VULNERABILITY OF SOUTH PACIFIC ISLAND NATIONS TO SEA-LEVEL RISE

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ABSTRACT

Anxiety among Pacific peoples about the effects of future sea-level rise comes from their past experience and familiarity with the vulnerability of their island environments. This vulnerability includes physical (material) vulnerability, typified by the low islands of unconsolidated sand and gravel which many atoll islanders inhabit, and socioeconomic vulnerability. Many Pacific island nations have fragile economies as most of their inhabitants grow their own food. In addition, undesired environmental changes are occurring increasingly in the name of development.

This paper concentrates on Fiji, Tonga, and Samoa, three nations of predominantly high islands in order to emphasize the point that these too are highly vulnerable to future sea-level rise. Among the common problems of these nations are the effects of increased hurricane frequency, clearance of protective mangroves, degradation of protective reefs, building of inappropriately designed artificial structures along coasts, and generally complex systems of land ownership which are not conducive to relocation of coastal settlements under threat. A strength lies in the resilience of the traditional systems for self-help and support following natural disasters.

Additional Index Words: sea-level rise, Pacific islands, island vulnerability.

INTRODUCTION

By their very nature, nations comprised of large numbers of small islands have much larger coastlines proportional to their total land areas than continental countries. The resulting importance of the coastal zone is accentuated by the concentration of island people and economic activity along island coasts. Pacific islands with large or small interiors all have populations that have settled near the shore. An extreme example is provided by Rarotonga

Island in the Cook Islands, where only a handful of people occupy the island's high mountainous interior. On Taiwan, people have recently started to farm the island's mountainous and highly unstable slopes in the interior as the surrounding lowlands have become overcrowded.

Among all future dangers which threaten our planet, that involving sea-level rise driven by anthropogenically-induced temperature rise, is that most feared by Pacific island peoples. In 1989, President Amata Kabua of the Marshall Islands eloquently expressed the view:

> It is truly frightening to think that our ocean will turn against us. We have been sustained by the ocean for two millennia. It has been bountiful and continues to yield to us its bounty. We have learned that this harmony may be interrupted by the action of nations very distant from our shores. I hope that the appeal of the peoples of the Pacific can help convince the industrialized nations to discontinue their profligate contamination of the atmosphere.

Estimates of sea-level rise have been lowered in recent years, but the probability of a significant rise by the end of the next century remains. Given these revised estimates, sea level could rise as little as 0.2 m or as high as 1 m. Such a sea-level rise would represent an acceleration in the rate in the Pacific islands of around 4-5 times (Wyrtki, 1990; Nunn, 1993).

Sea-level rise over the past hundred years has had severe consequences for many Pacific island coasts (Nunn 1992). Should the predicted sea-level rise come about, the consequences will be far more severe, more widespread, and will require more sophisticated solutions than those which have ever been adopted by humans in the region to date.

How much and how fast future sea-level will rise, and what its effects will be on Pacific island coasts, is information which is clearly of importance to Pacific island governments and their people. In addition, if governments are to make optimal plans for mitigating the worst effects of this sea-level rise, they must know where their countries are vulnerable and just what options they have to reduce vulnerability. This paper addresses some of these issues.

ISLAND NATIONS OF THE SOUTH PACIFIC

Island nations of the South Pacific have varying degrees of vulnerability to sea-level rise and climate change. It is misleading to generalize about an entire country as this may disguise significant variations and also encourage extremes of complacency or resignation. For example, the large islands comprising nations such as Fiji, Vanuatu, and the Solomon Islands in the western Pacific have commonly been regarded by decision-makers as having low vulnerabilities to future sea-level rise. Yet, most of the people in these countries live along the coast and most development is there; the economic future of these countries is almost wholly dependent upon activities along the coast. Were these areas to be adversely affected by future sea-level rise, the consequences for the nations' future could be severe if no substantial pre-planning has taken place.

Another example involves low atoll islands of a kind that dominate the Pacific nations of Kiribati, Tokelau, Tuvalu, and the Marshall Islands. Many atoll islands (*motu*) could be rendered uninhabitable by flooding associated with water-table rise or salt-water intrusion within the next few decades. Other atoll islands, which rise slightly higher and are differently constructed compared to the widespread *motu*, could endure longer and perhaps remain habitable, even after a sea-level rise of 0.5 m.

The autonomous Pacific island nations are generally considered part of the "developing world". In terms of climate change and sea-level rise, this means that they have neither the in-house expertise to address the many associated issues nor have they the resources to confront the worst impacts with expensive "big-fix" solutions as have many more prosperous countries. The emphasis in many such countries is thus on accommodating the worst effects of sea-level rise and climate change rather than attempting to moderate or mitigate them.

Most Pacific people living in the island nations are largely self-sufficient. They plant enough land to grow adequate food to feed themselves and their dependents. Their cash needs are met in various ways, including producing surplus crops for sale and receiving money remitted home by family members working for wages elsewhere. Foreign investment on the islands generally pays its largest dividends to shareholders outside the islands. Many large projects are funded by aid or soft loans. Development aid in the Pacific islands has singularly failed to generate self-sustaining growth as aid-dependency continues to increase (Gibson, 1993).

Most land in the Pacific is communally owned by the indigenous peoples. This is not conducive to foreign investment and has been cited as a hurdle to many varieties of development. Ownership by a kinship group rather than an individual complicates matters still further, particularly if one section of the group opposes the view of another concerning the future of their land.

Many Pacific islanders also retain a strong bond with the land which transcends simple ownership and use and involves a metaphysical dimension. For example, many groups respect the land as their ancestors, many traditional chiefs are regarded as the personification of the land. Ravuvu's (1983) discussion of the *vanua* is representative. Such religion-cultural ties are an important element of assessing coastal vulnerability.

Over the past few years, we have been part of teams studying the impacts of future sea-level rise and climate change on Pacific island nations coordinated by the South Pacific Regional Environment Programme (SPREP). The goal of the first set of projects was to make a rapid overall assessment of the likely impacts of predicted sea-level rise and climate change (e.g., Chase and Veitayaki, 1992; Nunn and Waddell, 1992). A second set of projects focused on adapting the common methodology for assessing vulnerability of sea-level rise (IPCC, 1992) to the Pacific Islands; work has been partly completed for Fiji and Western Samoa (Nunn et al., 1993, 1994a, b; Kay et al., 1993).

To illustrate the nature of vulnerability on various types of islands and island nations in the Pacific, we discuss three case studies: Fiji, as an example of a generally high vulnerability, but

diverse island nation: Tonga, as an example of a group of predominantly limestone islands with low-high vulnerability: and Western Samoa, as an example of a group of volcanic islands with high vulnerability. The Fiji economy is growing; the other two are not. All three nations have a large and disproportionately important coastal zone, all are largely subsistence-based, and all have expressed their concern about the impacts of predicted future climate change and sea-level rise.

Fiji, Tonga, and Western Samoa all lie in the southwest Pacific Ocean. Island-building processes associated with the convergence of lithospheric plates in this region have been largely responsible for the origin of these islands (Nunn, 1994). Owing to their location within the tradewind zone, high islands in these groups commonly exhibit a difference in vegetation between windward and leeward sides. All three island nations lie within the tropical cyclone (hurricane) belt although Western Samoa is on its margins and receives fewer. Most island coasts are coral-reef fringed and extensive areas of mangrove occur throughout the groups. Beaches of coralline and mafic sand-size material are common in these islands. Tidal ranges rarely exceed a meter.

FIJI

Fiji consists of approximately 360 islands that are greater than 0.5 km^2 in area, approximately ninety of which are permanently inhabited. The largest is Viti Levu (10,388 km^2). The population is approximately 800,000; the largest city is Suva, with a population approaching 200,000.

The longest temperature record in the Pacific islands comes from Government House in Suva and shows a 0.4 - 0.6° C rise in the last hundred years. Tide gauge records are much shorter, and long-term trends are difficult to interpret because of the islands' tectonic instability (Nunn, 1991). Long-time residents of coastal settlements in Fiji have witnessed submergence of lower lying lands that is likely associated with a recent rise in sea-level. Sea-level rise scenarios indicate a future acceleration in the rate of rise (Figure 1).

The nature of the recent shoreline inundation and/or retreat in Fiji, which has been attributed to sea-level rise, has been studied in some detail (Nunn, 1993; Nunn et al., 1994a). Some island coasts have retreated more than 100 m inland which has produced social problems because of Fiji's complex system of native land ownership. People cannot simply move their settlements inland because this may involve living on land other than their own (Figure 2).

Human responses to sea-level rise have often involved building seawalls. Such commonly impermeable vertical structures have resulted in increased scour and sediment mobility offshore, and collapse of the wall through undermining by wave action can occur over a relatively short time. The effects of inundation and shore erosion due to sea-level rise have been exacerbated on many coasts by the clearance of coastal vegetation, particularly mangroves, the mining of sand, and construction of other artificial structures without a clear understanding of coastal dynamics (Figure 3).

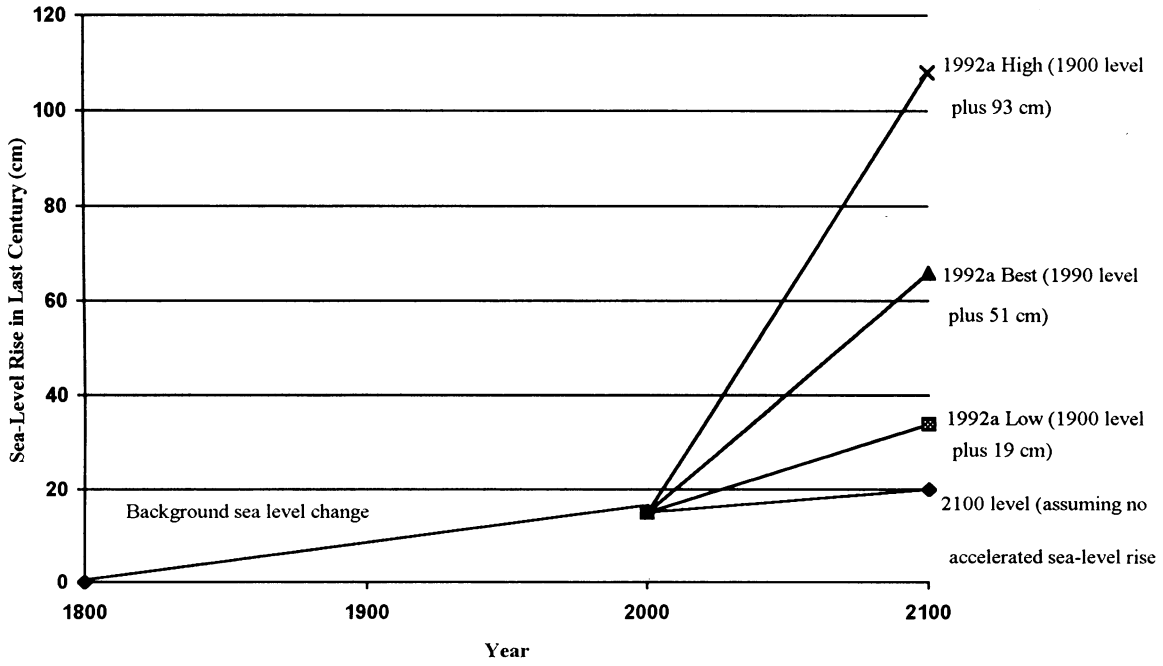

Figure 1. Scenarios for future sea-level rise in Fiji (Nunn et al., 1994a).

Figure 2. The village of Tovu, Totoya Island, Fiji. Although it does not face the open ocean, the shoreline has receded some 30 meters in the last 70 years or so. Shore erosion has caused the village itself to migrate slowly inland; note the cleared area behind the village where the school and several houses are now situated. A solitary groin is the sole shoreline protection; more vegetation could be planted.

Figure 3. The shoreline at Nasauvuki Village, Moturiki Island, Fiji. Problems of shore erosion and flooding have been caused largely by mangrove clearance. Mangroves are growing back but are pulled out when they get about 0.5m in height. The seawall is typical. The house has a raised front door, but water still spills over the doorstep at high tide. Tidal range is about one meter. This site faces a reef-enclosed lagoon.

Rising sea level along Fiji's coasts for the past hundred years has resulted in erosion in some places, which is an expected consequence. Along reef-fringed coasts, the response is not so easily modeled, although probably similar. Yet, it seems that the comparatively slow rate of sea-level rise for the past hundred years has resulted in only very slow changes in the equilibrium profiles of sandy shorelines in Fiji which have gone undetected by the residents. Such changes may not have been detected because of their slow rate and because they have been overshadowed by rapid changes associated with tropical cyclones (hurricanes). Tropical cyclones affect Fiji most years, and there is evidence that their frequency in the Pacific region has increased in recent decades (Figure 4; Nunn, 1992, 1994). Storm surges associated with tropical cyclones commonly result in large amounts of sediment being transported to Fiji's shores in addition to massive amounts of erosion and flooding. The observed increase in tropical-cyclone frequency may have disturbed the long-term equilibrium of many coastal systems in Fiji; this disequilibrium is likely to be maintained as sea level rises much faster in the future.

In Fiji, there is clearly an additional dimension to vulnerability assessments involving a site's location relative to the capital island. Places on Viti Levu Island, by far the most developed in

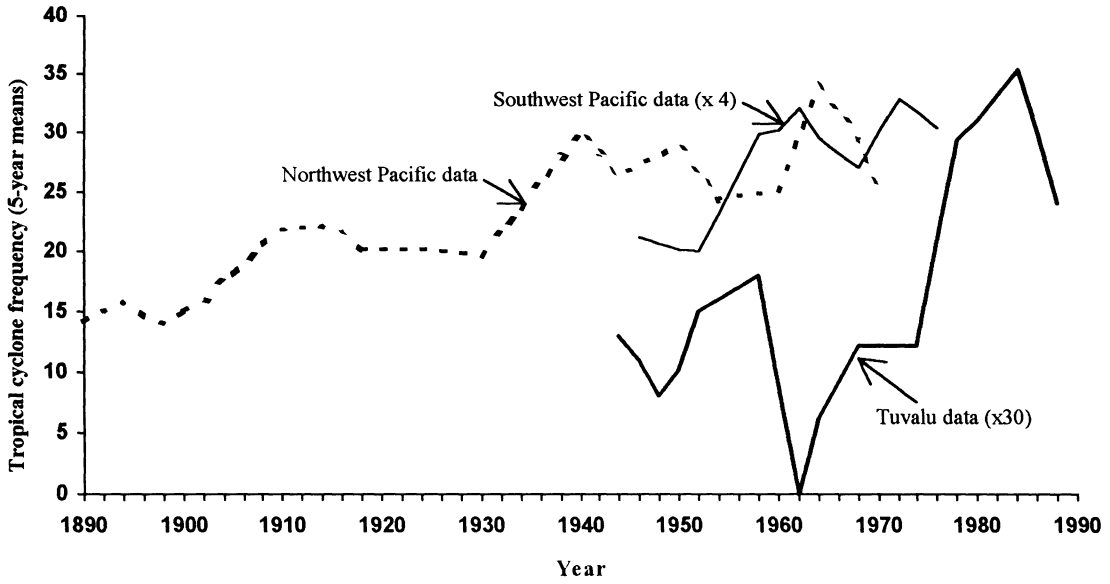

Figure 4. Tropical cyclone frequency in the Pacific Basin (Nunn, 1994).

terms of infrastructure, are closest to the urban centers like Suva and Lautoka and, for this reason receive better advice and more substantial direct assistance than places at the periphery, particularly outer islands.

The effects of future sea-level rise (Figure 1) on the physical character of Fiji's coasts have been studied in detail (Nunn et al., 1993, 1994a). Vulnerability is discussed under two categories: natural and anthropogenic.

Natural Vulnerability

Natural vulnerability combines the materials from which a particular coast is made with natural hazards such as storm surges and high waves, landslides, tsunamis, earthquakes, and tectonic movements. Natural protection provided by mangroves and coral reefs is important in maintaining a low vulnerability (and high resilience); loss of these ecosystems through human activity and/or natural environmental stress (pollution, ocean-surface warming, etc.) is an increasing concern.

If sea level rises 0.5 m in the next 100 years, this will increase erosion along sandy shorelines and, for this reason, natural shoreline protection provided by coral reefs and mangroves should be optimized. Increased soil erosion, probably associated with both human impact and climate changes (particularly increased tropical-cyclone frequency), should also be halted.

Anthropogenic Vulnerability

Many human population settlements in rural Fiji can respond effectively to increasing coastal inundation and degradation by rebuilding or slightly shifting their settlements. Many houses are built of materials which are easily renewable at little cost, though more and more permanent homes are being constructed, limiting the options and increasing the vulnerability. Further, options for distant relocation, which may become necessary in the future, are restricted by the complex system of land ownership.

As the urban areas of Fiji have grown over the years, more land has been reclaimed from the sea in response to the demand for flat land close to the shore. Much of that reclamation was not designed to support large buildings and is made from material which may be easily eroded when sea level rises. Yet, the value of property threatened by sea-level rise in urban Fiji is so great that artificial protection from the sea is the only option.

Most roads have been built adjacent to the shoreline of Fiji islands, and many roads will be threatened as sea level rises. Yet, the economic impact would not be particularly great unless major routeways were repeatedly washed out. Other infrastructure that would be disrupted would include sewage treatment plants, refuse dumps, ports, and airports.

National institutions, particularly those associated with government, are likely to be able to respond most effectively to future disruption associated with sea-level rise. Government is likely to stretch its resources to protect essential services. Other institutions, particularly traditional ones in rural Fiji, are being broken-down today and sea-level rise is likely to catalyze this process (Ravuvu, 1983; Nunn et al., 1994a).

Most major investments would be shielded or artificially protected from the impacts of sea-level rise. Yet smaller investments, including smaller tourist resorts "off the beaten track", might become highly vulnerable. It is likely that here, as elsewhere, economic vulnerability would be exacerbated by sea-level rise.

In rural Fiji, many important crops for both domestic and export markets are grown in the coastal zone and could be threatened by sea-level rise. A good example is sugar cane, a crop which is highly intolerant of saline groundwater, and yet which dominates lowland areas on the two main islands in Fiji and is a highly significant export nationally (Table 1). New approaches to the agricultural economy, including the development of new crop strains that are more tolerant of saline conditions, are necessary (Aalbersberg, 1993).

As land is lost to the sea and traditional remedies fail, so young people are likely to become more disillusioned with the traditional ways and abandon them. This problem is likely to extend into the area of land tenure in rural Fiji in the future as certain family groups (*mataqali*) are displaced from their traditional land and old conflicts about property rights elsewhere are revived. This problem is likely to be least acute on small outer islands where population densities are low and most land is owned by only a few groups.

Table 1. Value of sugar relative to other exports 1992-1994; figures are in US $ million

	1992	1993	1994
Sugar	147.2	149.6	171.5
Garments	79.2	83.5	95.5
Coconut Oil	3.8	2.4	2.6
Gold	40.4	43.3	42.6
Fish Products	26.1	28.0	44.7
Forestry Products	23.9	20.0	21.2
Molasses	8.7	6.5	9.2
Other	41.1	48.3	59.0
Domestic Exports	370.4	381.6	446.8
Re-export	74.7	67.5	97.6
TOTAL EXPORTS	445.0	449.1	544.4

Source: World Bank, 1995.

Despite these problems, Fijian culture remains strong and traditional support networks are activated in times of crisis. This system is likely to endure and even become stronger if a major crisis, such as major land loss caused by cyclones and sea-level rise, should come to pass.

The cultural value of particular sites is likely to be lost in cases where those sites are impacted by erosion and/or inundation. A good example is the oldest-known settlement site in Fiji at Natunuku on the north coast of Viti Levu. This site has been eroded by the sea for decades and much has been lost; the cultural value has been lost for the Fijians in the area; nearby Indo-Fijian farmers rebury the human bones found along the shore.

TONGA

The islands of the Kingdom of Tonga have a land area of 668 km^2 distributed among some 169 islands; the total population is just under 100,000. The islands occur in two groups: a volcanic and a limestone group. Most people live on the limestone islands as many of the volcanic islands are still active.

There is good evidence of sea-level rise in records kept at Nuku'alofa, the capital of Tonga. Sea-level rise impacts have affected all studied coastal sites in Tonga except on Niuatoputapu Island, which is being uplifted by tectonic activity (Nunn, 1990b). Other parts of Tonga may also be rising but the most densely-populated area, the north coast of the island of Tongatapu, is not. This area appears to be slowly sinking at present, and problems associated with this subsidence are manifest.

All land in Tonga is ultimately Crown Land but in effect it is divided between the royal family, the nobility, and the government. Most adult Tongans are allocated part of the nobles' land for farming but land has now run out on Tongatapu, the largest island, and people are thus

crowded into the narrow strip of government land (or land below high water, which is unallocated) along the north coast on either side of Nuku'alofa.

Problems of shore erosion have been addressed by seawall construction, such as along Nuku'alofa. Coastal erosion has been exacerbated by a long history of beach mining. In recent years, sand has been mined; earlier beachrock in the intertidal zone was quarried to provide tabular facings for graves in particular.

The nature of the shorelines in Tonga and the likely consequences of future sea-level rise and climate change have been studied in a number of reports (Fifita et al., 1992; Nunn and Waddell, 1992). The principal effects are summarized below.

Natural Vulnerability

Many coasts on the limestone islands of Tonga are high and cliffed and appear to resist marine erosion quite effectively, at least compared to a human lifespan. On low-lying coasts, particularly the densely-populated north coast of Tongatapu, considerable inundation and erosion has probably occurred in recent decades, associated in places with mangrove clearance and beach-sand mining. On the low islands of the Ha'apai group, coastal erosion has occurred locally, but much of the sand moved appears to have found its way back to the shore (as is common with reef-surrounded atoll islands).

Future sea-level rise will render low (and low parts of high) islands even more difficult to develop. Rise of island water tables may cause widespread freshwater flooding. Increased shore erosion will also occur, resulting in increased offshore sediment mobility and consequent smothering of coral reefs. Reef smothering will reduce both the successful functioning of this ecosystem and its effectiveness as a form of physical protection against large waves, particularly during storms.

Anthropogenic Vulnerability

The most-threatened populations are in low-lying areas, and most are already under considerable stress because of overcrowding, frequent inundation (during storms), and other environmental problems. On high islands like Vava'u, populations will not be affected by sea-level rise although many of their neighbors in the low Ha'apai group may be displaced with a 0.5 m rise. The problems associated with displaced peoples will have to be addressed alongside the question of land tenure. If the King and his nobles are not prepared to release more land to commoners for settlement, trouble may arise.

Few roads are threatened by sea-level rise in Tonga. Most settlements and roads are located well inland and often tens of meters above sea level. Except in and around the capital, Nuku'alofa, and on some of the smaller islands, there should be no problem.

The international airports on Tongatapu and Vava'u are both high above the water. Major port facilities in Nuku'alofa are likely to be under serious threat if sea level rises as predicted. A 0.5

m rise of sea level would inundate approximately 16% of the existing port area, but would probably render much more unusable (Nunn, 1988).

Faced with the prospect of low-lying Nuku'alofa being inundated as sea level rises, the government is contemplating relocating some departments to higher ground, particularly around the international airport at Fua'amotu and at Neiafu on Vava'u.

Most Tongans grow the majority of their own food, and few of the agricultural areas are in locations where they would be threatened by sea-level rise. Many Tongans are dependent on remittances from relatives working overseas. Although there is a small agricultural export industry, this has proved unreliable as a foreign-currency earner (Fonua, 1992). Current new initiatives in manufacturing, tuna processing, and even hydrocarbons may, if successful, allow Tonga's economy to prosper.

Tongan culture appears to have resisted outside influences quite successfully and would probably withstand major environmental changes associated with future sea-level rise and climate change. Yet the land-access issue is one which needs addressing at the highest level. Traditional support networks appear to be quite strong and are reinforced by the Christian churches in Tonga.

WESTERN SAMOA

Western Samoa comprises two main islands, Savai'i and Upolu, and has a population of approximately 160,000. More than 80% of the islands' inhabitants live in villages, commonly along the coast.

There is clear evidence of recent sea-level rise in Western Samoa. According to the 30-year record from Pago Pago in adjoining American Samoa, the ocean surface has been rising at around 2 mm/year. This interpretation is confirmed by data collected and analyzed by Nunn (1990b) for several coastal sites on Upolu.

The islands of Western Samoa lie away from the convergent plate boundary in the region and have not thus experienced the uplift or differential tectonics that characterize many islands in Fiji and Tonga. Although many authorities have regarded the islands of Western Samoa as sinking fast, there is clear evidence that instead they are stable or sinking very slowly (Nunn, 1997). Anomalous volcanism has occurred in both main islands within the last 10,000 years; the last major eruption on Savai'i was in 1905-1911.

Many coasts in both main islands are formed by the truncated ends of lava flows and thus form cliffs which have proved very resistant to erosion. Other coasts are lower-lying: coastal plains built from materials washed onshore and off the land.

Since the interior of the islands of Western Samoa, particularly Savai'i, is almost uninhabited, there are many more options here for settlements to move inland if their present locations become unsustainable in the face of rising sea level. In recent years, as the government has

built new roads inland, so people and settlements have followed. A good example is the area inland of Puapua on the east coast of Savai'i. The sandy, low-lying coastal site is being rapidly eroded and suffered great damage during the tropical cyclones of the early 1990s. Frustrated at the cost of maintaining the coastal road, the government has started to build another one several kilometers inland, and people are already shifting to this newly-accessible area.

Many environmental problems of Western Samoa are shared by Fiji and Tonga. Along the coast, the clearance of coastal vegetation, particularly mangroves, has occurred and beach-sand mining for construction (of buildings and roads) continues unabated (Richmond, 1991). Overcrowding in parts of the north coast of Upolu has resulted in some reclamation, but overall population density is sufficiently low for people to have remained on the existing land.

Western Samoa's vulnerability to future sea-level rise and climate change have been carried out by Chase and Veitayaki (1992), Kay et al. (1993), and Nunn et al. (1994b). Details are summarized below.

Natural Vulnerability

Owing to the widespread presence of lava-cliff coasts, the overall coastal vulnerability of Western Samoa is low. Many sites would not be significantly affected even if sea level rose one meter. Other sites, especially those along the coasts of western Upolu and eastern Savai'i which are low-lying and made largely from unconsolidated materials, would be greatly impacted. One problem is that, until 1990, Western Samoa had not experienced a tropical cyclone for more than 30 years because it is located on the northern edge of the tropical storm belt. During that time, natural systems (as well as humans) had adapted their form (and behavior) to an absence of extreme conditions. Thus, when Tropical Cyclone Ofa hit in 1990, the devastation was much greater (and much more difficult to cope with) than might have been the case had these islands been more used to dealing with tropical cyclones, as in Fiji and Tonga. Problems of shore erosion are being exacerbated in many areas by increased human pressure on reef and mangrove resources (Figure 5).

Anthropogenic Vulnerability

There is marked migration from rural areas to Apia, the island's capital on the central north coast of Upolu, and surrounding areas. This is putting a strain on the coastal environment of the area which is likely to be made worse by sea-level rise and attendant land loss.

Lifestyle changes are also a cause for concern. Traditional diets are rapidly becoming replaced by a dependence on imported foods leading to increasing obesity, hypertension, and diabetes (Hanna et al., 1986). As the traditional resource base in coastal lowlands has been increasingly depleted by the 1993 taro blight and a number of tropical cyclones, this trend is likely to continue in the future if sea level rises. It must be appreciated that while sea-level rise might accelerate such trends, they would probably continue irrespective.

Figure 5. Damage to the seawall at Apia, the capital of Western Samoa, caused by storm waves associated with Tropical Cyclone Ofa in 1990. Many seawalls in the Pacific islands exacerbate the problems they are intended to solve; many are of an entirely inappropriate design and construction.

Most roads are coastal and, in some places, are particularly vulnerable to erosion during storms coupled with sea-level rise. The government has already responded by building alternative routes inland (see above). The principal ports and airport are all well protected. Owing to their national importance, their protection would undoubtedly be appropriately upgraded if they came under threat from future sea-level rise.

As in many Pacific island nations, the traditional way of life (the *fa'a Samoa*) in Western Samoa is being lost, yet it still retains a great deal of authority, particularly in decisions relating to land use. Sea-level rise will probably contribute to its continued demise as the pressure on the best land increases.

The control of land along the Apia coast is minimal; there is no town council nor land-use planning legislation to manage urban development (Kay et al., 1993). Therefore, the increasing use of reclaimed land in urban areas is another problem worsened by sea-level rise.

The Western Samoan economy is particularly precarious, a condition which has been exacerbated by recent cyclone damage and will be exacerbated by future sea-level rise. The population, both rural and urban, is largely dependent on food resources grown in rural areas

and increasingly on imported processed foods. Since many crops are grown in lowland areas subject to inundation in the future, the domestic agricultural base of the country is clearly at risk. The export sector is also dominated by agricultural products, particularly coconut-associated. Because some coconuts grow in low areas, a major part of the economy will become vulnerable in the future.

Remittances from family members working overseas are important and contribute to the economic resilience of the country in a way which is unlikely to be affected by climate change. For various reasons, Western Samoa's culture (the *fa'a Samoa*) is proving less resilient to outside influence and change than many other Pacific island cultures. However, sea-level rise will probably accelerate urban drift and the dependence of Samoans on imported products, both of which effects will undoubtedly dilute culture and traditions still further.

VULNERABILITY OF SOUTH PACIFIC ISLAND NATIONS

The primary effects of sea-level rise for Pacific islands are the inundation of lowlands, exacerbation of coastal flooding and erosion, intrusion of salt water into rivers and underground aquifers, changes in sediment depositional patterns, and a decrease in light penetrating the ocean (IPCC, 1992). These are all changes in physical environments of the coastal zone, and their implications and severity for ecosystems and human society change with geographic and social conditions. Yet, the island nations in the South Pacific are generally considered to be among those parts of the world which will experience the most severe impacts from future sea-level rise.

Vulnerability to Inundation and Flooding

The most extreme impact of inundation and flooding is to render very low islands uninhabitable. Owing to sea-level rise and fresh water flooding induced by rising water tables, it is anticipated that some low islands, such as in Kiribati, Marshall Islands, Tokelau, and Tuvalu, will become wholly uninhabitable, and people currently living on them will have to move to other islands. Even if they are not currently inhabited, inundation of such islands may mean a significant loss of territorial seas and exclusive economic zones.

This paper does not deal with such low islands. The main islands of Fiji, Tonga, and Western Samoa are all comparatively large and high islands. Large portions of their coastline consist of coral limestone and/or hard lava, which resist wave action. On these islands, the population has been concentrated on narrow plains fringing mountains along the coast. The coastal plains are favored for living because they are flat, fertile and well-drained, and because access to marine resources and overseas markets are comparatively easy. Even though the area of a whole island may be large and the average altitude far in excess of that to which sea level is predicted to rise, economic activities are mostly concentrated on the coast. It is therefore quite natural that the capitals of all three countries are situated on one of the largest coastal plains in each country. This, in turn, will make them especially vulnerable to future sea-level rise.

In recent years, all three countries have experienced the migration of people from outer islands to their capital areas, and the population has sharply increased in these urbanizing areas. Since such migration is often associated with economic difficulties, and because the land ownership system does not allow it, migrants cannot buy or find secure lands to settle. Such population pressure often leads to intensive reclamation of coasts and lagoons. Sometimes people tend to live in very low and unsafe areas, such as a dumping site in Nuku'alofa, Tonga. All such social tendencies make the capital areas of these islands very vulnerable to sea-level rise and climate change.

One of the most significant effects of sea-level rise is the increased danger of extreme events, such as tropical cyclones associated with storm surges and high waves. Sea-level rise boosts the baseline for storm surges. Moreover, storm surges will be accompanied by high waves, since waves become higher as the protective function of coral reefs becomes less effective as sea level rises.

Vulnerability to Exacerbated Beach Erosion

Another common concern is the exacerbation of beach erosion. As already mentioned, all the countries have experienced an increased rate of shoreline retreat over the past few decades. There are several reasons for this erosional trend, rising sea level being one of the most important contributors. It is anticipated that sea level will rise two to four times faster than during the past century, resulting in significantly exacerbated beach erosion.

Human activities also contribute to beach erosion in this region. In many places, mangroves were cleared for fuelwood and land reclamation. Beach sands are intensively used as construction material and for decoration of tombs (Figure 6).

Sandy beaches play important roles in providing coastal protection. The supply of sand is often very limited, since the main sources are biological activities of offshore coral reefs. Appropriate management of both sandy beaches and coral reefs are therefore essential to maintain the sandy beaches. This is a necessary response to sea-level rise and climate change.

Vulnerability to Salt Water Intrusion

The most significant effect of salt water intrusion is the agricultural sector. Subsistence economies still dominate in the South Pacific, and people grow root crops, bananas, and coconuts around their villages. Since these are situated mostly on the coast, if salt water intrudes into aquifers, damage is anticipated to occur to these crops and fruits. Yet there is commonly high precipitation in this region, thus there is plenty of groundwater, so the effects of salt water intrusion may remain minor for large and high islands like Viti Levu in Fiji or Savai'i in Western Samoa. This is not the case for small, low islands.

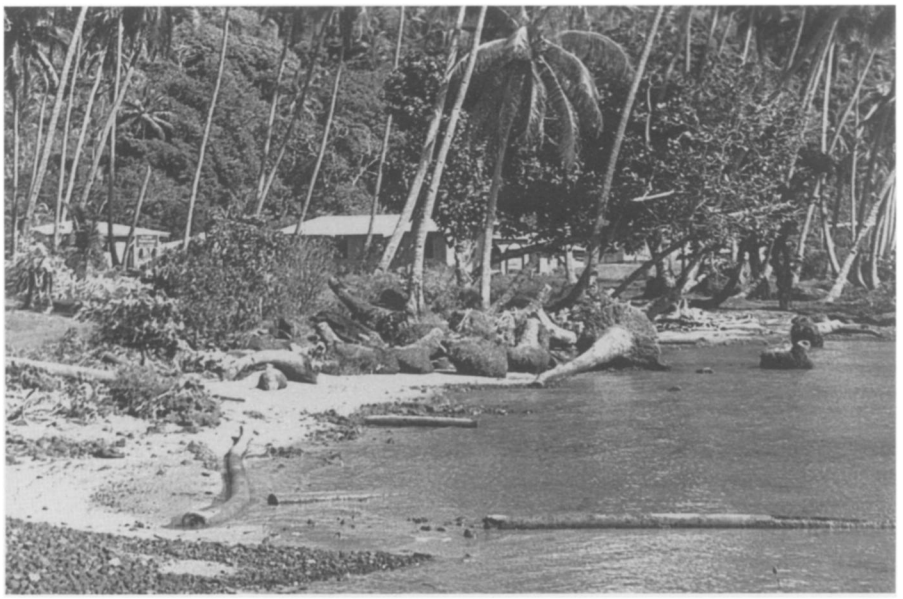

Figure 6. Shore erosion at Nasinu Village, Ovalau Island, Fiji is evidenced by the large number of recently fallen coconut palms, which line most undisturbed shorelines in the Pacific islands. The problem of shore erosion associated with sea-level rise and vegetation clearance is here exacerbated by the arbitrary extraction of sand and gravel from the shoreline for construction, and a noticeable increase in tropical-cyclone frequency over the past few decades.

Vulnerability of Infrastructure and Society

Another concern associated with sea-level rise is impact on infrastructure. Roads often follow the coast, so there is a possibility of severe damage as a consequence of future sea-level rise. Ports and airports are also important facilities, commonly located in coastal areas, which tie the nations with overseas as well as other islands. Usually, main ports and airports are the most modernized facilities in these countries, and have enough resources to hold back the sea. In face of future sea-level rise, the sea defenses will have to be raised and/or reinforced.

Discussion

All the examples mentioned above involve impacts on the physical components of the society. These physical changes may lead to changes in lifestyle, and even accelerate them. Generally, the coastal systems in the South Pacific, both natural and human-social ones, have long adjusted to the indigenous conditions of the South Pacific. Recently, their traditional lifestyle has begun to change. The effects of future climate change and sea-level rise may accelerate

such trends. If the speed of change is too fast, unstable social conditions may occur in these nations.

APPROACHES TO VULNERABILITY MITIGATION

There is a clear pattern of vulnerability of South Pacific island nations. In order to mitigate such impacts, it is important to recognize that the natural systems and human societies are not merely passive ones. Each of them has an ability to respond to the impacts induced by climate change and sea-level rise. It must be understood that vulnerability has two components; one is the susceptibility of natural and human systems to environmental changes, and the other the resilience to them. The vulnerability is determined by the balance of the two factors. In other words, vulnerability is considered to be the ability of a society to cope with climate change and sea-level rise.

Then what is the resilience of the South Pacific island nations? These nations have important resilience in the form of their natural systems: barriers to hazardous forces of the sea such as coral reefs, mangroves, sandy beaches, and beachrock. These effectively protect the coastal lowlands, coastal ecosystems, and society by reducing and dissipating energy of incident forces. It is thus important to preserve them from the viewpoint of future climate change and sea-level rise.

Another resilience is found within the social system and institutional hierarchies of traditional Pacific island societies. Since these countries are experiencing a transition from a traditional system to a new one, it is unclear how a new flexible social community will form. Regarding technology and financial resources, the combination of in-country capacity building and appropriate foreign assistance is essential. Furthermore, a precautionary approach is important to reduce the natural and social vulnerability. Integrated coastal zone management, which is internationally recognized, is an important policy measure that needs to be implemented.

CONCLUSIONS

We have discussed some of the problems facing certain Pacific island nations in the future and the ways in which these problems can be addressed. We have deliberately focused on the high islands since these are popularly perceived as being at less risk than low islands. Future work in these islands should concentrate on meshing traditional systems of coastal management with more recent approaches with a view to identifying optimal solutions to specific problems associated with future sea-level rise and climate change.

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