# HUMAN IMPACT ON MANGROVE HABITATS MAINTENANCE AGAINST SEA-LEVEL CHANGE: CASE STUDY OF TONGATAPU ISLAND, THE KINGDOM OF TONGA, SOUTH PACIFIC

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*Abstract* Mangrove forests and their habitats have been formed and maintained under changing conditions in sea-level over the past few thousands of years. The human impact generated by use of mangrove environments is analyzed in respect to habitats maintenance against sea-level change with a case study dealing with sedimentary structure under mangrove forests on Tongatapu Island and socio-economic environments of the island. First, the application of island classification based on topography and subsurface geology to evaluate mangrove habitats maintenance was examined. It reveals that habitats located on the low islands consisting of reef limestone are most sensitive to sea-level rise. Second, the use of mangrove environments on Tongatapu was described with reference to socio-economic background: the human impact was little within traditional use of mangrove plants because of usage in the consideration of regeneration. But change of usage of mangrove plants and rise of exploitation of mangrove habitats have occurred corresponding to a shift of socio-economic background. These changes have a strong impact on mangrove ecosystems resulting in the decrease of biological productivity of mangrove plants, which is important for habitats maintenance on Tongatapu as a "low island".

**Key words:** mangrove forest, sea-level change, habitats maintenance, impact of exploitation, Tongatapu Island

## 1. Introduction

Mangrove forests characterize coastal landscape with coral reefs in tropical and subtropical regions. It is feared that mangrove forests will be affected by predicted sea-level rise resulting from global warming in the next tens of years. Although mangrove forests cover only a little area in the world compared to other types of forest, they possess huge amount of carbon with below ground biomass in the form of remains of root system. This means that they play an important role for the carbon cycle on the global scale and that vicissitudes of mangrove forests corresponding to sea-level change significantly affect carbon cycle, which results in global environmental change (Fujimoto *et al.* 1996a).

Coastal areas have always been important for humans as residential and cultivation areas from ancient times. While mangrove vegetation itself provides commodities such as construction materials, firewood, charcoal, dye, and medicine, mangrove ecosystem provides fish and crustaceans as food, and protection from surge, coastal erosion, water pollution, and increased siltation in coastal areas for the inhabitants. Recently many mangrove areas have been converted to nursery ponds for shrimp or fish. This is an example of exploitation of mangrove habitats which provide high production of organic matter as their food and nursery grounds for juvenile. Moreover, mangrove areas have been reclaimed and converted to other land use such as residential areas, airports, harbors, and farm lands on a large scale. These conversions are major factors contributing to the loss of mangrove forests. In the developing countries, most of mangrove forests are destructed due to the over-exploitation for such use (Ajiki and Miyagi 1991).

The human impact on mangrove ecosystems has significant influence on maintenance process of mangrove habitats against sea-level change. As we will discuss later, the maintenance process differs depending on geomorphological settings, and habitats located at lagoons or tidal flats where no discharge is found have been maintained with accumulation of peat to keep the ground level at moderate height by mangrove plants themselves (Miyagi 1992). Thus, distributional change of mangrove forests corresponding to use of mangrove environments decreases biological production, and results in making them vulnerable against sea-level rise.

This paper aims to examine the human impact on mangrove ecosystems in respect to mangrove habitats maintenance against sea-level change and to propose the possibility of sustainable use of mangrove environments facing to abrupt sea-level rise. For this purpose, analysis will focus on 1) classification of physical setting of mangrove ecosystems concerning with sea-level change, 2) case study on the use of mangrove environments on the island of Tongatapu, Tonga, and 3) socio-economic background to estimate the future of the use of mangrove environments.

We should start by defining some of the expressions employed, before turning to closer examinations. The term "use of mangrove environments" is employed here as a general term of utilization which does not specify the manner or the objects of use. On the other hand, terms "exploitation of mangrove habitats" and "use of mangrove plant" specify the objects of use; the former one refers to "use of mangrove environments as land resources"; the latter to "use of forest products within mangrove environments". Furthermore, we represent the notion of "sustainable use of mangrove environments" with the term "exploitation of mangrove ecosystem". In this way of use of mangrove environments, human activities are minimized to be one of the processes within the mangrove ecosystem not to disturb it.

## 2. Study Area

The Kingdom of Tonga consists of 171 islands, of which only 36 are inhabited.

scattered between lat. 15°and 23.5°S, long. 173°and 177°W. The total area of the Kingdom is 360,000 km², but the land area is only 750 km². The major island groups are Tongatapu with 256km², Vava 'u with 143km² and Ha 'apai with 119km². In 1986, the total population of the the Kingdom was 96,000 out of which 64, 000, the equivalent of 67% of the total population, lived in Tongatapu where Nuku 'alofa , the capital city, is located (Tonga Statistics Department 1991).

In the Kingdom of Tonga belonging to the southeast trade wind zone prevailing wind direction is east to southeast and the average speed is 6-7.5m/s. The annual rainfall is 1, 571mm (1967-1992), annual average high temperature is 27.5℃ and low one is 20.9℃. From November to April, the climate is warmer and wetter, and cooler and drier from May to October. Cyclones hit this region during the former season.

Tongatapu Island (lat. 21°08'S, long. 175°11'W) consists of raised limestone of Quaternary origins (Taylor and Bloom 1977), and is a typical "low island." Early Pleistocene uplift forms the south coast ridge, which includes the highest point about 65m A.S.L. Due to such topographic features of the island, mangrove forests fringe only the northern coast of the island and the Fanga 'uta lagoon which cuts into the center of the island (Fig. 1).

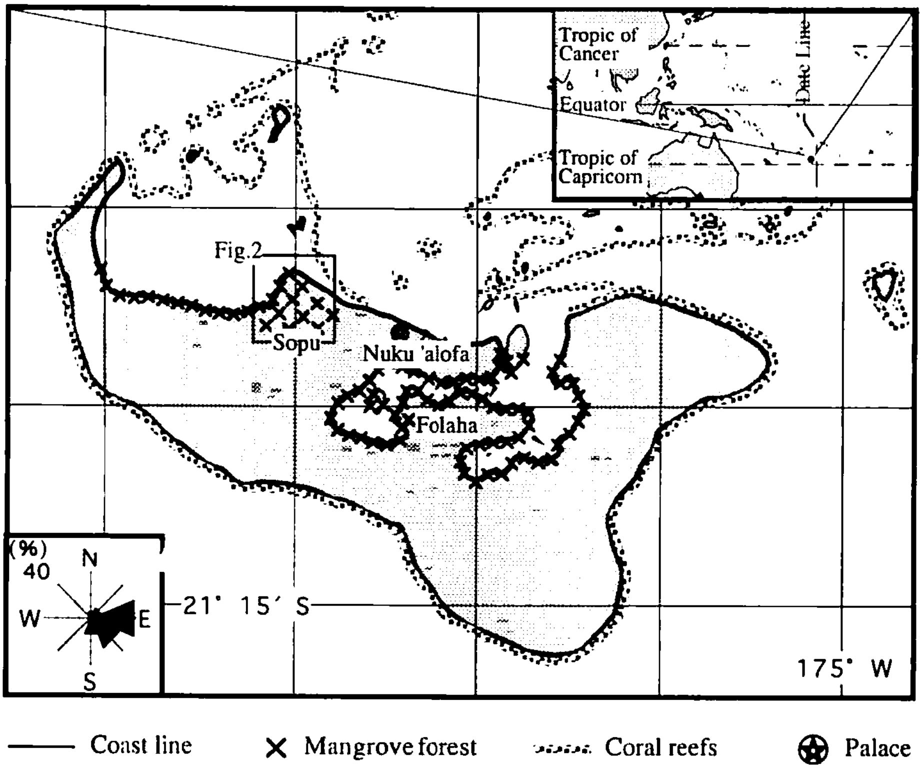


Fig. 1 Study area
Rose diagram shows annual frequency of winds.

On Tongatapu, mangrove forests occur between 0.4 and 0.9m above M.S.L., with a mean tidal range of 1.07m (Ellison 1989). These mangrove forests consist of mangrove species, which are *Lumnitzera littorea*, *Bruguiera gymnorrhiza*, *Rhizophora mangle*, *R. samoensis*, *R. stylosa*, *Excoecaria agallocha*, *Xylocarpus granatum*, *X. moluccensis*, *Acrostichum aureum*, and mangrove associates, which are *Hibiscus tiliaceus*, *Pandanus* sp., *Fiscus obliqua* (Zann 1984a). Of these mangrove species, the former five species are major elements of mangrove forests, which adapt to the intertidal environment with their morphological specialization, viviparity of the embryo and physiological mechanism for salt exclusion. They form pure stands, but the rest of them are minor elements occupying peripheral habitats and rarely forming pure stands (Tomlinson 1986). *E. agallocha*, however, comparatively forms pure stands on Tongatapu. On this island, *R. mangle*, *R. samoensis*, and *R. stylosa* are dominant species of seaward stand showing dwarf forest: the average height is less than 5m and average diameter at breath height is less than 5cm. *B. gymnorrhiza* and *E. agallocha* are dominants landward; their average height is up to 10-15m and average diameter at breath height is about 10cm. The rest of plants are scattered in landward stands.

## 3. Environmental Settings Concerning the Formation and Maintenance of Mangrove Habitats and Their Classifications

### Significance of islands classifications for mangrove habitats

Mangrove forests give an impression that they are developed only at the mouth of rivers. In fact, due to the high rate of sedimentation which enlarges their habitats, mangrove forests flourish there. But that is not the exclusive requirement for them. For example, sometimes small mangrove forests are found on not only raised but living coral reefs or even on ridges consisting of storm debris within small atolls where little runoff is present (Stoddart 1980; Fujimoto and Miyagi 1993; Scoffin 1993). Mangrove habitats formation is depending on the development of the tidal flat which is located at intertidal level, especially within the range of mean sea-level and high water spring. Generally, it is connected with the evolution of coastal landforms which are deltas, estuaries, lagoons, backmarshes and so on, corresponding to sea-level change during last few thousands years. Studies dealing with sedimentary structure under the mangrove forests clarified that histories of mangrove forests differ according to these geomorphological settings and sea-level curves (Grindrod and Rhode 1984; Woodroffe *et al.* 1985; Fujimoto and Miyagi 1993; Fujimoto and Ohnuki 1995).

Although mangrove forests can be found on various geomorphological settings, they do not maintain their habitats against sea-level rise in the same manner. Miyagi (1992) had divided mangrove habitats into three types based on geomorphological settings: the type located in estuaries or deltas (estuary/delta type), the type located on and around backmarshes or lagoons formed with barriers or beach ridges (backmarsh/lagoon type) and the type located on coral reefs or tidal flats without discharge of rivers (coral reef/ tidal-flat type). Now, the mangrove habitats maintenance against sea-level rise is whether the ground surface is kept at between mean sea-level and high water spring, and whether coastal processes such as wave action and tidal currents, which are altered by sea-level rise, attack the habitats. First, among these types, fluvial processes bring terrigenous sediment to accrete the level of substrate for estuary/delta type. Erosion by coastal processes might have a less significant effect on them if they are located in the inlet, and in other cases active progradation might keep the position of coast line, though they might not expand the habitats. Second, for backmarsh/lagoon type, mangrove plants themselves form peat to keep their substrate height under the framework of habitats such as protection by beach ridge and sand bar which were established by marine processes. Third, maintenance of tidal-flat type strictly relies on production of mangrove forests under opportunistical conditions. So each habitats type could be ordered according to the tolerance against sea-level rise from tolerant one to sensitive one as follows: 1) estuary/delta type, 2) backmarsh/lagoon type, and 3) coral reef/ tidal-flat type.

Here we will take an example to emphasize the different maintenance processes of habitats under each geomorphological setting but not under sea-level curve. In Australia where tectonic movement is not so active, sea-level change was relatively smooth, although some lags exist depending on regions: until 6000 years ago, sea-level rose to a level closed to the present, and then it was largely stable (Thom and Roy 1985; Woodroffe *et al.* 1985; Miyagi *et al.* 1997). Under such conditions, mangrove forests located at the mouth of large rivers (estuary/delta type) expanded to upper reaches corresponding to sea-level rise with large amount of sediment supply. While active sedimentation was continuing, landward mangrove forest was replaced by freshwater swamp and was forced to migrate downstream (Woodroffe *et al.* 1985). On the other hand, backmarsh/ lagoon type is maintained by adjustment of height with peat which was formed by mangrove plants during sea-level rise. Mangrove forests on this type of habitats have not been replaced by freshwater swamps under the stable sea-level, due to poor supply of sediment and characteristics of mangrove peat which was never formed above high water spring (Grindrod and Rhode 1984).

The categories presented above include both continent and islands. However, is it possible to apply those to small islands? Difference in geological history of each island determined the geographical location, difference in geology and degree of weathering, and that in the profile and scale of islands. From this point of view, Forsberg (1965) considered the consequence of interaction between physical settings and fauna including human being as well as flora as an island ecosystem, and classified islands into "high island" and "low island", based on their profile, which ancient islanders had just used on their inter-island voyage.

Mezaki (1985) redivided the Ryukyus into mountain island, volcanic island, terrace island, raised coral reef island and sand cay island to examine islands' ecological characteristics according to their origin. On the other hand, to emphasize understanding about island ecosystem in reference to living environments for human being and land use, Hori (1996) added further criteria evaluating the behavior of water: whether or not the subsurface geology is reef limestone for low islands and whether or not the highest point is above 500m for high islands. That is to say, in the case of islands consisting of limestone, precipitation immediately infiltrate not to become surface runoff. So on these islands it is difficult for fauna and flora to use water. The height of 500m for high islands is the criterion of the covering rate of clouds. High islands above 500m have more chances than low islands to be covered with clouds bringing much precipitation.

Since runoff is an important agent bringing sediment into the habitats to maintain them, as it has been pointed out, Hori's (1996) classification is helpful to evaluate physical setting around mangrove habitats, and mechanisms of maintenance and tolerance to sea-level rise. For example, we can find estuary/delta type of mangrove habitats on Kosrae Island, Federate State of Micronesia, which consists of raised coral reef. The presence of a peat layer, without fluvial sediments, up to 3m thick below the forests, however, indicates that mangrove forests have kept up with sea-level rise by maintaining their habitats on their own (Fujimoto *et al.* 1996b). This result suggests that among the same type of habitats, the tolerance of mangrove habitat against sea-level change differs depending on the island type; mangrove forests on "low islands" are considered more fragile than those on "high islands".

**Environmental settings for mangrove habitats on Tongatapu Island**

Mangrove habitats could be divided into three types based on geomorphological setting in respect to habitats maintenance as previously discussed. On Tongatapu, mangrove habitats may belong to the backmarsh/lagoon type, because rivers are not developed, as a result of geomorphological and geological setting, and riverine detritus inflow to mangrove forests is negligible as well. The biological products such as litter and roots of mangrove plants being another source of deposit are considered not so available compared to mangrove forests on islands near the equator, because this island is located near the southern distributional limit of mangrove species. The decline of biological production is reflected in the smaller size of trees. Another aspect of this marginal position is concerned with species composition. Environmental setting is generally harsh to organisms in such biogeographical conditions, and even a small environmental change could be a catastrophic event, and competition with others which occupy a close niche to theirs would be a serious problem. For example, mangrove forests comprise a small number of species in such a distributional limit. Thus, after cutting down the mangrove species, that habitat would be replaced by other plant species, not mangroves. It seems that this would be likely to occur at the boundary of mangrove and terrestrial forests where people cut trees extensively due to the easy accessibility, and both physical processes and reactions of mangrove species have mitigated severe conditions for terrestrial species.

These habitats vary depending on location within the island. The mangrove habitats located on the north coast of the island face the ocean across the reef lagoon and are expected to be affected by coastal processes, while the mangrove habitats fringing the Fanga 'uta lagoon are relatively protected from them because of enclosed features of the lagoon against the ocean.

The detailed vegetation map around the Sopu district on the north coast of the island where the largest mangrove forest extends is shown in Fig. 2. A sand bar covered with terrestrial species exists on the seaward side of this habitat. This indicates that the

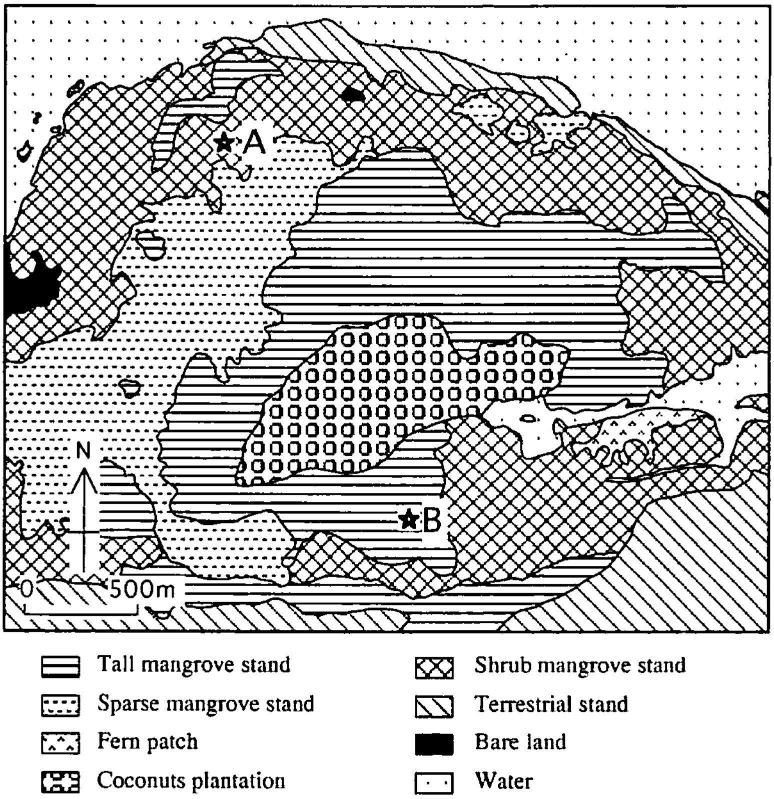


Fig. 2 Vegetation map around Sopu
Source: Aerial photograph taken in 1981

habitat formation was preceded by development of the sand bar (while it is not clear when it developed) providing protection from coastal processes for the establishment of mangrove forest over an extensive area. Fossil micro-atolls are found in some part of this forest, indicating that a micro-atoll field had been changed into mangrove forest. The top of these micro-atolls and the ground surface level are same and mangrove species *R. mangle, R. samoensis, R. stylosa* and *E. agallocha* grow directly on them. The top of living micro-atoll is usually equivalent to the level of mean low water spring. Since mean low water spring is 50cm below M.S.L. on Tongatapu and *E. agallocha*, which needs highest level among mangrove species on this island, grows at 70-90cm above M.S.L. (Ellison 1989), direct growth of this species on fossil micro-atoll implies that relative sea-level fall of at least more than 1m should have been occurred. Other studies have estimated, however, that the recent sudden sea-level fall was 20-40cm. Zann (1984b) estimated the rate of sea-level change in comparison with the upper level of living and dead corals. Ellison (1989) also discussed that the pollen component within the upper peat covered lagoon deposits directly, and showed the sudden shift of lagoon to *B. gymnorrhiza* stands, supporting Zann's idea about sea-level change. This disagreement of estimation results from the lack of description about the level of fossil corals in reference to sea-level and limitation of Bruguiera pollen to be used as a sea-level indicator according to the depositional characteristic as Ellison (1989) has recognized. At least we may conclude that this habitat has experienced drastic change corresponding to this abrupt fluctuation of relative sea-level, although we need further discussion to estimate the rate of change.

To examine the history of the mangrove forest on the north coast, excavations were done at Sopu (Fig. 3). Under seaward mangrove stand of this forest (point A), the sedimentary structure could be divided into two units. The lower unit which is 43-70 cm below ground surface consists of branched coral fragments filled with marine sand. The density of fragments decreases with depth. The upper units are characterized by the presence of coral pebbles. Zann (1984b) observed large amounts of dead coral on patch reef at the entrance of the modern lagoon. He attributed these high mortalities to high siltation which is effective at such location. Organic matter is rare all over the depth including surface sediment which is sandy deposit at this point. It is considered that such a high content of coral fragments and the lack of organic matter may indicate that establishment of this mangrove stand is quite recent. that is, although this stand has been established previously, the status was poor.

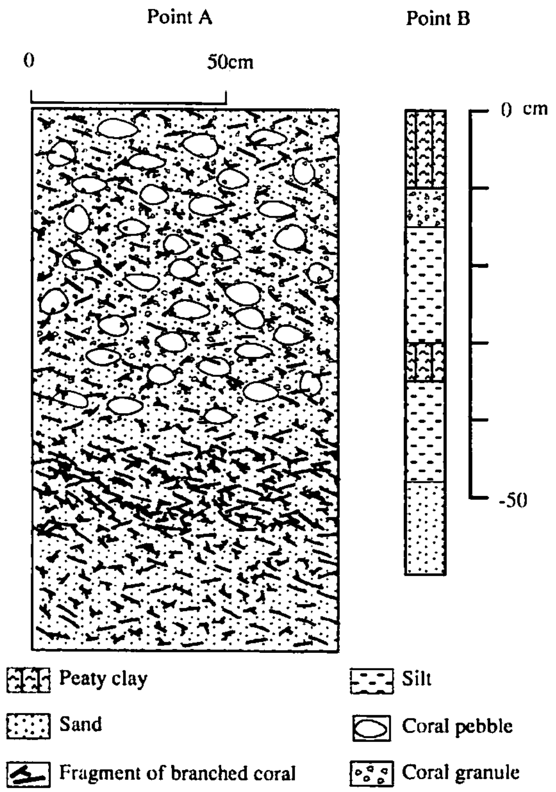


Fig. 3 Sediments profile under mangrove forest around Sopu
See Fig. 2 for locations.

Point B is in a tall mangrove stand which is dominated by *B. gymnorrhiza* and *E. agallocha*. At this point, we could find two thin peaty layers at 0-10cm and 30-35cm below ground surface, which means the mangrove forest existed at that time. They form alternating beds with marine sediments reflecting sea-level fluctuation. The second unit composed of sand contains oxidized yellowish granules. This finding may suggest abrupt fall and rise of sea-level during this period, but there is not enough evidence to decide this event and it is impossible to relate the oxidized layer to the abrupt fall of the sea-level mentioned above. On the other hand, in the largest mangrove area in western arm of the Fanga 'uta lagoon at the Folaha district, mangrove peat was found at the depth of 0-30cm below ground surface and 130-230cm below M.S.L. (Ellison 1989). The presence of the lower peat unit at that level is restricted to Folaha, and Ellison (1989) attributed it to the protection by the lagoon.

Of the results presented above, although qualitative, the comparison of ratios of organic and inorganic matter and that of peaty layers thickness between both sites indicate that the forest located on the inner-most side of the lagoon has more ability to tolerate sea-level change than that located on the more exposed area on the north coast of the island. Apart from the sea-level rise, it is considered that the difference of modern status of mangrove forests might be reflected in whether die-back stands are found or not. The sparse stands composed of dead *E. agallocha* are present in Sopu. Fujimoto and Ohnuki (1995) observed that *B. gymnorrhiza* stands had established on the natural levee where inundation frequency was high and usually *R. stylosa* stands would be found. They attribute the establishment of these unusual stands to the more sandy deposit at that sites compared to adjacent sites where *R. stylosa* stands are established, which is due to physical processes and results in better drainage properties. It is considered that a similar cause is involved in the case of presence of die back stands at Sopu. While surface sediments in the mangrove forest at Folaha consist of peat, those at Sopu consist of coral pebble, fragments of branched coral and sand. The latter is more sensitive to environmental change such as hydrological conditions.

## 4. Use of Mangrove Environments and Its Socio-economic Background on Tongatapu Island

The use of mangrove environments on Tongatapu can be divided into two categories based on types of resources (Table 1). This usage has changed corresponding to the change of the socio-economic background, and the change has given different meanings to mangrove ecosystem. In the following sections, we will describe the transition of human impact on the mangrove ecosystem (Fig. 4).

### Traditional use

The mangrove forests in Tongatapu produce bark used as dye for tapa cloth and as fiber for traditional cloth and tool of dye making, wood used as construction materials and firewood, and fruits used as medicine. Of them, the most extensive use has been dye

Table 1 Use of mangrove environments in the Kingdom of Tonga

| | Usage | Usage in Tonga | Species | Organs in use |
|---|---|---|---|---|
| Forest resources | Dye | Dye for tapa cloth | *Bruguiera gymnorrhiza, Rhizophora stylosa* | Bark |
| | Firewood | Fuel for dye making and cooking | *B. gymnorrhiza, R. stylosa, Excoecaria agallocha, Xylocarpus granatum* | Trunk/ Branch |
| | Medicine | Medicine for stomach | *X. granatum* | Fruit |
| | Construction material | Pole for house and fence | *B. gymnorrhiza, E. agallocha, X. granatum* | Trunk/ Branch |
| | Others | Traditional cloth, tool for dye making and handicrafts | *Hibiscus tiliaceus, Pandanus* sp. | Bark/ Leaf |
| Land resources | Rubish dump | Rubbish dump for urban residents | - | - |
| | Land for construction | Residential area, harbor, and cultural facility | - | - |

making. The tapa cloth is made from paper mulberry (*Broussonetia papyrifera*) which was formally used for clothing, but is recently treated as ornament in ceremonies such as the cerebration of King's birthday , weddings of family and relatives, and so on. Not only mangrove species but also a terrestrial species "koka", *Bischofia javanica*, is used as dye for tapa cloth. Tongans prefer mangrove species, however, to "koka" because of better color. On the contrary, they used to prefer terrestrial plants to mangrove plants, which grow in their tax 'api, government-allotted farm land, as construction materials and firewood, and coconuts husks as firewood (Central Planning Department 1991). It is considered that this was due to the difficulty of collection concerning the limitation of mangrove forests distribution on Tongatapu.

Mangrove plants have been used selectively depending on purpose and the collection activities of such materials are also selective, like thinning. For example, specific species were barked in the forest without cutting down the whole tree. The barked trees used to survive in usage for dye making. Even in usage as construction materials, if the tree had been branched, not all the branches were cut down in consideration of regeneration.

**Change of socio-economic background and recent use of mangrove environments**

To predict the perspective of use of mangrove environments on Tongatapu, it is necessary to evaluate their socio-economic background. Tongan economy has drastically changed during last few decades. The major industry in the Kingdom of Tonga was formerly agriculture cultivating coconuts. The coconuts industry suffered, however, depression all over the world. That makes Tongan start looking for other jobs, wage work. Change of the industrial structure shows the development of service industry (Fig. 5).

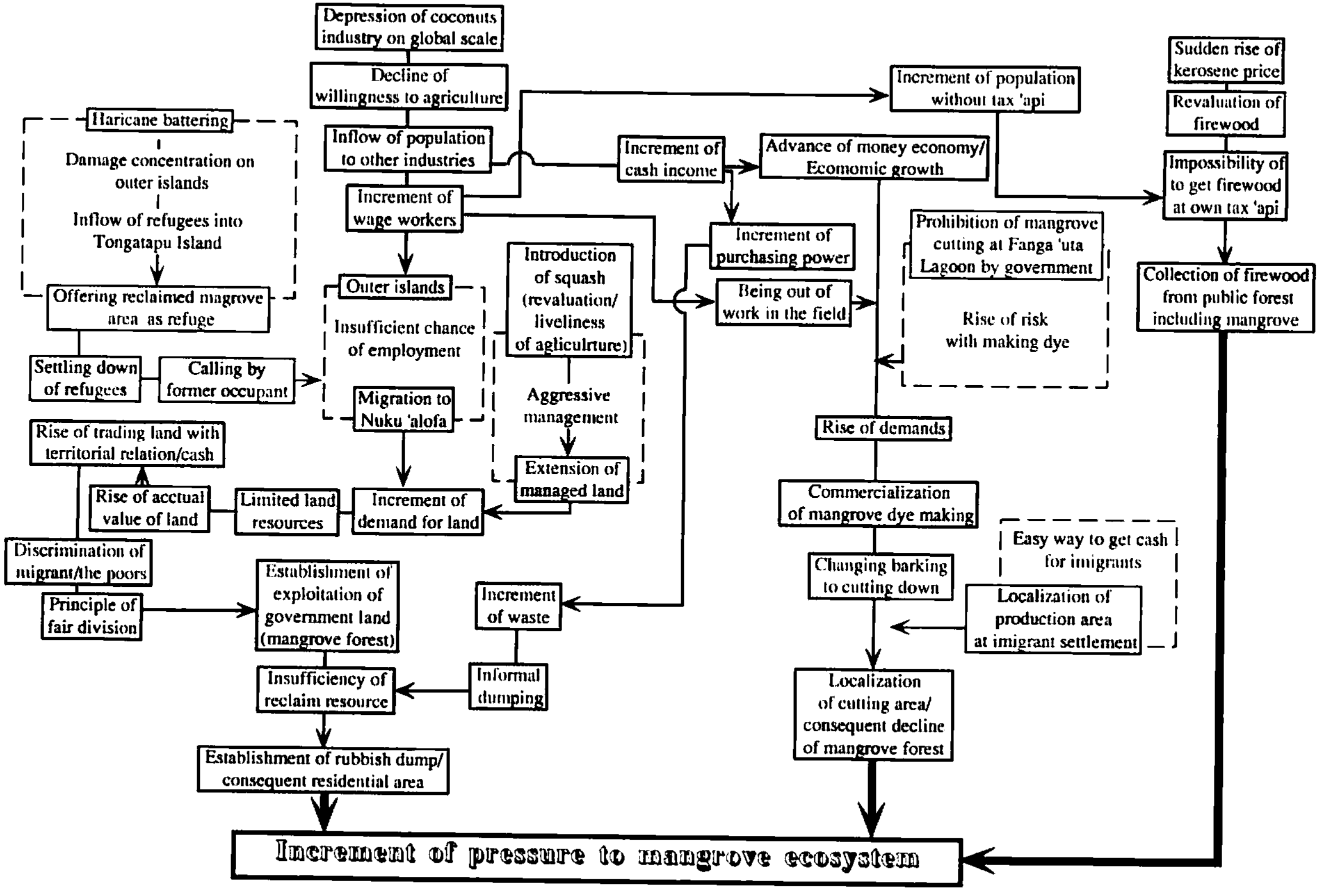


**Fig. 4** Sosio-economic background of use of mangrove environments on Tongatapu Island

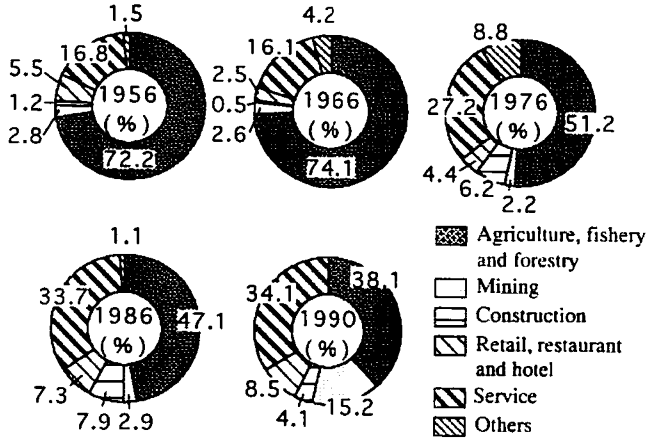


Fig. 5 Change of industry structure in the Kingdom of Tonga
Source: Ministry of Work

Due to increments of wage workers, the Kingdom of Tonga has been involved into "money economy", and this is one of the keywords concerning the changes in the use of mangrove environments. The coconuts farming, in fact, brings some money to people, but they can afford only daily necessities. Their purchasing power has been increased these days, and people start to spend money for luxury goods. Squash cultivation for Japanese markets also brings big money to farmers and would be a factor changing whole of Tongan economy. One example is the surge in the numbers of cars registered coinciding with the start of squash export to Japan. Change of mangrove dye status from subsistence product to commercial one may result from the advance of money economy and subsequent rise of demand by urban residents. Urban residents tend to avoid the work in the field. And as the government has prohibited the cutting of mangrove plants fringing the Fanga 'uta lagoon by the Birds and Fish Preservation Act in 1974, people have faced the risk of a fine to make dye. So, since the end of 1980s, dye has been sold at market in Nuku' alofa and urban residents prefer to buy it instead of making it on their own.

Corresponding to the change of mangrove dye status, shifting from barking to cutting down for collection of mangrove bark has occurred in order to manufacture larger quantities of mangrove dye. People collect bark 2-3 times a week with cutting off the branch or even cutting down the trunks instead of barking there once a week. This change of the way to get bark is related to how to produce dye from bark. Bark is soaked into water, and then boiled to squeeze tannin out of it. To operate this process, large amounts of firewood is needed, and people start to cut down mangrove plants to use them not only as dye material but also as firewood. As mangrove dye industry has developed, some villages are specialized to make the mangrove dye, and cutting areas of mangrove forests seem to be localized. This means decline of mangrove forests at specific sites and it has been reflected in the expansion of the cutting field to the small islands in the lagoon by villagers due to the shortage of suitable trees in the previous site.

At the same time, the land tenure system in the Kingdom of Tonga is concerned with recent increase of human impact on mangrove ecosystem. All the land of the Kingdom is the ultimate property of the Crown. It is divided into the King's hereditary estates, the Royal Family's hereditary estates, the hereditary estate of the nobles, and government land. The two last categories are subdivided into allotments for the population. Each Tongan male reaching the age of sixteen is entitled to an allotment of 3.34ha of rural land for farming, and that of 1,618.8m$^2$ in town for residential purpose. These allotments are allocated by government and are hereditary. This land entitlement, however, has not been fully honored in recent years because of shortage of available land. Although the constitution states prohibition of selling any land in the Kingdom of Tonga, it is possible to expand their farm lands and residential lands by lease contract based on the territorial relation or money. Rapid growth of population on Tongatapu and liveliness of agriculture due to the introduction of squash brought a rise in the actual value of land in making contracts. This resulted in difficulty to get new land on Tongatapu especially for immigrants from outer islands who are unlikely to have territorial relation or money. This trade of lands had prevented even regular allotment, and it was estimated that only a third of Tongan males over sixteen have registered allotments (Central Planning Department 1991).

There has been a tendency to subdivide allotment and register low-lying areas reclaimed for housing adjacent to the urban center of Nuku 'alofa as town 'api (land for residential purpose) concentrically to solve this problem. This is the result of the characteristics of population growth on Tongatapu. One of the factors of rapid population growth on this island is immigration from outer islands where people can scarcely get a wage work. More than 90% of the service industry (except tourism industry) is concentrated around Nuku 'alofa. So most of immigrants are wiling to live around the city. Moreover, when Hurricane Isaac battered the Kingdom of Tonga in 1982, the worst damaged areas were concentrated on the outer islands. At that time, the government provided reclaimed mangrove habitats as temporal refuges to refugees. Then, they settled down there and started to call their relatives and established the settlements in these areas.

These areas adjacent to Nuku 'alofa have another role for urban residents. Government has located municipal rubbish dump in these areas. Tongatapu Island is insufficient for natural resources such as gravel and sand which are used for reclamation of mangrove habitats. Thus rubbish is considered as substitute of them to some extent. Other conversions to pier for hotels or private and to cultural facilities run by government are found, but their number and area are relatively small. Of these conversions, therefore, the cutting for rubbish dump and residential areas is most destructive for mangrove forests.

It is expected that the impact on mangrove ecosystem for use as firewood will increase. The change of kerosene price and fuel type used in household are presented in Fig. 6 showing that the major type of cooking fuel has shifted from kerosene to firewood after the sudden rise of the kerosene price in the end of 1970s. This shift brought the shortage of terrestrial plants as firewood and not only the mangrove dye makers but also people who do not have tax 'api (farm land) have recently used mangrove plants which

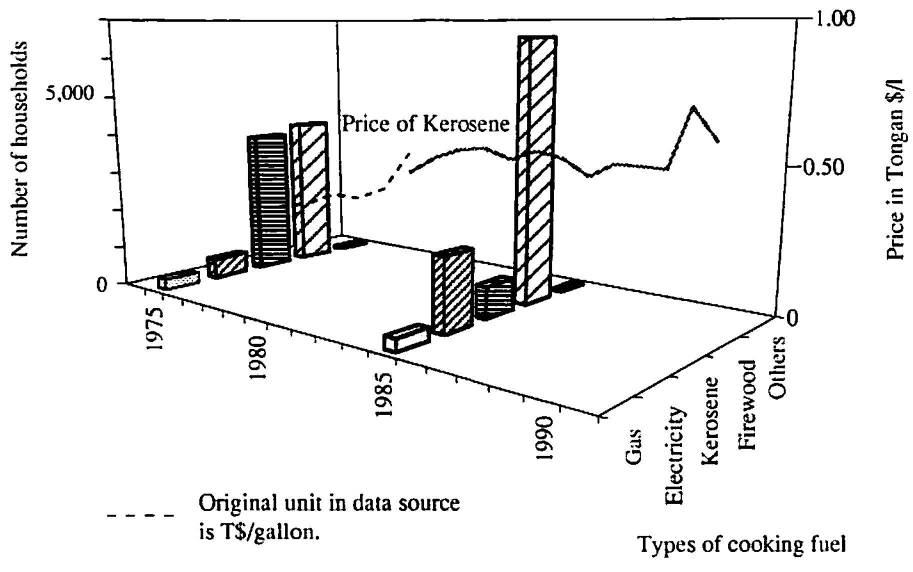


Fig. 6 Change of Kerosene price and types of cooling fuel in the Kigdom of Tonga
Source: Tonga Statistics Department

were generally considered as communal forest resources.

## 5. Possibility of Sustainable Use on Tongatapu Island

As mentioned above, while mangrove forests on Tongatapu are sensitive to environmental change, especially to sea-level rise, they have suffered high pressure of human impact since the mid-1980s. This increase of impact is a consequence of the shift of socio-economic environment in the Kingdom from the subsistence economy to the money economy, and it is considered that this increase of impact is as irreversible as the shift of socio-economic environment. Thus, over-usage of mangrove environments will cause the utter destruction of mangrove forests, and this destruction of forest will in turn cause the complete disappearance of mangrove forest on Tongatapu, since maintenance potentiality of the mangrove habitats on this island against predicted sea-level rise relies on their biological production.

The limitation in natural resources for the Kingdom as a characteristics of island countries is. however. another fact. Mangrove environments as forest products resource and land resource are highly indispensable for Tongan life and use of mangrove environments is unavoidable. Therefore, it is needed to manage the forests in an appropriate way. As one of the major cause of over-usage of mangrove forests is dye making. one possibility is to resort to cultural identities of Tongans by making them aware of the meaning of what they have done. The use of mangrove plants as dye material is closely related with passage courtesy and celebration of the King, and it is considered as one of the identical practice for Tongans. Due to the need of best quality of color as dye for tapa cloth, there is no substitute of mangrove dye. So the loss of mangrove forests could result in the loss of identities for Tongan. Some villagers selling the dye at the market have shifted the barking practice to the previous way to conserve mangrove forests. We consider that the best way of conservation of ecosystems should be voluntary reduction of their use.

Another cause of mangrove forest destruction is reclamation for other land use. This is inappropriate not only for mangrove ecosystem but also for Tongan life in respect to natural disasters and health problems that resulting from poor sanitation. The reasons for shortage of lands are concerned with land tenure system and concentration of job availability on Nuku 'alofa. So it is considered that the only way to stop reclamation of mangrove habitats should be improving policies on these matters.

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