The Coastal Ecosystem in Tuvalu and Geo-ecological Management against Sea-Level Rise

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in

Foram Sand Project

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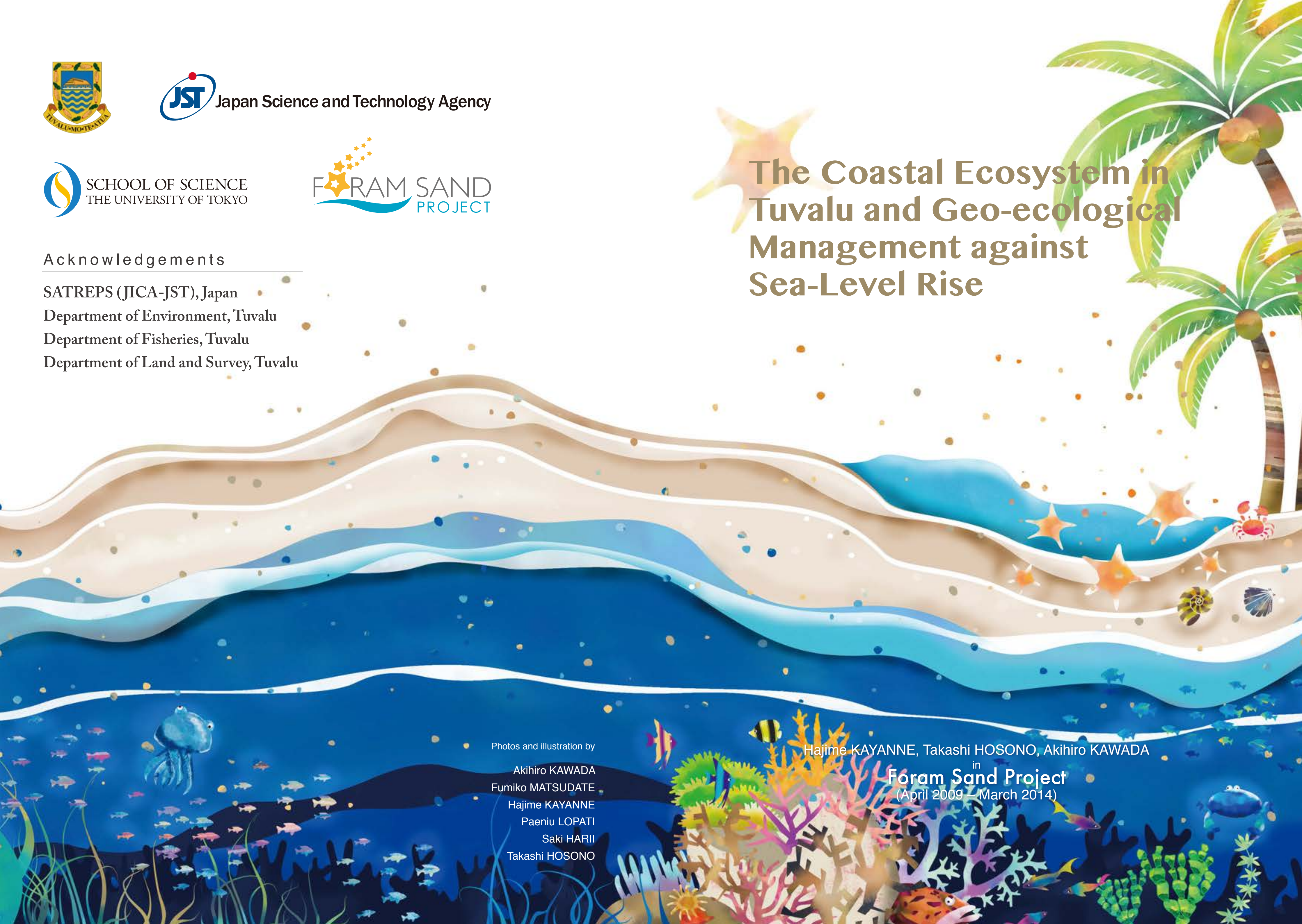

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PART 01

Atolls and coral reefs

Atolls are ring-shaped coral reefs standing in mid-ocean and surrounding a shallow lagoon. They are the final stage of coral reef evolution: a newly born volcanic island is first fringed with coral reefs (fringing reef). As the island subsides, the coral reef grows upward to form a barrier reef separated from the island by a shallow lagoon. Finally, the island subsides well beneath sea level to form an atoll. This hypothesis was proposed by Charles Darwin in 1842 during the survey of the HMS Beagle and then tested by deep drilling at the Funafuti Atoll in 1896-1898, which failed to reach the volcanic basement but recovered more than 300 m of shallow coral reef sediments, implying subsidence. Darwin's subsidence theory was eventually substantiated by deep drilling at the Eniwetak Atoll just after WWII, which penetrated into volcanic rocks 1267 m below the sea surface that were overlaid by coral reef limestone. Today, the initial volcanic island and its subsidence are explained by plate tectonics in which a volcanic island is formed at a hot spot and then travels and subsides with a plate.

Approximately 500 atolls exist in the world, with 400 located in the Pacific Ocean. Tuvalu consists of 9 atolls. They are aligned from southeast to northwest, corresponding to plate motion. Tuvaluan atolls have travelled from the southwest. Islands on the atolls are formed by unconsolidated coral gravel and foraminifera sand over several thousand years.

PART 02

Islands formed by marine animals

Tuvalu is a chain of atoll islands several hundred meters wide with elevations ranging from one to four meters. The islands of Tuvalu are formed on a rigid framework of coral reefs, which have been constructed by piling up the skeletons of hermatypic corals. Corals are cnidarian animal relatives of jellyfish and sea anemone that precipitate calcium carbonate skeletons. They pile up to form coral reefs that provide a foundation for the island and act as a natural breakwater. However, coral reefs never accumulate above low water level.

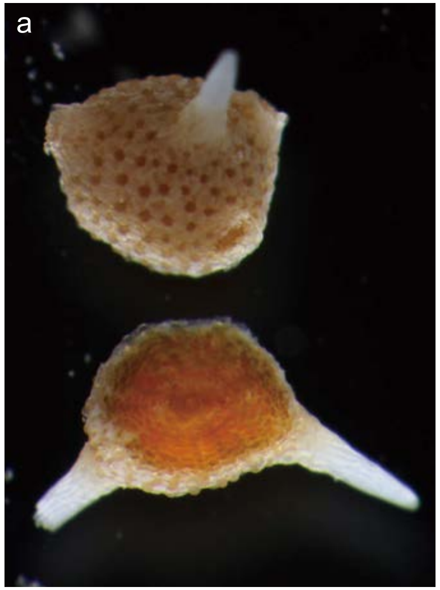
Those islands above high water level serving as habitable land for humans have been formed by coral debris and foraminifera (foram) sand tossed up onto the coral reef. The debris of coral skeletons are tossed up to form the ocean-side storm ridge. Forams are protozoa, which live on the reef flat by attaching to turf algae and that precipitate calcareous shells of one to two millimetres in size. The major part of the island body (the lagoon-side ridge and the central depression) is formed by the shells of the forams (foram sand).

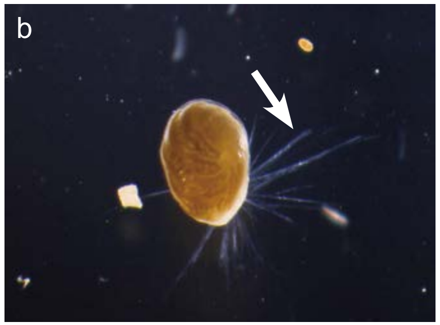
Coral and foram are the two major players that construct the islands in conjunction with several other calcifying organisms, such as molluscs, calcareous red and green algae, and sea urchins. Therefore, island formation is governed by both physical and ecological processes. The sustainability of the national land of Tuvalu depends fully on coral and foram.

a. Beach sand in FUAKEA Island.
b. Coral community in the lagoon of FUNAMANU Island.
c. Foraminifer population in TENGAKO Island (TH).

PART 03
Corals and foraminifers

Corals and foraminifers belong to quite different phylogenetic groups. However, their nutrient acquisition methods are similar. Coral and foraminifer contain symbiotic algae within their bodies. They utilize sunlight and allow their symbiotic algae to photosynthesize. Then, they acquire nutrients from the photosynthetic products of the symbiotic algae. They also eat plankton from the water column using tentacles by the coral and pseudopods by the foraminifers.



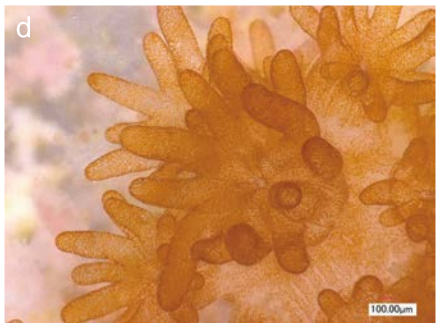


a. Surface and inside of a foraminifer (*Baculogypsina sphaerulata*). Orange color inside the foraminifer is a symbiotic diatom (TH).

b. Foraminifer (*Amphistegina lessonii*) attached to a glass microscope slide. The arrow indicates a pseudopod (TH).

c. Corals (SH)

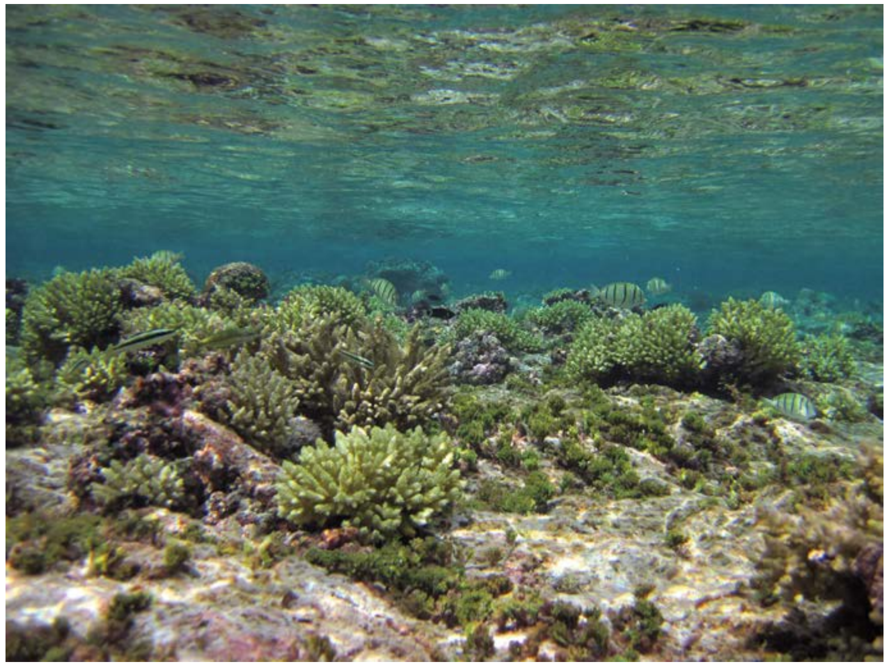
d. Tentacles and symbiotic algae (SH).



PART 04
Marine animals and the ecosystem

Corals and foraminifers can be found in littoral and sublittoral zones in Tuvalu. They utilize sunlight in shallow areas to acquire nutrients.

However, they need more to survive than only sunlight and nutrients. Corals also need a hard substrate for attachment, and foraminifers also need macroalgae for attachment. In addition, they still require more than these three factors to survive. Coral easily die in polluted environments, can become bleached or be covered with algae. Foraminifers also die and can become bleached under some conditions.



Coastal ecosystem in the reef of FUAFATU Island (TH).

PART 05 Big drought in 2011 and resilience of the coastal ecosystem

The big drought occurred in 2011, and its negative effects have mostly subsided. The dry breadfruit trees have returned to life. Many water tanks donated from foreign countries will not be used until the next drought. However, that prolonged drought caused significant problems that affected many lives. At the same time, we also recognize the degradation of the ecosystem in our sea. One example is the black-coloured algae that were unnaturally overgrown in the lagoon. Coastal ecosystems that have low resilience are supposed to easily change their forms in response to small external forces. Sometime after the rain returned, the ecosystems appeared to recover their former forms, and therefore, the current ecosystem exhibits some resilience. However, the drastic changes in the coastal ecosystem during the big drought clearly reflect strong anthropogenic stress and weak resilience in the coastal ecosystem.

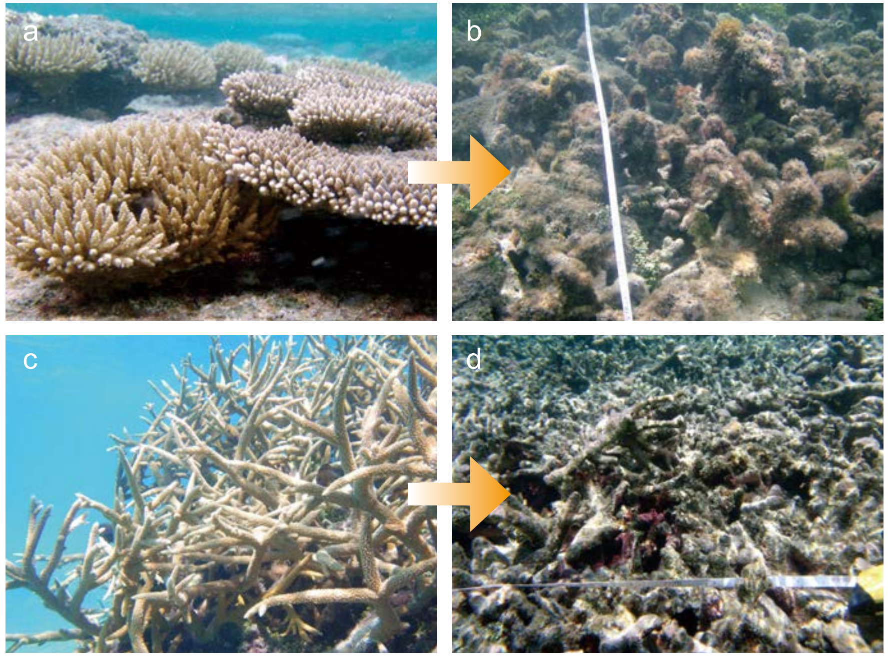
a. Landing of water tanks donated as relief supplies from foreign countries (TH).

b. Lagoon beach of the island covered with spoiled algae (FM).

c. Black cyanobacteria-covered branching coral in the lagoon of Fongafale Island during the drought (PL).

PART 06 After the collapse of the coastal ecosystem

We can easily understand the damage that the coral community experienced after the collapse of the coastal ecosystem and the loss of resilience when the following pictures are compared.



a. Table coral in a healthy coast of the Funafuti Atoll.

b. Dead table coral in the lagoon of Fongafale Island.

c. Branching coral in a healthy coast of the Funafuti Atoll.

d. Dead branching coral in the lagoon of Fongafale Island. (HK).

PART 07

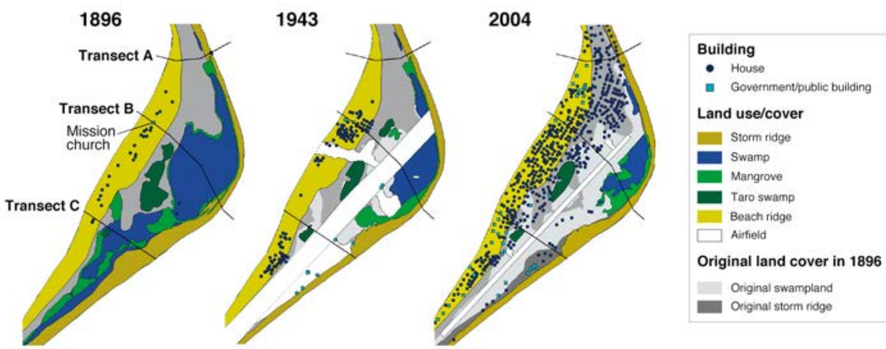
Is Tuvalu sinking?

During the spring high tide (King tide), the inland areas of Fongafale Island become inundated with seawater. Such inundation has been occurring more frequently. Local people argue that they have never experienced such inundation before and that it is therefore caused by rising sea levels induced by global warming.

The landform of Fongafale Island consists of a coral reef, a storm ridge, a central depression, and a lagoon-side ridge from the ocean side to the lagoon side, which are typical geomorphological features of atoll islands. The storm ridge reaches 4 m in elevation above the mean sea level (MSL), which is the highest on the island, and is formed by coral debris tossed up during storm events. The habitable area of the island is protected from ocean waves and swells by the coral reef and storm ridge. The lagoon-side ridge reaches as high as 2.5 m and provides the main human habitat. Between these two ridges, the central depression, with an elevation of only 1 m, extends into the island, where an air strip

exists. The spring high tide reaches 1.2 m, and thus the central depression is naturally inundated by spring-tide water.

An old geologic map revealed that the central depression was formerly covered by a large salty swamp fringed with mangrove trees. A report published as a companion to the map in 1896 stated that "at high tide it is covered by ankle deep with water which drains away at half ebb", the same phenomenon observed today. The natural landscape became obscured by the construction of the air strip during WWII by the US Army against the expansion of the Japanese occupation, which reached Tarawa just north of Tuvalu. The inland inundation is the result of the expansion of residential areas into the original lowland due to the growth of the population.



Expansion of residential areas into the lowland region (Yamano et al. 2007).

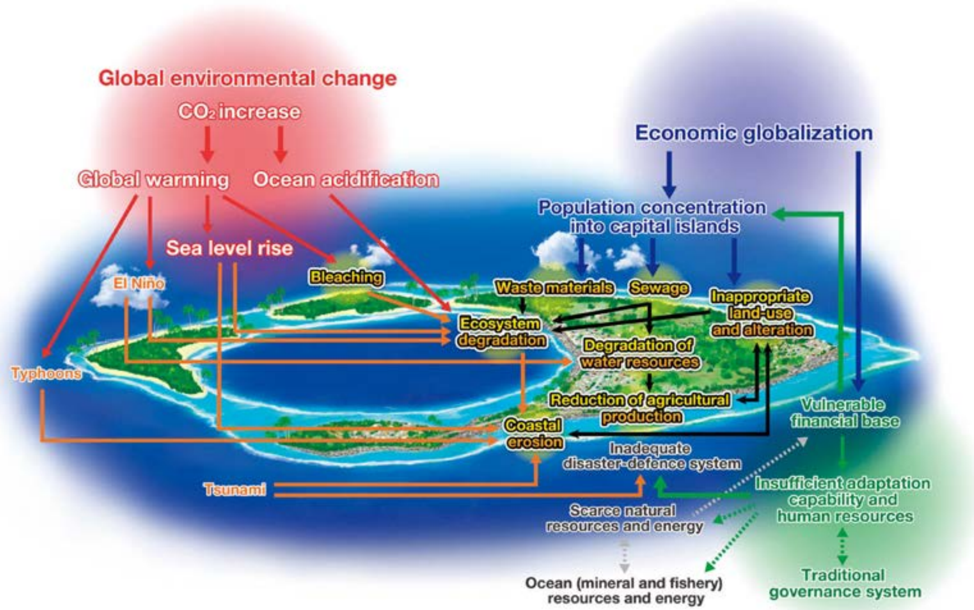
PART 08

Obstacles to the island formation process

The islands of Tuvalu were first formed by coral reefs. They still act as a natural breakwater in front of both the ocean-side and lagoon-side coasts. Corals also provide sand and gravel. However, coral reefs have never grown above low water level, and the islands above high water level were formed by gravel and sand from the calcareous skeletons of organisms. The major body of the island was formed by the sand of foraminifera, coral, calcareous algae and shells, with foraminifera contributing more than half and up to three-fourths of the sediment. The main contributor to the sediment is the foraminiferan *Baculogypsina sphaerulata* (star sand). The major site of foraminifera sand production is the ocean-side reef flat, and this sand is first delivered to the lagoon through the channels between the islands and then transported along the lagoon-side coast by the longshore current.

A healthy ecosystem with living coral and foraminifera is fundamental to island formation, and sand production, transportation and sedimentation is the key process in island formation. Fongafale Island is formed on a rigid framework of coral reef and located at the terminal of the sand transportation from the north and south.

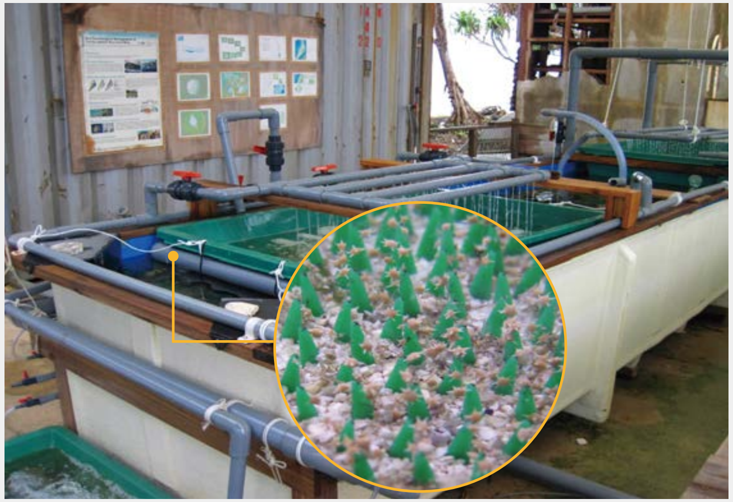
However, this natural process is now inhibited by human pressure and the



Combined stresses

anthropogenic construction of coastal landforms. The production of coral and foraminifera sand has been greatly reduced by reef ecosystem deterioration as a result of coastal water pollution. This pollution is caused by sewage seeping from the island accompanying the tidal cycles. Sand transportation from the ocean to the lagoon is blocked by the causeway between Fongafale and Tengako Islands. The transportation of sand along the lagoon coast is interrupted by jetties and dredges. Finally, sand sedimentation is prevented by revetment and the loss of coastal vegetation. Before World War II, the Fongafale coast was fringed by a sandy beach, which was lost by a landfill during the war. Only a small amount of sand remained along the Alapi coast, and never recovered. We judge that the no recover of the sandy coast resulted from all these obstacles to sand production, transportation and sedimentation. The loss of the sandy beach represents the loss of the island formation process, which should continue to preserve the island against increases in sea level.

Local human activities have stressed and degraded the local ecosystem and natural island formation process. Global warming and ocean acidification have also contributed to ecosystem degradation, and a rise in sea level would cause submergence. If the coral and foraminifera are healthy, they have the potential to keep up with the rising sea level to form a natural breakwater and island. However, local stresses have increased the island nation's vulnerability and damaged the natural resilience against the projected rise in sea level.



Culturing foraminifer.

PART 09 Geo-Ecological management of the islands

To protect islands against rising sea levels, the natural island formation process needs to be rehabilitated by removing obstacles. Based on the known obstacles to sand production, transportation and sedimentation, we propose the feasible options herein.

To regenerate coral and foraminifera production, ecosystem rehabilitation is necessary, which should be achieved by improving the coastal environment via sewage treatment and waste management. This rehabilitation would be supported by foraminifera and coral culture and transplantation and the generation of their habitats. However, the improvement of the coastal environment is a prerequisite.

Any engineering plans for coastal protection must not conflict with, but rather should enhance, the natural processes. An open-cut causeway will enhance sand delivery from the ocean to the lagoon, nourishing the lagoon coast. Removal of the jetties or their reconstruction with piles and backfilling the dredges would re-open the transportation passage along the coast. A vertical seawall will enhance erosion rather than sedimentation at its base. Therefore, beach nourishment is proposed as a shorter-term coastal protection and rehabilitation plan that enhances but does not conflict with the long-term rehabilitation of the sandy beach.

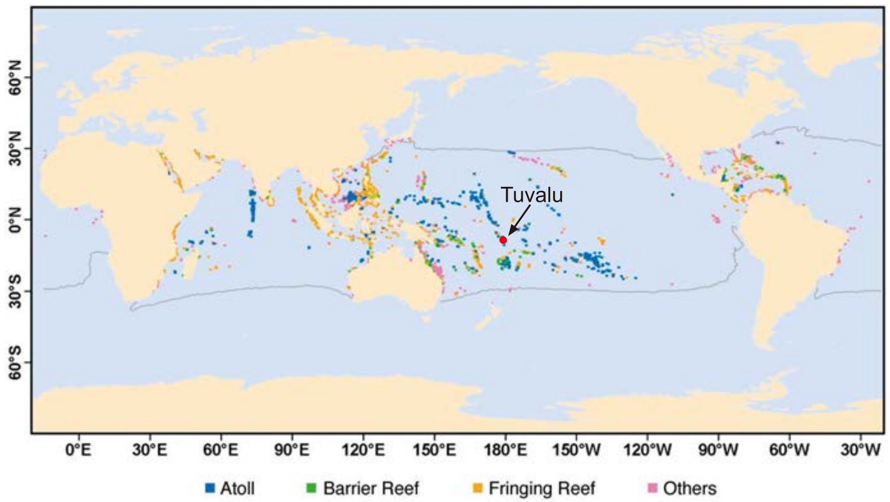
These proposed plans have different timescales and technologically challenging levels. The effectiveness of beach nourishment will be clearly visible, and the required technology is well established. However, improvement of the coastal environment needs a longer timescale to achieve. The technologies responsible for foraminifera and coral culture and transplantation have just been established and require further challenges for adaptation to the site. However, these novel technologies should be applicable to other atoll island countries.

Re-opening the transportation passage along the coast.

PART 10 Application to other atoll island countries

There are approximately 500 atolls around the world, mainly located in the Pacific. All atolls suffer from local and global environmental issues.

Some of these atolls form atoll island countries, such as the Marshall Islands, Kiribati, Tokelau, and French Polynesia in the Pacific Ocean and the Maldives in the Indian Ocean. The establishment of geo-ecological management in Tuvalu would represent the first successful application in the world. If this strategy can be applied to the atolls in Tuvalu, it can also be applied widely to other atoll island countries. Technologies from Tuvalu will help solve a central concern of island societies.



World distribution of atolls

PART 11 Our Island is alive

Our island is alive, breathing and ever growing. It has been entwined as a part of our cultural heritage that has been treated with care and handed down by our ancestors. But now, our human activities have polluted the ocean and harmed our island, causing its natural resilience for change to get weaker.

Construction of an artificial island protector may be the answer to this. It is a method that has already been used. This option however required endless maintenance after construction, which causes it to be a burden for generations to come. Is this acceptable?

Islands have a natural mechanism against waves and rising sea level. What we have to do is to support the recovery of this mechanism. What we can do is take the initiative in regarding a cleaner ocean and giving time for our island to recover.

The important thing is that we all treat our ocean with care and give it the respect that was given by our ancestors. Then, coral and foraminifera will return to us. Our island will regain natural resilience and save us from ocean threat.

AK

FM

FM

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