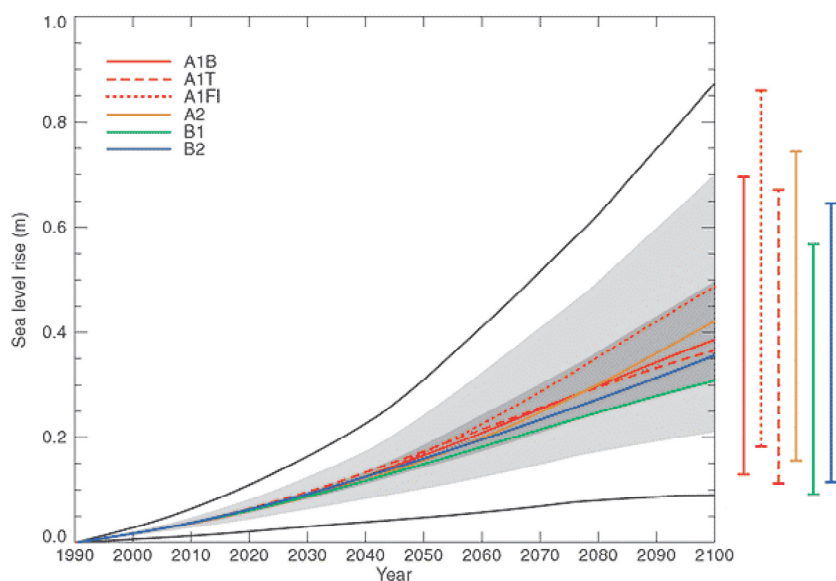


Fig. 5 Projected curves of predicted sea level rise in the 21st century from the 'IPCC Third Report.'

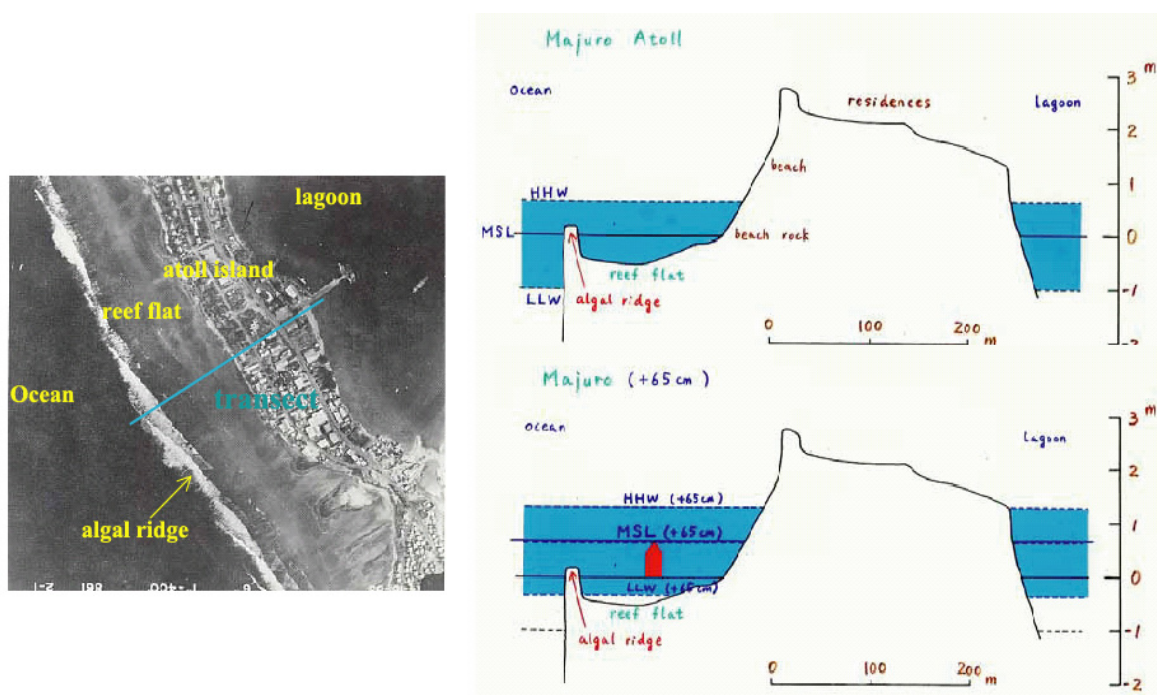


Fig. 6 Schematic diagram of effect of sea level rise at Uliga Island, Majuro Atoll.

reef flat, storm ridge, central depression and beach ridge from ocean to lagoon (Fig. 8). This geomorphological zonation is generally applicable to other atoll islands as well. The storm ridge is composed of coral boulders with diameters of several tens of centimeters. They are thrown up on the ocean side of the islands during heavy storms. The ridge forms the highest elevation, up to 4 m in many atoll islands. The beach ridge along the lagoon coast forms the other high ridge. This ridge is composed of sand-sized calcium carbonate fragments of coral, foraminifera and other organisms.

Secondly, coral reefs on the ocean side of the islands act as a natural breakwater and provide bioclastic materials. If a coral reef is healthy, it has an upward growth potential of as much as 40 cm/100 years. This potential rate matches the median predicted value of sea level rise. Thus a coral reef has a

potential to keep up with rising sea levels to maintain its function of a natural breakwater and sediment source. However, global warming induces frequent bleaching of corals, which degrades the reef potential, and the breakwater function is also degraded.

The formation of atoll islands is closely related to coral reef formation from a geological point of view. The coral reef flat was formed 3,500 years ago in Majuro Atoll, and served as a basis for atoll islands. The core of the atoll islands was formed 2,000 years ago firstly at the central depression over several decades in response to slight lowering of sea levels. Then, the island extended lagoonward to form the beach ridge. Occasionally, storms piled up coral boulders on the storm ridge along the ocean side of the island.

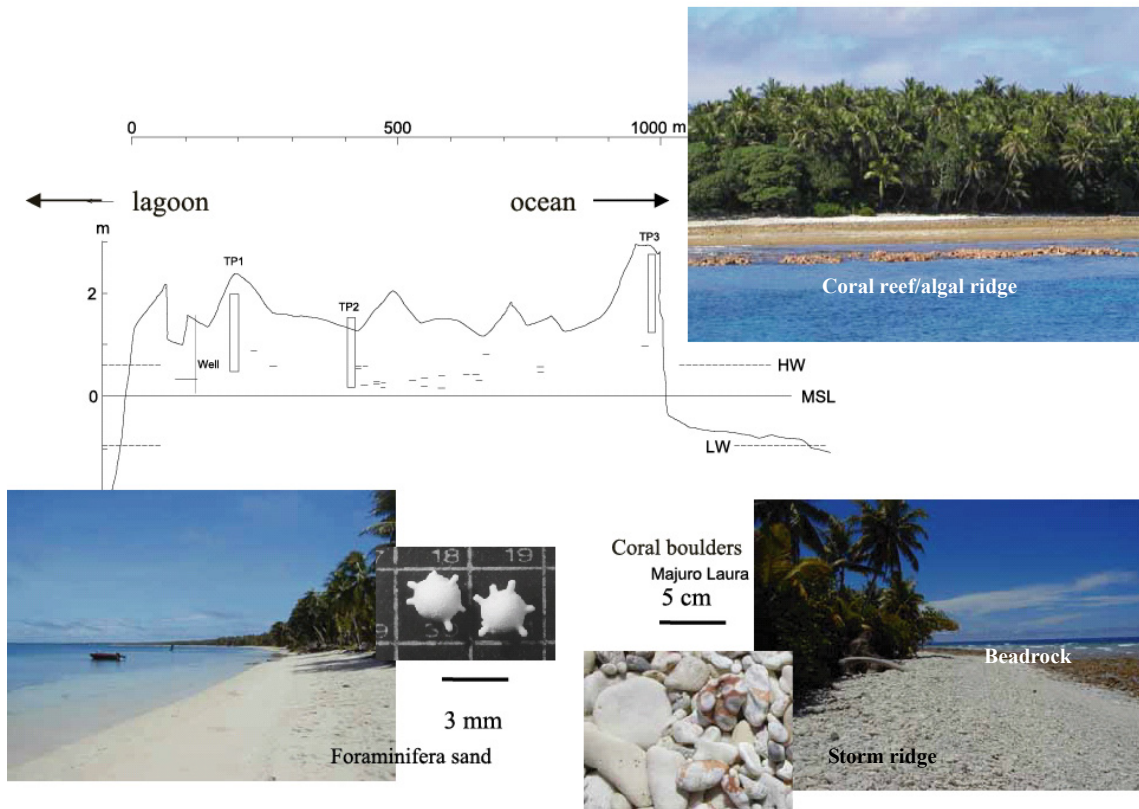


Fig. 7 Function of ecology in atoll island landform formation.

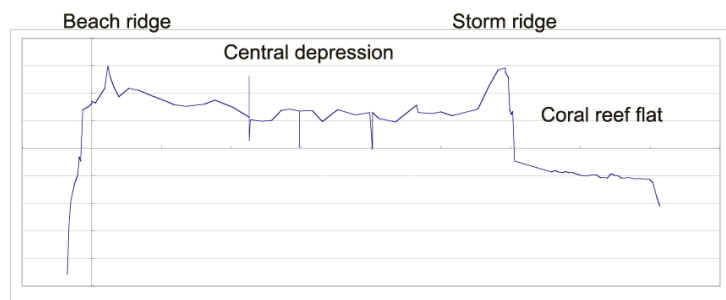


Fig. 8 Cross traverse and zonation of an atoll island at Laura Island, Majuro Atoll.

3. Function of Traditional Human Management

Traditionally, the resident people on atoll islands have acted to maintain island landforms through preservation and management of vegetation (Fig. 9). Many species of plants (taro, pulaka, banana, breadfruit, coco trees, pandanus, sugarcane) were introduced to atoll islands by people for their use as food and architectural materials. They implemented special protection and management strategies. Island vegetation has served not only as various resources but also for maintaining soil and landforms. Roots of plants act to stabilize landforms. In particular, coastal vegetation is most important for the protection of beaches. Knowing their functions, people have planted and protected them to prevent coastal erosion.

However, traditional management systems collapsed in the wake of modernization and urbanization. Since the introduction of the copra economy, island landscapes changed to one of copra monoculture. The expansion of coco forests led to loss of other plant species. In the 1980s, the price of copra declined and transportation costs increased. As a result, copra production declined and ill-maintained coco forests often became overcrowded. Authorities or bureaucrats have often replaced traditional leaders. Agroforestry management has become difficult because of changes in the human population structure, progressive depopulation, and changes in social politics. As a result, the vegetation on many Pacific atolls has been devastated. In urban areas, coastal vegetation has been replaced by dumping sites (Fig. 10).

In addition, urbanization of atoll islands degrades

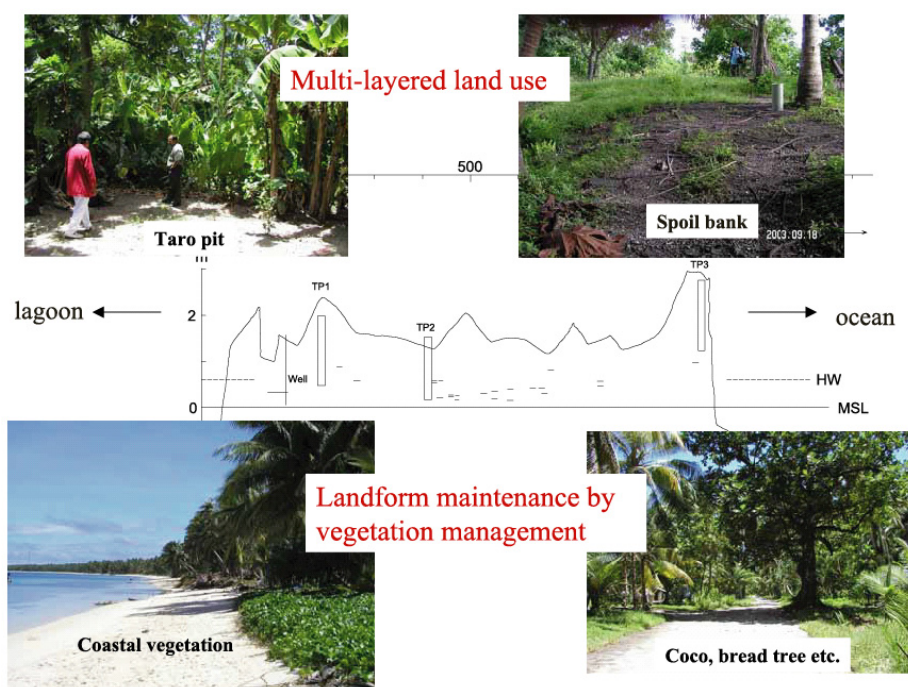


Fig. 9 Human function in atoll island landform maintenance.



Fig. 10 Dumping site along the storm ridge at Uliga Island, Majuro Atoll.

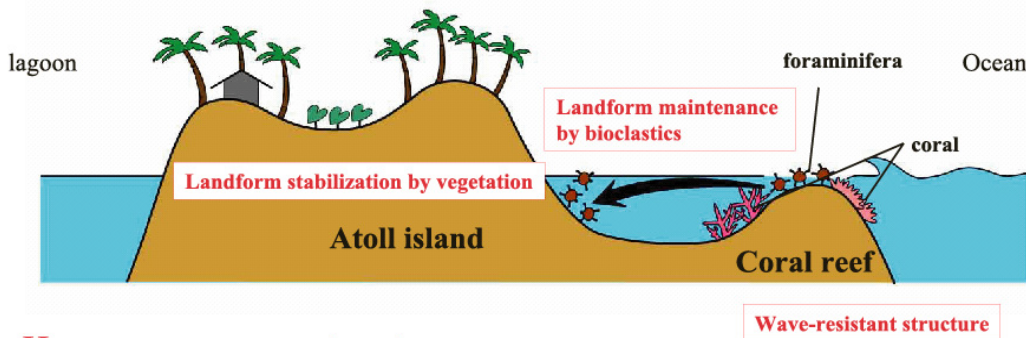
coral reef health, which then reduces the upward growth potential of the reefs and their biological function of sediment production. Calcium carbonate production, which provides sand to the island, is reduced to less than half the values on a reef flat in an urbanized area. Degradation of the coral reef community results in a reduced rate of sand formation and severely detracts from sustainability of the island landform.

4. Compound Threats and Sustainable Land Management of Atoll Islands

Threats to atoll island landforms are complex, not as simple as ‘submergence due to rising sea levels.’ The looming crisis to the atoll islands is thus a composite of global and local stresses. In natural processes, atoll islands are maintained by biological sand production, which is transported physically by waves and coastal currents (Fig. 11). Coral reefs

form a natural breakwater to protect islands from ocean swells. Traditionally, human management systems acted to maintain landforms. Sea level rises induced by global warming will lead to submergence of atoll islands as a direct consequence (Fig. 12). In addition, submergence of coral reefs leads to loss of their breakwater function. Global warming results in bleaching of corals, which degrades the potential of upward growth and production of coral reefs. Socio-economic changes increase human stress on coral reefs, leading to their degradation. Collapse of traditional management systems for island vegetation will lead to collapse of their maintenance function of landform.

For sustainable utilization and development of atoll islands, it is fundamental to evaluate the interaction between natural and human processes through interdisciplinary research among geomorphology, anthropology and coastal engineering. In 2002, we started a feasibility study on atoll island



Human management system
Fig. 11 Natural process of atoll island formation with traditional function of a human management system.

Compound threats

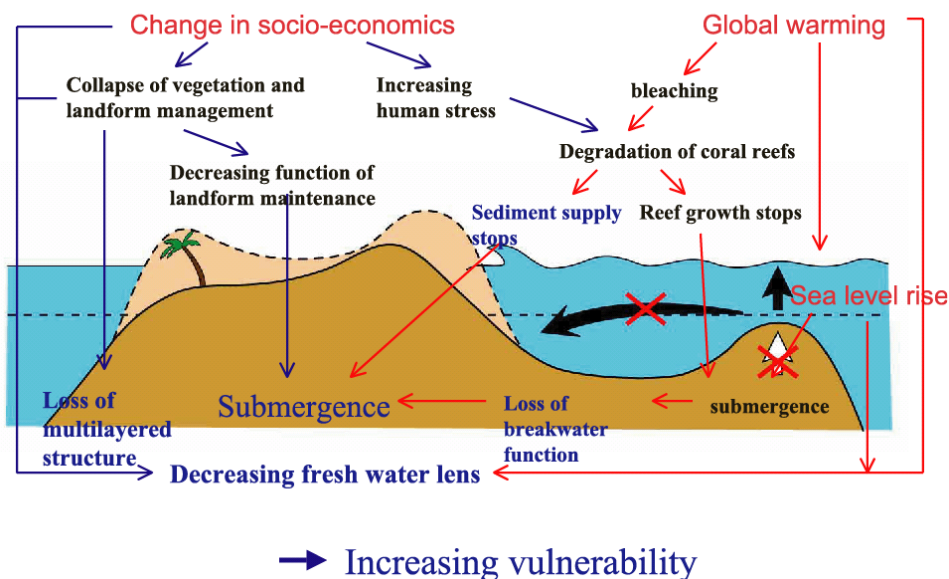


Fig. 12 Compound threats to atoll islands.

formation processes followed by our main research on 'Sustainable Land Management in Atoll Island Countries' from 2003 to 2005 funded by the Ministry of the Environment, Japan.

First, we classified atoll islands in relation to determining factors of atoll island formation and selected representative atolls for intensive field surveys based on this classification: Majuro Atoll in the Marshall Islands, and Funafuti Atoll in the Tuvalu Islands. In this issue of *Global Environmental Research*, some results obtained so far mainly from the research in Majuro Atoll are included. Yamano *et al.* (2005a) present an overview of the dynamics of atoll islands from geological, physical and ecological perspectives. Sediment transport along the lagoon coast is analyzed from an engineering point of view by Yokoki *et al.* (2005). On the other hand, Yamaguchi *et al.* (2005) reveal the settlement history at Majuro from archaeological point of view, and compare them with geomorphological development history of atoll island landforms. To generalize our field survey results, mapping and GIS technologies are necessary, which are shown in Yamano *et al.* (2005b) and Shimazaki *et al.* (2005).

The ultimate goal of our research is to establish a diagnosis of the present status and future response of atoll islands to environmental changes. This research aims to establish an 'atoll island model' to predict their landform changes in response to future sea level rises from geomorphological, ecological and coastal engineering points of view. Another objective is to re-evaluate traditional systems of human management

of island landforms and vegetation in effective utilization of resources and land. Based on the resulting evaluation, we will propose appropriate adaptation strategies to global changes. Remote sensing and GIS will provide effective tools for extending the results obtained in model fields to other atoll islands in general.

References

- Shimazaki, H., H. Yamano, H. Yokoki, T. Yamaguchi, M. Chikamori, M. Tamura and H. Kayanne (2005) Geographic database on the natural and socioeconomic conditions of reef island. *Global Environmental Research*, 9(1): 47-55.
- Yamaguchi, T., H. Kayanne, H. Yamano, Y. Najima, M. Chikamori and H. Yokoki (2005) Excavation of pit-agriculture landscape on Majuro Atoll, Marshall Islands, and its implications. *Global Environmental Research*, 9(1): 27-36.
- Yamano, H., H. Kayanne and M. Chikamori (2005a) An overview of the nature and dynamics of reef islands. *Global Environmental Research*, 9(1): 9-20.
- Yamano, H., H. Shimazaki, H. Kayanne, H. Yokoki, T. Yamaguchi, M. Chikamori, M. Tamura, T. Murase, Y. Suzui, K. Itou, M. Hirose, S. Sano, H. Takagi, M. Watanabe, F. Akimoto, S. Watanabe, S. Yoshii, A. Ishoda, N. Leeders and W. Forstreuter (2005b) Efforts to generate maps of atoll countries. *Global Environmental Research*, 9(1): 37-46.
- Yokoki, H., H. Yamano, H. Kayanne, D. Sato, Y. Minami, S. Ando, H. Shimazaki, T. Yamaguchi, M. Chikamori, A. Ishoda and H. Takagi (2005) Comparison between longshore sediment transport due to waves and long-term shoreline change in Majuro Atoll, Marshall Islands. *Global Environmental Research*, 9(1): 21-26.

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