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Vulnerability of Fiji's mangroves and associated coral reefs to climate change

Review by WWF South Pacific Programme

Vulnerability of Fiji's mangroves and associated coral reefs to climate change

A Review

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Executive Summary

This report was commissioned by the WWF to review and compile existing studies and other literature on the state of knowledge of the vulnerability of Fijian mangroves and adjacent coral reefs to climate change. Information is reviewed on strategies or methodologies to adapt or increase the resilience and resistance of the region to impacts of climate change.

The review has found that there is little work to date on methodologies and projects that have designed an adaptation strategy to climate change effects for mangroves or coral reef systems. The majority of work to date has been focussed on assessment of impacts.

Global climate change was not recognised as a major threat to coral reefs until recently, with direct anthropogenic stresses such as increased sediment loading, organic and inorganic pollution and over-exploitation being considered to be far more critical. With widespread coral mortality in the ENSO-related bleaching events of 1997-8, including pristine and remote reefs in Fiji, views on the importance of the threat of climate change to corals radically switched. This was confirmed by recent evidence that increased CO2 concentrations change the balance between carbonate and biocarbonate ions in seawater, reducing calcification rates (i.e. growth rates) of corals. Impacts of sealevel rise on reefs are thought to be insignificant, possibly even beneficial.

Inshore reefs in Fiji are particularly under stress because of threats of poor water quality, sediment loading, pollution, coastal development and overfishing. Strong links exist between healthy mangroves and healthy inshore reefs in Fiji that will provide resistance to climate change impacts. Coral reefs provide physical protection for the mangrove ad seagrass habitats, and provide sediments to these sedimentary systems. Mangroves act as filters to terrestrial runoff, facilitating nearshore oligotrophic conditions that benefit corals and limiting algal growth. Mangroves produce coloured dissolved organic matter (CDOM) that can be transported over near shore reefs affording them some sunscreen protection. Mangroves increase fish diversity and biomass in nearshore waters, including many species of use to subsistence and commercial fisheries.

Fiji has the third largest mangrove area in the Pacific Island region of 517 km2, with eight true mangrove species, and one hybrid. Largest areas are on the SE and NW Viti Levu shorelines, and the northern shore of Vanua Levu, however, on many coastlines smaller mangrove areas exist that are significant to coastal stability and community usage. Climatic variation across the larger islands in Fiji is an influence on mangrove distribution and ecology, indicating how increase or reduction in precipitation patterns may change these. Direct climate change impacts on these mangrove ecosystems are likely to be less significant than the devastating effects of associated sealevel rise. Increase in atmospheric CO2 can be expected to improve mangrove tree growth and litter production, provided mangroves are not limited by salinity or humidity.

Mangroves occupy an intertidal habitat, and are extensively developed on sedimentary shorelines such as deltas, where sediment supply determines their ability to keep up with sealevel rise. Studies of sediment accretion rates in Fiji's mangrove areas do not exist, hence comparison with rates of sealevel rise projected must use inferences from elsewhere. Mangroves of low relief islands lacking rivers have been shown to be the most sensitive to sealevel rise, owing to their sedimentdeficit environments. However, mangroves on larger islands will also suffer disruption and retreat. Mangrove zonation patterns will retreat with sea-level rise inland, with mortality at their present locations. In Fiji these future mangrove habitats are lowland forests on the windward areas of large islands, or salt flats in the leeward areas of large islands. Unfortunately, the areas where mangroves will seek habitat with sea-level rise are those areas most favored by human development.

Fiji has a well established climate monitoring service, but the tide gauge network is not adequate to show differential rates of sea-level rise that will result from the complex tectonic settings of the region. Some areas will have higher relative sea-level rise impacts of erosion and mangrove loss due to subsidence as well as global sea-level rise. Areas known to be subsiding include the North Coast of Viti Levu, Yasa Yasa Moala and Vanuabalavu.

Fiji does not have the financial resources to support coastal engineering or beach replenishment in response to coastal erosion with sealevel rise, and there is mediocre evidence of the success of these elsewhere anyway. Therefore a long-term planning approach to deal with these changes if they occur would be prudent to adopt now. A precautionary principle should be adopted with respect to climate change hazards that are projected, that anticipatory planning should include future plans to retreat from the coastline. Migration zones behind current mangrove swamps should be reserved for future mangrove habitats.

Reef monitoring in Fiji is not systematic or designed to indicate long term changes that may result from climate change effects. Mangrove monitoring though identified as a requirement in the Regional Wetland Action Plan has not commenced. A systematic long-term monitoring programme of representative or critical sites, in conjunction with existing research-based monitoring, would improve identification in Fiji of mangroves and reefs responding to climate change effects. Coastal monitoring programmes are recommended to demonstrate the erosion expected with sea level rise.

Rehabilitation of degraded mangrove and inshore reef areas will increase their resilience to climate change effects. Site selection should consider value for money, the level of community or stakeholder support, benefits to adjacent systems and the relative risk of sea-level rise. Any rehabilitation programme should initially remove the stress that caused decline, decide on whether to use natural regeneration or active replanting techniques, in which case us of local sources of seeds or juveniles will reduce loss of genetic variation across Fiji. A monitoring survey should collect baseline data before rehabilitation commences, to enable demonstration of improvement in water quality, reef cover and fisheries with progression of the rehabilitation project.

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Mangroves and Inshore Reefs of Fiji

Fiji consists of about 844 islands and islets, of which 106 are inhabited, located between the latitudes of 15o 30' and 20o 30'S, and straddle the 180o meridian. The total land area is 18, 272 km2, and 87% of this occurs in the two largest islands, Viti Levu (10, 386 km2) and Vanua Levu (5,535 km2). Larger islands are of volcanic origin, and smaller islands derived from calcareous deposits and limestone. All islands are surrounded by fringing and barrier reefs, and Fiji has the third most extensive mangrove area in the Pacific Island region.

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Mangroves of Fiji

The mangroves of Fiji are extremely important ecosystems, and are among the better studied in the Pacific Island region. They provide ecological and environmental services, such as protection of the coast from wave action and erosion, they provide habitats and nursery grounds for coastal fisheries, they trap sediment and pollutants to maintain the clarity of near shore waters, as well as play a major role in the cultural and economic life of coastal communities (Thaman and Naikatini, 2003). Mangroves are well known to be vulnerable to climate change and sealevel rise, hence there is a strong possibility that these values of mangroves to Fiji may be lost in the future in the climate change projections come about.

Mangrove Extent and Ownership

Fiji has the third largest mangrove area in the Pacific Island region, after PNG and the Solomon Islands. Mangrove areas are one of the better wetland types inventoried in the Pacific Islands (particularly Fiji), though the information sources are fairly dated (Watkins, 1999). The mangrove area was estimated by Spalding et al. (1997) from a forest cover map prepared by the Ministry of Forests, Fiji based on a 1985 survey, with mangroves distinguished using the Fiji Forest Inventory carried out 1966-9. This gave a total mangrove area for Fiji of 517km^2. Largest areas are on the SE and NW Viti Levu shorelines, and the northern shore of Vanua Levu (Richmond and Ackermann, 1974). Only 19.7 km2 of mangrove was recorded for Fiji by Saenger et al. (1983), an area which is not accepted by other writers.

The most detailed of other mangrove area estimates is Watling (1985), who found 385.43 km^2 remaining of an original mangrove area of 410 km^2, with 24.57 km^2 (7%) developed to other uses. In the early 1970s, 3km^2 of mangroves was impounded for aquaculture. The greatest mangrove area loss occurred about 100 years ago when the Colonial Sugar Refining Company (CSR), poldered about 23 km^2 in the Labusa delta for conversion to agriculture (Lal, 1991).

Coastal mangroves of Tikina Wai, Nadroga

The distribution of remaining mangrove areas in Fiji is shown in Figure 1. Over 90% of mangroves occur on Viti Levu and Vanua Levu (Watling, 1985), the largest stands in deltaic situations on the Ba, Rewa and Nadi rivers on Viti Levu and the Labasa river on Vanua Levu.

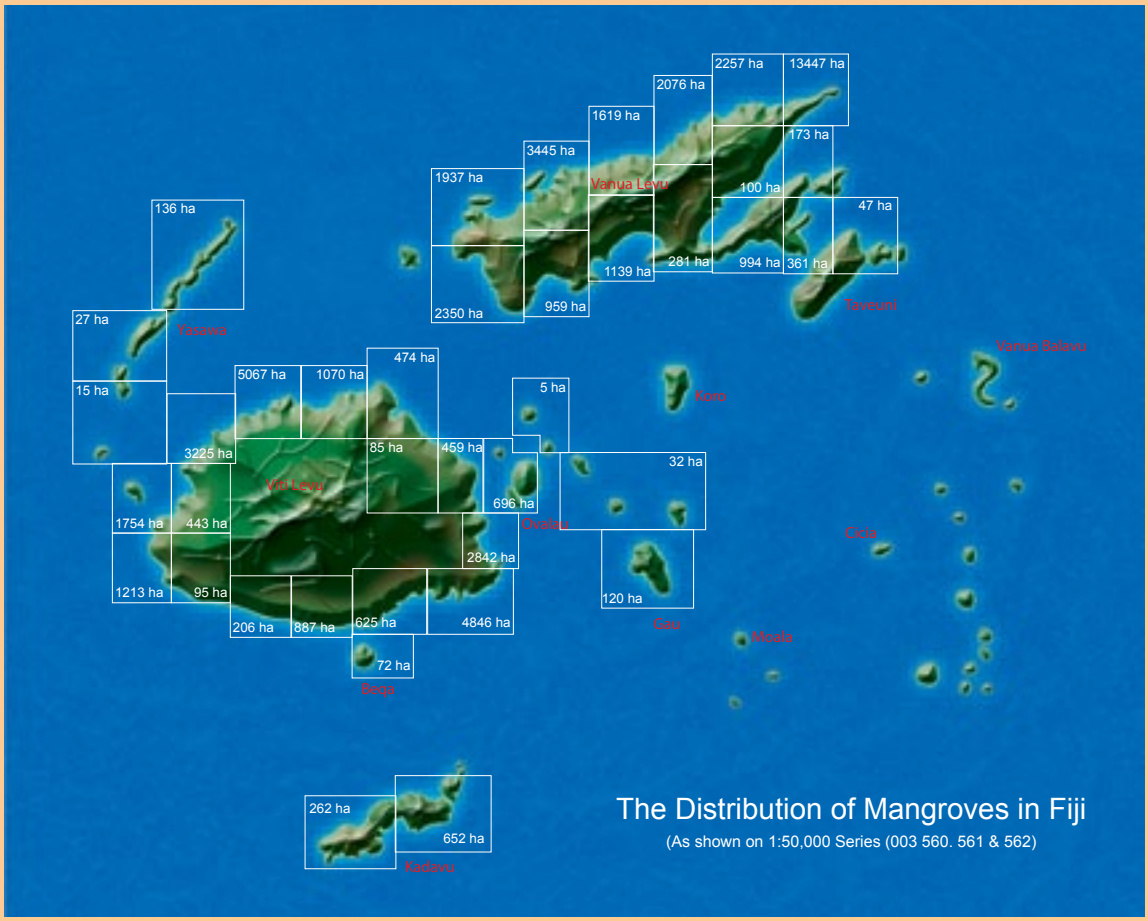
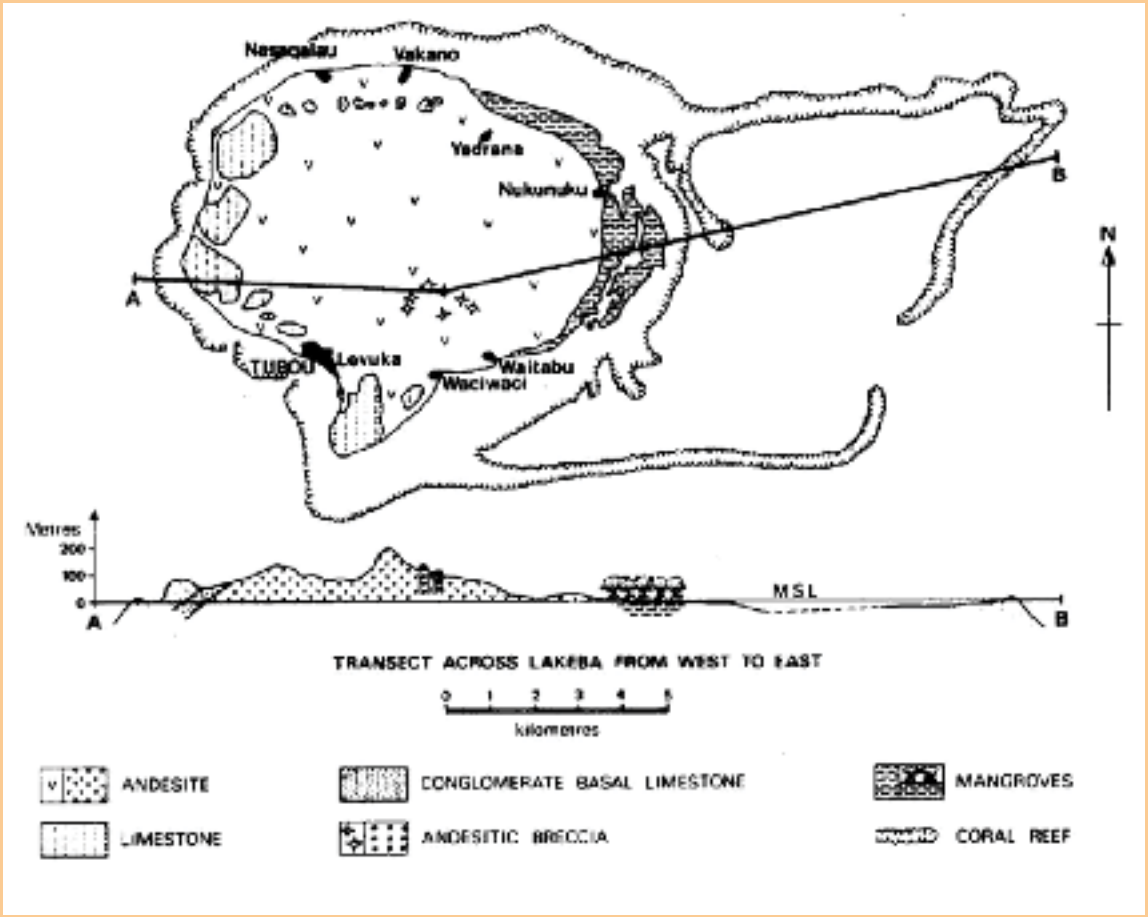


Figure 1
Distribution of major mangroves areas in Fiji. (from Fiji Mangrove Management Committee, 1986).

However, on many coastlines smaller mangrove areas exist that are significant to coastal stability and community usage, illustrared by Figure 2 showing a small mangrove area on Lakeba which dominates coastal character on a large prpportional of island's shaoreline.

On Ovalau to the east of Viti Levu, fluvial sediment from Bureta River has caused shoreline progradation over the last few decades (Nunn, 2000a). The delta front has advanced across reef flats killed by sedimentation, and the maximum rate of mangrove extension since 1961 is estimated at 1.8ma-1.

Figure 2
Distribution of mangroves on Lakeba, illustrating the importance of a small mangrove area to coastal environmental character (map from Latham, 1979).



Following British Colonial law, all land below high tide mark is Crown Land. In 1933 all mangroves were designated as Forest Reserve to be managed by the Department of Forestry. This designation was lost in 1975, and mangroves were placed under the jurisdiction of the Department of Lands and Survey. Traditional Fijian land-water ownership systems exist, and fishing is regulated by Traditional Fishing Right owners (Lal, 1990a). There are piecemeal legislations of British derivation such as forestry licences under the Forestry Act which can go against traditional systems (Lal, 1990a: 11).

The GEF funded International Water Project carried out environmental legislative reviews in 5 countries including Fiji (Evans, 2006). This found that much legislation in use is old and outdated, with very little attention given to environmentsl issues, and little opportunity given to stakeholders to have a say (Evans, 2006) In newer legislation, coastal wetlands are given some management protection under the 2005 Environmental Management Act, which if enacted introduces obligations to protect the environment and use resources sustainable. This includes and an environmental impact system, and a natural resources inventaory, database and management plan. However, the coastal zone definition in the Act excludes water and includes only land (Evans, 2006).

More comprehensive inventory and mapping of mangroves is recommended to update older records (Finlayson et al., 1999), including update of the Scott (1993) Directory of Wetlands in Oceania (Watkins, 1999).

Mangrove Ecology

Seven mangrove species occur in Fiji, and one hybrid (Table 1), taxonomy and observations from Fiji are reviewed by Ellison (1995). The majority of these are of the Australian/ PNG center of mangrove biodiversity, Fiji being located where mangrove distributions are becoming limited with distance from west to east across the Pacific. However, mangrove distributions have changed over geological time, in Miocene dark peat sediments on Viti Levu, Ladd (1965) found pollen of *Sonneratia*, which today extends only east as far as Vanuatu.

Table 1 *Mangrove species of Fiji, biographic affinity, and position in the mangrove swamp*

Species	Seaward/ Landward	American/ Asian
Rhizophora stylosa Griff.	S	Asian
Rhizophora mangle L. or R. samoensis (Hochr.) Salvoza	S	American
Rhizophora x selala (Salvoza) Tomlinson	S	Mixed
Bruguiera gymnorrhiza (L.) Lamk.	L	Asian
Heritiera littoralis Dryander	L	Asian
Lumnitzera littorea (Jack) Voigt.	L	Asian
Excoecaria agallocha L.	L	Asian
Xylocarpus granatum Koenig	L	Asian

One native American species occurs in Fiji, *Rhizophora samoensis* or *R. mangle*, only also found in this S.W. Pacific area in Tonga, Samoa and New Caledonia (Ellison, 1991). In Fiji and New Caledonia only a hybrid between *R. mangle* and *R. stylosa* occurs, *Rhizophora x selala*, (Tomlinson, 1978). Of these species in Fiji, the *Bruguiera* and *Rhizophora* species/ hybrid are the most commonly occurring (Watling, 1985). Associate mangrove species that would be found in inner zones of mangroves and are not restricted to mangrove habitats are listed by the Fiji Mangrove Management Committee (1986) and Swart (1992). These are not obligate or true mangroves. One common example is the grounddwelling mangrove fern *Acrostichum aureum*.

Zonation patterns are typical to mangroves worldwide (Smith, 1992) and reflect the specific range of conditions (e.g., frequency of tidal inundation, physical and chemical state of the soils, degree of faunal predation) under which different mangrove species can survive (Smith, 1992; Bunt, 1996, Duke et al., 1997). The seven mangrove species and hybrid in Fiji have preferences within the intertidal spectrum that results in typical species zonation (Table 1).

Climatic variation across the larger islands in Fiji is an influence on mangrove distribution and ecology (Watling, 1985). The windward SE shores receive consistent rain through the year. Leeward coastlines lie in an orographic rain-shadow so receiving less rain, the majority falling December to March, and with more variability. In these drier leeward areas hypersaline mudflats are a characteristic feature which a re virtually absent from wetter windward mangrove areas, which have more luxuriant growth. Such mudflats comprise 3.7 km2 of the Ba and Lebasa deltas which lie in the leeward, dry zone of Viti Levu and Vanua Levu respectively (Jaffar, 1992).

In leeward, dry areas, *Rhizophora stylosa* occurs as the seaward edge of about 5 m tall, followed by a zone of taller trees of up to 15 m. In extensive mangrove formations large areas of stunted *Rhizophora stylosa* of 1-2 m are behind these taller zones, adjacent to hypersaline flats inland. *Bruguiera gymnorrhiza* is present but never dominant in dry areas. Thaman, and Naikatini (2003) describe a typical mangrove alliance at Tikina Wai on Nadi Bay, adding that *Xylocarpus granatum*, *Excoecaria agallocha* and *Hybiscus tiliaceus* are also present in landward areas. At Lomawai Reserve on this coast, an extensive salt pan area occupies about one third of the mangrove reserve area.

Rhizophora stylosa is dominant on exposed locations, particularly on sandy or coarse (rocky) substrates. The hybrid *R. selala* shows wide ecological amplitude occurring either inter-mixed with *R. stylosa* and *R. mangle*, or in stands of its own. This sterile hybrid flowers profusely but produces no *hypocotyls* (seeds). On reef flat mangroves of small islands, Ghazanfar etal. (2001) describe a seaward zone of *R. stylosa* and *R. selala*, and a landward mangrove zone of *Excoecaria agallocha*, *Heritiera littoralis*, *Xylocarpus granatum* and *X. moluccnesis*. *Lumnitzera littorea* and *Bruguiera gymnorrhiza* are rare on small islands relative to Viti Levu.

In estuaries, on soft, fine-grained sediments *Rhizophora mangle* occurs as the seaward zone, and fringing creeks. *Bruguiera gymnorrhiza* is dominant with up to a 18 m canopy height at inner zones in wetter delta areas. *Xylocarpus granatum*, *Lumnitzera littorea*, *Excoecaria agallocha* and *Heritiera littoralis* are usually found at drier and more elevated (inland) locations in the mangrove margin.

Litterfall was recorded by Lal et al. (1993) of 1100 gm2 a-1. Tyagi and Pillai (1996) demonstrated significant differences between flowering and propagule setting between mangrove communities in the wet and dry zones of Fiji. The mangrove species of *R. stylosa*, *R. samoensis* and *B. gymnorrhiza* all showed more flowering in the wet zone relative to the dry, however, differences in propagule setting between the zones were less significant. Further analysis by Tyagi (2001) found that during a drought year the number of flowers and propagules produced per plant was sign ificantly lower than during a non-drought year.

Raj and Seeto (1982) and Raj et al. (1984) provided a preliminary list of mangrove associated fauna. Thaman and Naikatini (2003) provide assessment of fauna biodiversity and abundance from three mangrove reserves on the dry coast of Viti Levu showing high levels of each, probably as a result of habitat heterogeneity between proximal salt pans and fresh water. Lal (1984) provides a comprehensive assessment of the mangrove fish fauna of Fiji. Mangroves, lagoons and coral reefs are an important source of fish for subsistence and sale in Fiji (Zann and Vuki, 2002). Over 60% of Fiji's commercially important fish and 83% of subsistence fish species depend on mangrove areas for some phase of their life cycle (Lal, 1983). Several species of mangrove crustaceans are vital to the subsistence industry. Lal (1990b) estimated the value mangrove-associated fisheries products harvested commercially and for subsistence consumption to be F$31 million per year. In areas where extensive mangrove reclamation has occurred, there has often been an associated decline in fish and crustacean population (Vuki et al., 2002).

Mangrove Uses and Threats

Mangrove resources have been traditionally exploited in Fiji for construction wood, herbal medicines, and the gathering of crabs, fish and fuel wood (Ellison, 1999a, 2003a). These traditional uses of mangroves are described in detail by Pillai (1985) and Lal (1990a; 1990b). In Fiji, an estimated 1.5 to 4.5 thousand cubic meters of mangroves are harvested each year, for poles, charcoal and firewood (Jaffar, 1992). This is reduced from past levels, owing to increased use of imported petrol. In a recent study, Thaman (1998) found that the importance of these traditional uses is diminishing due to the use of alternative modern products, less time available to collect because of other commitments, and the loss of traditional knowledge in the preparation and use of these products.

In addition to major mangrove reclamations in Fiji reviewed above in section *'Mangrove extent and ownership'*, small scale developments have continued to result in loss of mangroves (Lal, 1983; Thaman et al., 2003). Singh (1994) listed threatened wetland sites in Fiji. The mangroves of Rewa delta were listed as needing urgent consideration for biodiversity conservation, while the mangroves of the Ba and Labusa deltas were listed as requiring urgent consideration in terms of their hydrological functions. Mangroves play an important role in Fiji's sewerage treatment programs, most facilities are associated with mangroves.

A Pacific Regional Workshop on Mangrove Protection and sustainable use was held by SPREP at Suva in June 2001, involving mangrove personnel from all countries in the SPREP region (Aalbersberg et al., 2003). The strongest message to come from the workshop was that the process of engaging communities in managing their mangrove resource is still not working well in the Pacific and that the project/donor-funding process is fundamentally flawed in this regard.

Community member participating in mangrove health baseline surveys

The workshop generally concluded that, while the specifics vary from country to country, the underlying causes of mangrove degradation are similar. The underlying cause is predominantly the shift from a subsistence-based economy to a commercial (market-driven)/ industrial based economy. With this shift comes population growth and social changes that involve exploiting natural resources for commercial purposes. New needs, aspirations and wants are being also created. Consequently, the countries are facing new challenges of balancing their economic development goals with those of conservation of their natural resources. Attaining this balance is essential given the limited natural resource endowments and economic opportunities in the islands, high population growth rates generally, and their vulnerability to natural disasters such as hurricanes and cyclones.

Threats to mangroves identified in Fiji were classed as high, medium or low. High threats included: Coastal development, dumping and improper waste disposal, reclamation and collection of firewood. Medium threats included: Overfishing, watershed alteration and coastal sedimentation, and industrial and hazardous waste spills. Low threats included: Global warming and sea level rise, aquaculture ponds, sewerage, pesticide runoff, animal waste, introduced species, logging, and bio-prospecting for natural products.

Priority management actions for mangroves in Fiji were classed as high, medium or low importance. High priority actions included awareness and education efforts for mangrove conservation, improvement of agency capacity, and address of traditional values. High-medium priority actions identified included mangrove monitoring programs, and improvement in stakeholder participation. Medium priority actions included improvement in socio-economic valuation of mangroves, improvement in public support for regulations, improvement in enforcement, and improvement in political will to support management. Medium-low priority actions included development of accurate maps and GIS database coverage of mangroves. Low priority actions included mangrove restoration, and development of new industries for mangrove resources.

The workshop concluded:

1. Despite modernisation and development, many coastal communities throughout the Pacific remain dependent on mangrove ecosystems and the services and products they continue to provide for their wellbeing and economic livelihood, mostly through non market based or subsistence exploitation. Because of their long association with mangroves, communities also have a wealth of traditional empirical and scientific knowledge on the direct and indirect benefits of the mangrove ecosystem.

2. Even if these benefits provided by mangroves could be replaced, the expense would be far too great for most Pacific Island rural and urban communities to absorb.

3. The environmental goods and services provided by mangrove systems in the Pacific are being used unsustainably by a range of stakeholders, without regard to the external costs that their actions impose upon the ecosystem and upon others who also depend upon this ecosystem. The “total economic value” of mangrove ecosystems must be taken into account in determining use types and levels, including all direct and indirect uses and benefits.

4. For resource use to be modified, the economic and socio-cultural interests of all parties must be taken into account. The incentives to change or modify behaviour must be carefully considered. In addition to measures to minimize environmental damage, specific measures need to be undertaken to address the particular constraints that poor resource- users face. Attempts to change resource use and promote sustainable mangrove management must consider the development needs of those communities that depend on these resources for their livelihood and survival needs.

5. The need to harmonise diverse stakeholder concerns and find shared interests that can be built upon to achieve environmentally sustainable mangrove management is of primary importance.

6. Management action must be multisectoral with representation of all primary stakeholders, especially the community.

7. In order to work towards more sustainable mangrove management, key gaps in data/ knowledge need to be addressed. Management needs to be based on good science. Sound data on biological and human-environment indicators is needed to guide policy and set parameters for sustainable resource use.

8. There is a real need to strengthen and enforce the rules and regulations governing the extraction and use of the mangroves at the national and local level.

9. The region needs a stronger focus on mangrove wetland management.

Mangrove Management

A Mangrove Management Committee was created in 1983 partly to facilitate consultation between various departments over mangrove development and usage. A further objective was designation of uses of different mangrove areas, such as National Reserve (full protection), Traditional Use Zone and Development Zones (sewage, urban, tourism) (Swart, 1992). A priority for this committee was management of the Rewa, Ba and Lebasa deltas (Jaffar, 1992), but the management plan produced did not achieve legal status. The committee still exists to advise the Lands and Survey on all matters concerning mangroves in Fiji (Thaman et al., 2003), though a later written report comments that the Committee is currently nonexistent (Thaman and Naikatini, 2003). A key goal of the most recent Fiji Strategic Development Plan 2003-2005 is to review the Mangrove Management Plan (Parliament of Fiji, 2002).

The Suva-Navua mangroves and the Nadi Bay mangroves were considered by Watling (1985) to be the most threatened from human impacts. Mangroves of the Ba Delta and the Labusa estuary needed the most urgent conservation in terms of hydrological function (Singh, 1996). The Ba estuary has the largest contiguous area of mangrove in Fiji, but is probably the least diverse. Scott (1993) described mangroves in Fiji as having little legal protection.

Thaman et al., (2003) list recent workshops on mangroves in Fiji, and recent projects. This includes the GLOMIS mangrove database that collects references on mangroves and lists personnel involved in mangrove research. There has been activity in mangrove replanting by the Women in Fisheries Network and OISCA. Mangrove planting has been carried out from Ra/Ba to Ra/ Tailevu to reduce coastal erosion (Waqairoba, 1996). Advances have been made in public education on the value of mangroves, by booklets produced by the Women in Fisheries Network, and incorporation of mangrove awareness into the school curriculum. There are some local and focussed mangrove monitoring efforts on use of mangroves for dye, and mud-lobsters. Government monitoring of mangroves is limited to regulation of commercial logging, and sizes of mud-crabs sold at markets.

Inshore Reefs of Fiji

Fiji consists of about 844 high islands, cays and smaller islets, and around 1000 coral reefs extend offshore of these (Zann, 1992). The total reef area is estimated at 10,020 km2 (Spalding et al., 2001). Like elsewhere in the world, the distribution of reefs in Fiji has altered over the last 10,000 years following sea-level changes. The major reef types are fringing reefs which surround high islands, and barrier reefs which lie at the edge of island shelves. Inshore reefs are shallow water or lagoon patch reefs, with water exchange or just foodchain connections to coastal mangroves, as opposed to fringing reefs more in connection with deeper water offshore.

Reef Ecology

Fiji's marine environment has been better studied than most other Pacific Island countries, though generally in an ad hoc manner (Zann and Vuki, 2002). There have however been very few long term ecological studies on the reefs of Fiji (Vuki et al., 2002). Marine studies in Fiji are facilitated by a good marine research and training capability at the USP.

Whippy-Morris and Pratt (1998) review knowledge on Fiji's coral reefs, including descriptions of coral areas, and coral taxonomy. Fiji's reefs are a significant proportion of the world's coral reefs, and are recognized as being of high ecological significance from a biodiversity standpoint (Obura and Mangudhai, 2001). However, Fiji's coral reef biodiversity is not well known (Vuki etal., 2002). Some areas such as the Coral Coast of Viti Levu, the Suva Reefs, the Mamanucas and the Nadi Waters and Ovalau, have had coral reef communities described. The Great Astrolabe Reef on Kadavu is the best studied, including coral distributions and ecology, water quality, and fisheries (Schlacher et al, 1998; Morrison and Naqasima, 1999; Obura and Mangudhai, 2001), which does not include inshore reefs of the type relevant to the present review. Other reef areas in Fiji presumably lack baseline survey.

Fiji's marine biota includes almost 298 species of scleractinian corals, 15 zoanthids, 123 species of gastropods from 12 families, 253 species of nudibranh Inshore Reefs of Fiji gastropods, 102 species of bivalves from 25 families, 60 species of ascidians, 1,900 species of fish from 162 families, 5 species of sea turtles and 3 species of sea snakes (Vuki et al., 2002).

Reef Monitoring

Reef monitoring programs are underway off Suva, Astrolabe Reef (Kadavu), Ovalau Island and other sites (Zann and Vuki, 2002). These studies are best established offshore of Suva owing to its proximity to USP, where major disturbances affecting the structure of reef flat communities have been documented (Vuki et al., 2002). The continuous presence of *Acanthaster planci* has been documented since at least 1979, with contribution from anthropogenic factors. Coral reefs are also monitored around Yadua and Yaduatabu by Greenforce (Sulu et al., 2002). There is a major

gap in information regarding Fiji's reefs on monitoring that can identify vulnerable fringing reefs in urban and rural areas (Vuki et al., 2002). Through the Marine Studies Program at USP there is a prime education, research and training facility in Fiji (Veitayaki and South, 2001), though, people in government trained in reef monitoring tend to move to other positions and do not utilise these skills (Sulu et al., 2002). There needs to be better central organization of monitoring data, such as a single database (Vuki et al., 2002).

Threats to Inshore Reefs

Owing to the higher temperatures of inshore waters, inshore reefs tend to be most prone to bleaching, and various types of disturbance being closer to shore, and as a consequence tend to have higher proportion of soft coral and algae relative to hard corals. Other stressor contribute to bleaching, such as pollution, sediment loading, a reduction in marine salinity, intense solar radiation, or exposure to the air (Burns, 2000a), and all are more likely to occur in inshore waters than offshore reefs. Reefs that have been degraded by pollution in Fiji are most affected by coral bleaching (Vuki et al., 2002). Spalding et al. (2001) cite 68% of Fiji's reefs as being at risk. Inshore reefs are more vulnerable than offshore reefs.

Barrier reef slope, Fiji

In some coastal areas, inshore water quality is poor, as has been found in Laucala Bay adjacent to Suva. Morrison et al. (2001) showed that sediments in the bay were of terrigenous origin, and a significant natural source of trace metals found in the bay was suspended solids transported into the bay by rivers. Contributions from anthropogenic sources were suspected. The Laucala Bay and Suva lagoons have very high levels of nutrients from sewerage and runoff (Vuki et al, 2002). Pollution, elevated nutrients and crown of thorns starfish predation have significantly degraded coral reefs off Suva. Mosley and Aaldersberg (no date) from sampling in 2002 demonstrate elevated nutrient (nitrate and phospate) levels in river outflow and nearshore waters of the Coral Coast of SW Viti Levu, and argue that this has caused a shift from hard corals to algal dominated reefs similar to findings by McCook (1999) for the inshore reefs of the GBR. These algal reefs are known to have reduced biodiversity and fish stocks.

The clearing of coastal and catchment vegetation in Fiji has caused extensive soil erosion and sedimentation of rivers, estuaries and lagoons. Mayer (1924) noted that reefs in the Suva area has deteriorates by the 1920's, and attributed this to silting following the clearance of the Rewa watershed. Fish kills are relatively frequent in the major river estuaries, possibly caused by acid sulphate soil runoff (Zann and Vuki, 2002).

Catchment erosion, and sediment accretion in a lower floodplain has been demonstrated in the Rewa catchment of Fiji by Terry et al., (2002). 137Cs was used to date an accretion rate in an upper catchment floodplain of 3.2 cm a-1 over the last 45 years, a record that exceeds rates recorded elsewhere. Greater cyclone intensities with future climate change are expected to increase floods in the Rewa catchment, and increase rates of floodplain sedimentation.

Inshore coral reefs in Fiji are also under development pressure. Coastal construction is responsible for degradation of coral reefs and erosion of coastal areas (Maharaj, 2000), citing two thirds of reefs offshore of Fiji being at risk. Damage to reefs results in increased risk to the shoreline, as functions of wave dissipation across reef flats are lost. Inshore reefs also tend to be under heavier pressure from commercial collection (Lovell, 2000), Fiji being the major exporter of live coral in the Pacific Islands, along with exploitation of reef products for a range of other purposes. Dynamiting of coral reefs is common in western Viti Levu, and the use of poison (such as Derris) are relatively prevalent in most areas of Fiji (Vuki et al., 2002).

Coral reef health of two Fijian islands, Ovalau with heavy industry and commercial agriculture,

and Vatulele, with no agroindustry was compared by Hoffman (2002). This study showed that the reefs of Vatulele have much lower mortality index values and higher hard coral species diversity than reefs of Ovalau, the latter being affected by industrial effluent. High fishing pressure on some of the most isolated reefs in the Lau Group have caused outbreaks of crown of thorns starfish because of the removal through fishing and gleaning of the spectrum of predators of juvenile and adult stages (Vuki et al., 2002).

Inshore reefs support a major subsistence and moderate commercial fishery (Vuki et al., 2002). The most common method used is hand line fishing, as well as fish traps, fish fences, gill nets, seine nets, hand nets, fish drives, spears, use of poisonous plants (such as Derris roots), line trawling, reef gleaning at low tide, and scuba diving. One key goal of the Strategic Development Plan 2003 - 2005 (Parliament of Fiji, 2002) is a moratorium of reef mining implemented by 2003. Approximately 23,253 tonnes of inshore fisheries are harvested annually with an estimated value of US$ 64.1 million, of which 74% is for subsistence purposes. Inshore finfish closer to population centers are declining rapidly due to overfishing.

Over-fishing in Fiji is well documented over several decades, with consequent decline in mullet numbers, stout chub makerel and trevally (Lal, 1983; Fong, 1994; Jennings and Polunin, 1996, Vuki et al., 2002). There is no systematic monitoring to detect overfishing (Vuki et al., 2002), and better management of inshore fisheries needs additional resources (Hunt, 1999). Fisheries are also depleted by commercial collection of coral, due to the associated degradation in the coral reef habitat (Lovell, 2000). Reef community structure on Suva reef were affected by disturbance from tsunami, cyclone and flood damage, *Acanthaster* predation and the effects of human activities (fishing activities, dredging, pollution and reclamation) (Vuki et al., 2002). As well as higher incidence of coral bleaching, Hoffman (2002) found higher presence of filamentous algae on fringing reefs that were closer to the shoreline than those offshore. This was attributed to higher nutrient levels in the water column.

Inshore reefs were surveyed by Sykes (1999) at Waitabu on Taveuni, subsequent to an initial survey on establishment of a marine reserve. This study demonstrates the types of human impacts on inshore reefs in Fiji. The reserve status protected the reef from reef walkers, and improvement was noticed in hard coral cover. Soft coral beds immediately offshore were still 50% dead, with algal cover though this was improved from when the reserve was established. Protection from gathering by villagers had improved the populations of sea urchins, clams and sea cucumbers, and there was also improvement in fish numbers.

Over-exploitation has resulted in the recent extinction in Fiji of the giant clams, *Hippopus hippopus* and *Tridacna gigans*. Fijian breeding populations of green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmocheleys imbricata*) are very seriously endanged and will become extinct unless urgent action is taken (Vuki et al., 2002).

Sand flats occur between inshore patch reefs, of extensive sand deposits formed into ripples features by the action of currents and tides. Fisheries assessment and benthos sampling by Yakub (2002c) demonstrated some fish species common of estuaries, though of low abundance owing to human exploitation. There were no mangroves adjacent to this site, and results showed far lower levels of productivity and biodiversity relative to similar studies carried out adjacent to mangroves reviewed above. This was further supported by benthic surveys carried out adjacent to a nearshore wreck at Nabukeluvu, Kadavu by Batibasaga and Korovulavula (1996), finding an absence of live corals and associated fish species, and low biodiversity of finfish species. Oil pollution from the wreck was a further problem.

Mangrove/ Coral Reef Interactions

There is a closer association between mangroves, seagrasses and coral reefs in island settings relative to continental margins (Linton and Warner, 2003). These ecosystems exist in a dynamic equilibrium influenced by contact with land. Sediments and nutrients, carried by freshwater runoff are first filtered by coastal forests, then by mangrove wetlands, and finally by seagrass beds. The existence of coral reefs is directly dependant on the buffering capacity of the shoreward ecosystems which help create the oligotrophic conditions under which coral reefs flourish, so limiting the algal growth which can threaten coral reef health. Coral reefs in turn, buffer the soft sediment ecosystems shoreward from wave action.

Reefs are active producers of carbonate skeletal material. Rates of upward growth of reefs may be as high as 20-40 cm/ 100 years (Ogden and Gladfelter, 1983), and the resultant structures are effective barriers for the dissipation of wave energy and create low energy environments in their lee. Reefs therefore create the sheltered habitats of mangroves, and protect these sedimentary systems from erosion.

Coral reef flats have an upper limit to growth by exposure intolerance around the low tide mark depth. Sea-level rise should allow reefs more room to grow, through the raising of the upper limit to coral growth (Wilkinson, 1999; McCarthy et al., 2001). If sea-level rise is more rapid than the rate of coral reef growth, then the action of reefs in dissipating wave energy will be reduced, and wave impact on sedimentary systems in the lee of reefs such as mangroves should increase.

There is evidence from outside Fiji that coloured dissolved organic matter (CDOM) that can be transported over near shore reefs affording them some sunscreen protection through the control of UV penetration to the reef surface (Anderson et al., 2001). Research has indicated that decomposing phytoplankton detritus and decaying litter from seagrasses and mangroves are the major sources of UV-absorbing substances over the coral reefs in the Florida Keys (Obriant, 2003). Hence the proximity of mangroves to coral reefs in Fiji could reduce coral bleaching.

Mangroves are known to act as nursery sites for many commercial fish and crustacean species (O'Grady et al., 1996) and as a seasonal base for a variety of migratory species. Many studies have shown that mangroves harbour high densities of juvenile reef fish (Ley et al., 1999; Ley and McIvor, 2002; Ley et al., 2002). In the Caribbean islands, Nagelkerken et al. (2001) further demonstrated that mangroves and seagrass beds function as nurseries for juveniles of at least 17 different reef fish, many of them commercially important to reef fisheries. This was attributed to the high abundance of food and shelter to be found in mangroves, and reduced predation pressure. High dependence of juvenile fish on these nursery habitats was further demonstrated by Nagelkerken et al., (2003), who showed that reefs adjacent to mangroves and seagrass beds had complete absence or low densities of 11 of 17 fish species, compared with coral reefs offshore of mangrove or seagrass bays.

Mangroves in the Caribbean strongly influence the community structure of fish on neighboring reefs. In addition, the biomass of severally commercially important species is more than doubled when the adult habitat is connected to mangroves (Mumby et al., 2004). Mangroves enhance the adult fish biomass through provision of refuge from predators, and the provision of plentiful food that increases the survivorship of juveniles. Mumby et al. (2004) indicated that mangroves provide an intermediate nursery stage between seagrass beds and patch reefs, through alleviation of predatory loss, and increasing the survival of young fish.

In Fiji, the importance of healthy mangroves to benefit inshore fisheries has been acknowledged in reports by the Ministry of Fisheries for some time.

An assessment of fisheries and coral cover for an inshore patch reef on the lee shore of Nanuya (Turtle) Island in the Yasawa Group was carried out by Yakub (2002b), as part of an impact assessment for construction of a jetty. This area is immediately offshore of mangroves that densely cover this section of coast, and demonstrates the diversity and productivity of inshore reefs adjacent to mangroves. Ten edible fish species were caught in gillnets, and a range or coral and other benthic species are noted from line intercept transects.

Assessment of a mangrove area to be cleared at Laucala Bay for construction of a sports complex was carried out by Yakub (2002a), including assessment of offshore benthic communities and fisheries. The mangrove area showed little disturbance and high biodiversity despite being adjacent to a village and subject to subsidence fishing/ gathering. Water turbidity was high, and gillnet surveys showed a range of juveniles of species common in mangrove areas. This study demonstrates that a small and utilised mangrove area still has high levels of productivity and biodiversity.

Mangrove and benthic ecosystem assessment, and a fisheries survey were carried out by Whippy-Morris et al. (2001) at Rokobili in Suva. This is a port area that was once an estuarine delta with intertidal flats utilised by villagers as well as licensed fishermen. Shellfish are particularly gathered at low tide. Ten species of fish were caught in gillnets, those common for estuarine areas, but over-exploited as shown by small sizes. The mangroves supported three commercially exploited species, as well as a range of other invertebrates. This study demonstrates that even a degraded mangrove and offshore area contains a valuable range of biodiversity and commercially useful species.

This finding is supported by a fisheries survey carried out in a riverine area offshore of mangroves at Nabua by Drodrolagi et al., (2003). The mangrove area was dense and diverse, but heavily polluted with household and other rubbish. Despite this, benthic surveys showed high species diversity and abundance in mudflats in the area, and an abundance of fish.

Tikina Wai site

Response of mangroves and inshore reefs to climate change effects

Climate change and sea-level rise are recognised as one of Fiji's main environmental problems in the Strategic Development Plan 2003-2005 (Parliament of Fiji, 2002: 5.7).

Concern about the impacts of climate change and sea-level rise on small island states was first brought to global attention when President Gayoom addressed the United Nations in 1987 about possible impacts on the Maldives. This led to the Small States Conference on Sea-Level Rise held in Maldives in November 1989, at which members of Fiji's Government were participants. Following a rapid succession of vulnerability assessments and increased concern by small island governments around the 1992 Earth Summit, the United Nations Framework on Climate Change (FCCC) entered into force in 1994 (Burns, 2000b). At the Third Conference of the Parties of the FCCC, the parties adopted the Kyoto Protocol, which has still not come into effect owing to opposition by the governments of large developed countries.

The IPCC 4th Assessment found that between 1906 and 2005, the global average surface temperature has increased by 0.74 ± 0.18^{0}C. This rise in globally averaged temperatures since the mid-20th century is considered to be very likely due to the observed increase in anthropogenic greenhouse gas atmospheric concentrations (Solomon et al., 2007). The range in projections for the rise in global averaged surface temperatures from 1980 - 1999 to the end of the 21st century (2090-2099) is 1.1 to 6.4^{0}C (Solomon et al., 2007). Global sea-level rise is one of the more certain outcomes of global warming, it is already likely taking place (12-22 cm occurred during the 20th century), and the range of projections for global sea-level rise from 1980-1999 to the end of the 21st century (2090-2099) is 0.18-0.59m (Solomon et al., 2007), giving rates of sea-level rise of 1.5-9.7mm a-1.

In the Pacific region, the strongest natural fluctuation of climate from year to year is the El Niño Southern Oscillation (ENSO). Climate change scenarios are intricately linked with climate anomalies associates with ENSO cycles, both because past experience of significant climate change has been caused by ENSO events, and because of expected positive feedback between global climate change and ENSO events in the future (Meehl, 1997). This could include intensification of ENSO related drought conditions during future climate change.

The Pacific Islands Climate Change Assistance Program & Fiji Country Team (2003) presented an initial communication on climate change impacts on Fiji.

This recognised that:

- Sea-level rise may lead to coastal erosion and inundation, including retreat of mangroves.
- Increased sea surface temperatures may lead to an increase in coral bleaching, and reduction in reef productivity may contribute to shore line erosion.
- Human impacts in the coastal zone have already reduced the resilience of natural systems to cope with climate impacts.

Adaptations recommended included:

- Improved understanding of coastal systems.
- Mangrove and reef protection, including education, public awareness and legislative measures, such as penalties for mangrove and reef destruction.
- Reducing mangrove reclamation and promoting mangrove rehabilitation.
- Land use policies to encourage settlement away from low lying coastal areas.

Climate monitoring and climate change in Fiji

Climate monitoring in Fiji by the Fiji Meteorological Service is unique among the Pacific Forum countries, in that in addition to its national responsibilities it also provides extensive regional services to neighbouring countries (Brook et al., 1993). Recently the Fiji Meteorological Service was in the process of reviewing and formalising its climate observation network (Pacific Islands Climate Change Assistance Program & Fiji Country Team, 2003)

Fiji has a tropical marine climate, with average daily temperatures at Suva ranging from 20.4-26.5°C in July to 23.8-31.0°C in February (Fiji Meterological Service, 2003). In the lee of the mountains, however, the daytime temperatures often rise 1 to 2 °C above those on the windward sides or on the smaller islands. Also, the humidity on the lee side tends to be somewhat lower.

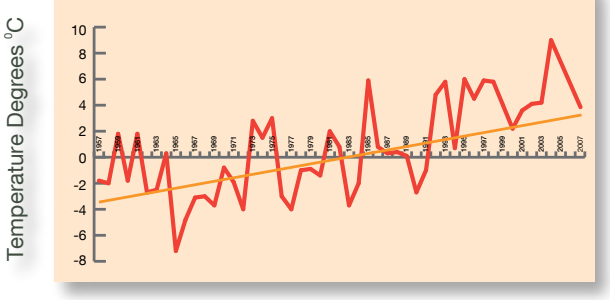
Average sea surface temperatures range from 26°C June to October, to 29°C in February. December to April are just below the February maximum with an average temperature of 28°C (Fiji Meteorological Service, 2003). Sea surface temperatures are not currently monitored in Fiji (Pacific Islands Climate Change Assistance Program & Fiji Country Team, 2003).

Temperature increases widespread across Fiji ~ 0.6 ^{0}C over the last 50 years (similar to neighbouring countries). Similar increase in rate for both day and night time temperatures.

Source: Fiji Meteorological Service, 2009.

Figure: 3a

Annual Mean Temperature Anomalies for Fiji

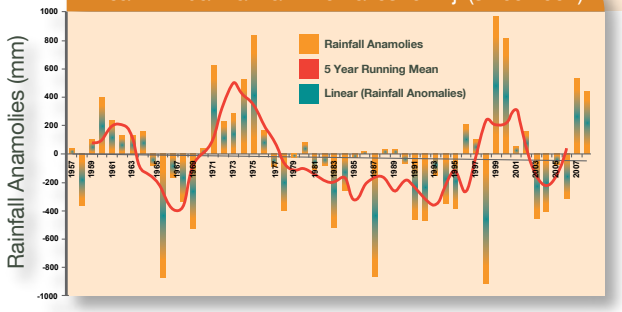


Almost no trend (slightly negative) over the last 50 years on a Fiji scale. El Nino (droughts) and La Nina (wet periods) effect on Fiji's climate significant e.g. almost -900mm in 1998 and almost +1000mm in 1999

Source: Fiji Meteorological Service, 2009.

Figure: 3b

Mean Annual Rainfall Anomalies for Fiji (since 1957)



Rainfall patterns show a pronounced orographic influence on larger islands, with leeward areas being drier and warmer. On Viti Levu for example the windward SE receives 3,000-5,000 mm while the leeward NE receives 2,000-3,000 mm. There is a wet season November to April, and a dry season influenced by seasonal migration of the South Pacific Convergence Zone (Fiji Meteorological Service, 2003).

Fiji experiences major changes in its oceanography during an El Niño year and this affects the migration of tuna and billfish. During an El Niño event, there are weak trade winds, low western Pacific oceanic temperature and less precipitation (Nunn, 1994). El Nino years are characterised by increased frequencies of cyclones and rainfall. Cyclones that coincided with high tide caused havoc in the Yasawas in 1997 because of saltwater intrusion. Droughts in Fiji are closely linked to the ENSO phenomenon, where a strong ENSO episode is associated with major drought, as happened during the 1982/1983 and 1997/1998 ENSO events.

The IPCC has found evidence of increase in precipitation over the equatorial Pacific in the last few decades, with decreases to the north and south (Houghton et al., 1996: 25). Scenarios of future climate change all show an enhanced global mean hydrological cycle, but there are uncertainties as to how this will affect rainfall patterns in the Pacific island area.

Analysis of climate records showed New Caledonia, Vanuatu, Fiji, Tonga, Samoa and the southern Cook Islands experienced a strong warming of 0.4 – 0.6° C from 1900-1977, which has since slowed to 0.1° C, with average rainfall declining by 15 percent after 1977 (SPREP, 1998). The UNFCCC National Communication Report for Climate Change adopted the climate change projections from two GCMs, projecting a temperature rise for Fiji of 0.5-0.6°C by 2025, 0.9-1.3°C by 2050 and 1.6- 3.3°C by 2100. These are the same projected temperature changes for Fiji used by Agrawala et al. (2003). Changes in precipitation are expected, but the direction of these uncertain.

Relative Sea-Level in Fiji

The latest projections from the IPCC are for a global rise in sea level of between 9 and 88 cm by 2100 (McCarthy et al., 2001), which equates to a rate of 0.9-8.8 mm a-1.

There are several sea-level rise projection for Fiji based on models. The UNFCCC National Communication Report for Climate Change adopted the climate change projections from two GCMs, projecting a sea-level rise for Fiji of 11-21 cm by 2025, 23-43 cm by 2050 and 50-103 cm by 2100 (Pacific Islands Climate Change Assistance Program & Fiji Country Team, 2003). Agrawala et al. (2003) project similar rates of sea-level rise for Fiji.

Figure: 4

Tectonic Divisions of Fiji

Source: Nunn and Peltier, 2001.

Understanding the history of relative Holocene sealevels on Pacific Islands such as Fiji is important for forecasting the future environmental conditions (Dickinson, 2001). Sea-level change occurs due to global eustatic causes, regional hydroisostatic causes, and local tectonic causes. The Holocene movement of Fiji's islands have been described by Nunn (1990c) and Nunn and Peltier (2001), showing that many islands are either rising or subsiding. Hence, direct application of global sea-level projections is inappropriate in Fiji. Nunn and Peltier (2001) revised the initial assessment of Numm (1990), dividing Fiji into tectonic areas (Figure 4), and reviewed and synthesised evidence to identify Holocene subsidence or uplift, summarised in Table 2 below.

Assuming these tectonic trends are correct, and will continue over the present century, these tectonic trends can be used to infer the differential impacts of projected global sea-level rise. Areas that are stable such as the south coast of Viti Levu, Ovalau and Motoriki will experience the rates of sea-level rise predicted globally. Areas subsiding such as the north coast of Viti Levu and islands of the Lau group such as Yasa Yasa Moala and Vanuabalavu will experience greater relative sealevel rise. Areas uplifting such as the north coast of Vanua Levu will experience less or negligible relative sea-level rise.

There is some differential movement of islands within some of the above Fijian tectonic subregions. Most Pacific Islands experienced a higher sea-level stand in the mid-Holocene, owing to regional hydroisostatic changes caused by postglacial deformation of the mantle. In Fiji this is modelled at 2.1 meters above present Nunn and Peltier, 2001), and occurred about 3000 to 6000 radiocarbon years before present (Dickinson, 2002). In the case of Vanua Balava in the Lau group, palaeo-shoreline evidence of this highstand now occurs at present sea-level, showing this island is subsiding at a rate of 0.5 mm a-1 (Dickinson, 2002).

Table 2
Holocene Tectonic Movement of different areas of Fiji identified in Figure 4.

Holocene Tectonic Movement Areas in Fiji

Tectonic Region (Figure 3)	Area	Holocene tectonics
A	Viti Levu South coast stable	North coast subsiding
B	Ovalau, Motoriki	Stable
C	Lau, Yasa Yasa Moala Vanuabalavu	Unstable Subsiding Subsiding (Nunn et al., 2002)
D	Vanua Levu	North coast uplifting Cadaudrove peninsular uplifting
E	Kadavu, Vatulele / Beqa	Unclear

Source: Nunn and Peltier, 2001.

This review also infers that Ovalau and Vanua Levu are subsiding at less rapid rates.

Nunn (1990b) used interviews with elderly people to infer sea-level rise over the last century at all of 16 coastal settlements in Fiji: 4 villages on Beqa (Table 2, region E), 2 on Gau (Table 2, region E), 2 on Lakeba (Table 2, region C1), 6 on Viti Levu (Table 2, region A), and 1 on each of Matuku and Totoya (both in Table 2, region C2).

One of the few shorelines which previously was thought to be stable is the northern shore of Viti Levu, where large mangrove deltas and a complex pattern of offshore reefs suggested Late Holocene sea-level stability (Nunn, 1998). However, interviews with elderly residents at Namoli and Natunuku both in the north-west shore of Viti Levu indicated that both have noticed sea-level rise during the last century (Nunn, 1990b). Nunn and Peltier (2001) revived Nunn (1998) and this area is now thought to be subsiding. There may be enhanced subsidence in deltaic areas, owing to shelf loading by sediment (Nunn and Peltier, 2001).

Dying mangrove stands in the salt flats, Nadroga

The AusAID SEAFRAME tide gauges have been established in the Pacific for about a decade, including one at Lautoka installed in October 1992. These records are too short for any reliable longterm estimate of change in mean sea level, but will prove invaluable over decades to come. The 10 years of record existing has shown a dramatic drop in sea-level associated with the 1997/1998 El Nino (Harvey and Mitchell, 2003). Mitchell et al. (2000) find considerable noise in regional sea-level trends from El Nino and La

Nina sea-level variations, though reporting that a 7 year tidal record from Suva has shown a rise in MSL of 1.01 cm, from which least squares analysis shows a rate of sea-level rise of 4.67 mm a-1.

From November 1987 Nunn (1988, reprinted as 1990a) carried out a map-based assessment of impacts of sea-level rise on 7 primarily urban sites in Fiji, to a range of sea-level rise predictions current at the time up to 3 meters. Although some sites included mangroves very little information is available from this study for the purposes of the current report, only that all mangroves would suffer near total loss with a sea-level rise of 1.5 meters, and total loss at 3 m. Mangrove losses with sea-level rises of 0.2 and 0.5 meters could not be determined due to lack of elevational survey detail from mangrove areas. Impact on mangroves was noted to be regulated by the contribution of sediment from adjacent rivers, with reference to Beqa Island which is a small high volcanic island with a narrow coastal plain.

Due to lack of tide gauge information on recent sea-level changes in the Pacific Island region, Nunn (1990b) undertook a questionnaire survey to elderly inhabitants of coastal settlements on coastal changes over their lifetimes. This included questions on changes in low tide and high tide levels, and USP student interviewers then surveyed the indicated changes to quantify this vertically and horizontally. There are many reservations about the quality of such a study, not in the wisdom of the elderly people but in the use of numerous student interviewers, and lack of separation of sediment erosion which may result in apparent inundation from rise in sea-level. Results from 16 interviews in Fiji indicated sea-level rise at all locations including 4 villages on Beqa, 2 on Gau, 2 on Lakeba, 6 on Viti Levu, and 1 on each of Matuku and Totoya. This approach was extended to Ovalau and Moturiki by Nunn (2000b), finding extensive accounts of shoreline erosion.

Fiji has a well established climate monitoring service, but the tide gauge network is nor adequate to show differential rates of sea-level rise that will result from the complex tectonic settings of the region. Some areas will have higher relative sea-level rise impacts of erosion and mangrove loss due to subsidence as well as global sea-level rise.

Mangrove Response to Climate Change and Sea-level Rise

There is increasing evidence that mangroves may be affected by coastal environmental change, including hydrological variations and sea level rise (Ellison and Farnsworth, 1997). The response of mangroves to such impacts tends to be gradual and, particularly in undisturbed systems, is manifested typically as a change in their extent, structure and species composition and hence their distinct zonation. As mangroves are sensitive to even minor transitions in coastal conditions (e.g., altered drainage patterns, saltwater intrusion, accretion or erosion in response to sea level variations), changes in the zonation of these ecosystems are often indicative of broader scale changes and associated impacts in coastal regions (Blasco et al., 1996; Ellison and Farnsworth, 1997).

The fate of mangrove habitats to climate change globally will depend on a number of factors, including current tidal range, sedimentology, salinity regime, community composition and shore profile. Low relief shorelines and low islands will show more change than narrow shorelines on higher islands. Sea-level rise will have more impact on intertidal systems in microtidal areas such as Fiji, than macrotidal areas.

Temperature Rise

Mangrove distributions are limited by temperature in subtropical latitudes, at the 16°C isotherm for air temperature of the coldest month, at the margins of incidence of ground frost, and where water temperatures never exceed 24°C. Mangrove distributions in Fiji are not limited by temperature, rather by distance, with lower mangrove diversity on eastern islands of Fiji relative to the larger islands in the west. Hence climate warming of the ranges predicted should not alter Fijian mangrove distributions.

While studies of mangrove survival under temperature stress have been carried out in thermally polluted areas such as power station effluents (Canoy, 1975; Banus, 1983), limits shown are far higher than the current climate change projections.

Combined with higher atmospheric CO_2 levels (discussed below), climate warming can be expected to increase mangrove productivity, characterized by increased growth and litter production at all locations. Mangroves in southern latitudes of Fiji are likely to become taller and more productive. With climate warming there may be change in phenological patterns (such as the timing of flowering and fruiting).

Increased CO_2

As well as its climate effects, increased CO_2 directly affects plant growth and development. Plants have different pathways of carbon fixation in photosynthesis, and mangroves operate the C3 pathway (Clough et al., 1982). In this case, metabolic responses with increased atmospheric CO_2 are increased productivity and more efficient water use (UNEP, 1994). Farnsworth et al. (1996) grew seedlings of *Rhizophora* mangle in doubled levels of CO_2 and demonstrated

significantly increased biomass, total stem length, branching activity and total leaf area compared with seedlings grown in normal levels of CO_2. Ball et al., (1997) found that the benefits of increased CO_2 may only occur where mangroves are not limited by high salinity or humidity. Investigation of photosynthetic performance by Cheeseman et al. (1991) in *Rhizophora apiculata*, *Bruguiera gymnorrhiza* and *B. parviflora* indicated that enhanced photosynthesis with higher CO_2 was unlikely.

Where mangrove canopy photosynthesis is partially limited by CO_2 supply because of low stomatal conductance, mangroves may respond to increased levels of atmospheric CO_2 by further closure of their stomata to minimize water loss (UNEP, 1994). In this case, rates of photosynthesis may not significantly increase. If stomatal conductance remains the same, then rates of photosynthesis would increase. The first is more likely because of the lack of availability of fresh water in mangrove habitats, and their consequent adaptation to water conservation. As a result, mangroves are more likely to respond to increased ambient CO_2 where water and nutrients are not constraints. In the case of Fiji, increased productivity from this factor is therefore more likely in mangroves of windward shores than those of leeward shore, where mangroves are stunted by salinity.

UV-B

Surface UV-B radiation has increased by approximately 6% in the Southern Hemisphere mid-latitudes and 130% in the Antarctica, relative to 1970's values (Madronich et al., 1998). The next half-century should show a return to pre-ozone depletion levels. Stratospheric ozone and UV-B monitoring are carried out in Fiji at the Laucala Bay campus of the USP (Pacific Islands Climate Change Assistance Program & Fiji Country Team, 2003).

A field survey showed that mangrove species of *Bruguiera* and *Rhizophora* varied in their response to UV-radiation. Differences in the contents of UV-absorbing compounds between species and UV treatments could be due to the level of carotenoids in mangrove leaves, and possibly due to leaf succulence (Lovelock et al., 1992). It was proposed that differences in species response to UV radiation may be influenced by their ability to dissipate excess visible solar radiation.

Precipitation Changes

Mangroves in Fiji demonstrate that taller, more productive and more diverse forests grow on coasts with higher rainfall, while on drier coastlines mangroves are stunted, of narrower margins, and interrupted by salt flats.

Figure 5a *Mangrove leaf litter dry weight from Bole Transect, Tikina Wai*

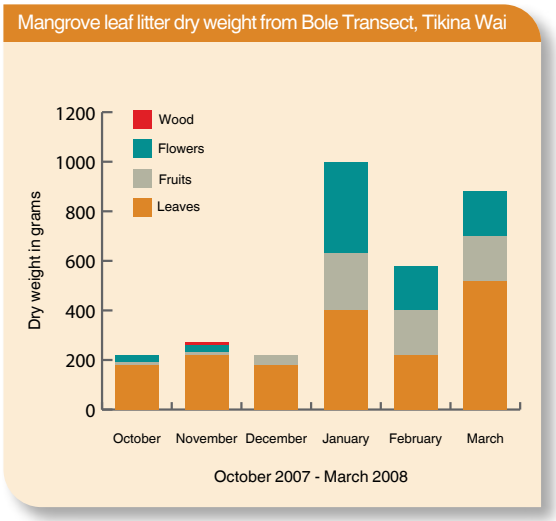
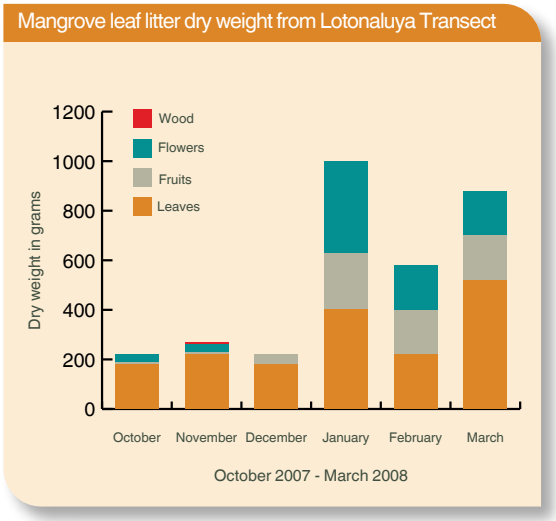


Figure 5b *Mangrove leaf litter dry weight from Lotonaluya Transect*



According to mangrove litter data collected from Tikina Wai site, seasonal productivity of mangroves increased from January to March due to the wet season. Litter production is seasonal with mangrove production at its maximum during the wet season (November-April) and at its lowest from May-September.

The reasons for these patterns relate to salt stress. Under humid conditions, mangrove soils are almost continuously leached by heavy rains and fresh water is available from river discharge and groundwater outflow, which provides nutrients. Under arid conditions, evaporation from the intertidal mangroves at low tide leads to high concentrations of salt, in some cases resulting in unvegetated hypersaline flats around high tide level.

In Fiji, Pillai and Tyagi (2001) found the success of flowering and propagule set of three species of mangroves was influenced by rainfall patterns. Higher

success was found on the wet coast of Viti Levu relative to the dry coast, and higher success also in a normal year relative to a drought year. This study indicated the potential influence of precipitation changes on mangrove reproduction.

Increase in salinity in mangroves leading to salt stress can result from a number of factors in addition to reduced rainfall, such as groundwater depletion owing to reduced freshwater flux, groundwater extraction, and sea-level rise. Two major physiological adaptations enable mangrove survival in saline ocean water (Scholander, et al., 1962), salt exclusion in species of *Rhizophora* and *Laguncularia*, and salt excretion in species of *Aegialitis* and *Aegiceras*. Salt excluders also cease or diminish transpiration and photosynthesis when exposed to saline water. Salt secretors can continue photosynthesis utilizing ocean water in transpiration, owing to salt glands in the leaves.

Stern and Voight (1959) grew 200 seedlings of *Rhizophora* mangle under different salinities, finding that seedling survival and growth increase by dry weight and seedling height were all inversely related to salt concentrations of the growing solutions. Ball and Farquhar (1984a) studied gas exchange characteristics in *Aegiceras corniculatum* and *Avicennia marina* under different salinity and humidity conditions. They showed decreased photosynthetic capacity with increase of salinity, with *Aegiceras* being the more sensitive. Ball and Farquhar (1984b) studied the gas exchange characteristics of *Avicennia marina* with increasing salinity, finding that CO_2 assimilation rate, stomatal conductance, intercellular CO_2 concentration and evaporation rate all decreased. Increased salinity has the effect of decreasing net primary productivity and results in reduced growth, with a differential effect on species. Reduced precipitation and a rise in sea-levels could result in stress to and changing competition between mangrove species.

Increased rainfall should result in reduced salinity and exposure to sulphate, and an increase in delivery of terrigenous nutrients (Snedaker, 1995). The extent of mangrove areas can be expected to increase particularly on leeward shorelines, with colonization of previously unvegetated areas of the landward fringe, and the diversity of mangrove zones and growth rates should increase. Decreased rainfall and increased evaporation would reduce the extent of mangrove areas, particularly with loss of the landward zone to unvegetated hypersaline flats.

These responses of Fijian mangroves to changes in precipitation will occur in combination with response to climate warming, increased CO_2 and sea-level rise. The net response of mangroves at each location will also be combined with local factors and other impacts. Understanding and management of these changes will require data the nature of mangrove changes in the region.

Sea-level Rise Impacts on Mangroves.

Mangrove species display a distinct zonation from their seaward margin to the high water mark, based on controls including the frequency of inundation and salinity exposure (Duke et al., 1998). This zonation is largely controlled by the elevation of the substrate surface relative to mean sea level.

The control of sea-level elevation on the seaward margin of mangroves has been demonstrated by the author through detailed survey of marine-dominated low island mangrove systems on the Northern Great Barrier Reef. The mean elevation of the mangrove/lagoon margins at Low Isles, Three Isles and Pipon was found to be 0.36 m below MSL, with insignificant differences in means between spatially separated islands. This showed mangroves to be closely controlled by sea-level elevation at their seaward margin, which demonstrates the importance of stable sea-level in controlling mangrove distributions.

Large mangrove ecosystems develop on sedimentary shorelines of gentle gradient, between mean sea level and the level of mean high water spring tides. Growing in the upper half of the tidal range, their close relationship with sea-level position renders mangrove swamps particularly vulnerable to disruption by sea-level rise. With most Pacific islands having a tidal range of less than 1 m, mangrove ecosystems will be disrupted by a sea-level rise of 0.3 m, and will retreat landwards with a sea-level rise of 1 m. However, factors such as physiographic location, tidal range, species assemblage and sediment supply contribute to heterogeneity in mangrove response to rising sea-level.

Research to investigate sea-level rise impacts on mangroves falls into two areas. First, sea-level effects on an ecosystem can be reconstructed from the past, by analysis of stratigraphic deposits, provided the evidence is available from microfossils (i.e. pollen, diatoms) that can be used to indicate the vegetation and environmental conditions. This technique has the advantage of indicating longterm complex system response, though detail of shortterm individual responses of species is usually only speculative. Second, present day case studies can be examined, such as areas of the world where sea-level rise is occurring, or areas where flooding of mangroves has been carried out for mosquito control. From these approaches, monitoring programmes can be developed for identification of changes in the mangrove ecosystem resulting fromclimate change and sea-level rise.

Past Records of Mangrove Response to Sea-level Rise

Comparing present trends in species and communities with palaeo-ecological records of past extents provides excellent information on how they may respond to climate change (Hansen et al., 2001; Hansen and Biringer, 2003).

Within the intertidal habitat of mangroves, species have different preferences for elevation, salinity and frequency of inundation, resulting in species zones. Elevation of the ground surface can be raised under mangroves, by accumulation of vegetative detritus to form a mangrove peat or mud, which may also contain matter brought in by the tides and by rivers. If the sedimentation rate keeps pace with rising sea-level, then the salinity and frequency of inundation preferences of mangrove species zones will remain largely unaffected. If the rate of sea-level rise exceeds the rate of sedimentation, then mangrove species zones will migrate inland to their preferred elevation, and seaward margins will die back. The accumulation of sediment under mangroves will help to compensate for rising sea-levels. However, expected rates of sedimentation must be established to assess the vulnerability of mangrove ecosystems. This requires analysis of Holocene stratigraphy. (Ellison, 2008)

Stratigraphy of Pacific island mangroves indicates that mangroves became established in expansive swamps during the middle of the Holocene Period, about 6500 years ago (Ellison and Stoddart, 1991). Before this time they were limited by the interactive factors of rapid sealevel rise and the absence of sedimentary shorelines. Mangroves probably survived this period as individual trees, as seen today on shorelines with too steep of a gradient or that are too exposed for expansive swamp development.

Island types in Fiji are high islands along with many low atolls (Maharaj, 2000). Mangroves of Fiji are most expansive in estuarine areas of high islands, though important ecosystems also occur as embayment, lagoon and reef flat mangroves of low islands. Deltaic and estuarine mangroves occur on islands sufficiently high to develop a river system, and so deliver significant quantities of sediment to the coastal zone. The mangrove areas receive fluvial sediment from the catchment, and also accumulate vegetative debris to form a mud. Stratigraphic reconstruction reveals fairly rapid accretion in estuarine mangroves of up to 45 cm per 100 years (Ellison and Stoddart, 1991). In Fiji Terry et al. (2002) show rapid floodplain sedimenttion, but no studies of estuarine sedimentation rates have been carried out.

Embayment, harbour and lagoon mangroves of low islands do not have a fluvial supply of sediment, and build up their substrate by accumulation of vegetative detritus to form a highly organic peat. Mangrove stratigraphy from low island mangrove ecosystems indicates rates of accumulation of up to 12 cm per 100 years (Ellison, 1989; Ellison, 1993). This reflects the rate of peat production within the mangrove system, there being few sources of inorganic sediment in these environments.

Mangrove response to sea-level rise has been investigated by reconstruction of Holocene analogues in Tonga as well as Bermuda. Radiocarbon dating of stratigraphy determined a sediment accretion rate of 1 mm/ year, indicating that low island mangroves could keep up with a sea-level rise of this rate. Mangrove recession events and replacement by lagoon environments are shown to occur during more rapid sea-level rise. In Tonga, a large mangrove swamp persisted between 7000 and 5500 yr BP during sealevel rise at a rate of 1.2 mm a-1, then retreated when the rate of sea-level rise increased (Ellison, 1989). Retreat of mangrove zones with slowly rising sea-level has also been demonstrated from the extensive coastal swamps of southern New Guinea (Irian Jaya) (Ellison, 1998). This indicates that while low island mangroves are likely to be the most sensitive to sea-level rise, high island mangroves will also suffer disruption and retreat.

Comparison of mangrove stratigraphy shows that low island mangroves are more susceptible to disruption by rising sea-level owing to relatively low rates of sediment accretion. Stratigraphy from high islands and continental coastlines, that have more sediment coming off the land into intertidal areas from rivers and longshore drift, indicates that mangrove ecosystems in these areas will be better able to keep pace with sea-level rise. Low island mangroves could keep up with sealevel rise of up to 1.2 mm per year. High island mangroves could keep up with rates of 4.5 mm per year, depending on fluvial sediment supply.

Global mean sea level is projected to rise by 0.09 to 0.88 m between 1990 and 2100 (IPCC, 2001). This gives an average rate of rise of 1 to 8.8 mm / year. Comparison of rates of global sea-level rise projected of with these rates of mangrove accretion indicates that all mangroves will experience serious problems with rising sea-level in the next 50 years, and low island mangroves could already be under stress.

Present Case Studies

Impacts of sea-level rise on mangroves have been investigated on Bermuda, where measured rates of sea-level rise over the last century have been within the projections for Fiji for this century. Tide gauge records since 1932 show sea-level rise at a rate of

28±18 cm per 100 years (Pirazzoli, 1986). The largest mangrove area at Hungry Bay had existed for the last 2000 years, and during the last century lost 26% of its area due to retreat of its seaward edge. Survey showed that swamp elevations were lower in the tidal spectrum than normal, and mangroves at the seaward margin were under inundation stress (Ellison, 1993; Ellison, 1997).

The rate of sediment accretion under mangroves in Bermuda for the last 2000 years has been 0.8 to 1.1 mm per 100 years (Ellison, 1993). The rate of sea-level rise has exceeded the rate of sediment accretion, leading to retreat of the seaward margin and erosion. The substrate elevation of the seaward margin of mangroves is below mean sealevel, the normal lower limit for mangroves.

Community involved in recent stratigraphy study

The record from Bermuda demonstrates that mangrove sediment is subject to erosion by rising sea-levels, with removal of mangrove substrate (above MSL) and with some deposition subtidally offshore of the mangroves (Ellison, 1993). This corresponds with the Bruun Rule, which has shown erosion of beach sediment to occur with sea-level rise (Bruun, 1962; Schwartz, 1967; Douglas et al., 2001). Sheet erosion occurs at the peat surface, indicated by a 20 to 25 cm difference between the peat level above a small cliff and the former peat surface as indicated by exposed horizontal roots of *Avicennia*. As trees recede and loosen the sediment, more rapid erosion occurs and forms a 40-50 cm small cliff. Such erosion exacerbates the existing problem, for as the mangrove substrate surface is lowered and creeks widen, the differential between elevation and MSL increases.

Accelerated coastal erosion is known to be associated with rising sea-level (Stewart, et al., 1990), and observations in Bermuda indicated that mangrove sediments are as susceptible as beach sediments. Increased efficiency of wave erosion with a higher sealevel causes removal of sediment from the upper part of the tidal spectrum and deposition in the lower part (Bruun, 1962). The Bruun rule was initially proven from wave tank experiments (Schwartz, 1967), and has since been shown for natural beaches (Diez, 2000). Erosion of beach sediment has been shown during long-term sea-level rise (Leatherman, 1987), short-term sea-level variation (Clark and Eliot, 1983), and for shortterm fluctuations in levels of the Great Lakes (Wood, 1991). The Bruun rule is expected to cause significant coastal erosion if the IPCC projected sea-level rise occurs (Leatherman et al., 2000).

Similar erosion patterns to Bermuda, with reversed succession as elevation declines, have been described by Semeniuk (1980) in N.W. Australia. The effect of sheet erosion on mangrove zonation is migration of pioneer/ seaward mangroves into more landward zones. The effect of cliffing on mangrove zonation is loss of the seaward zone, leading to truncated zonation and narrow fringes. The effect of tidal creek erosion is slumping of banks and loss of trees.

In the Northern Territory of Australia, Woodroffe and Mulrennan (1993) have documented dramatic recent changes to the Lower Mary River floodplain, with saltwater intrusion and upstream expansion of the tidal creek network. This has resulted in the death of freshwater wetland communities with loss of 60 km2 of Melaleuca forest and upstream invasion of mangroves. There are a number of possible reasons for these events, including relative sea-level rise (Woodroffe, 1995). Similar, though less spectacular, extension of creeks has occurred on other river systems, such as the Alligator rivers (Woodroffe, 1995). Loss of freshwater wetlands with saline intrusion is documented in the Florida Keys (Ross, et al., 1994), where longer tide records have enabled researchers to attribute the cause to relative sea-level rise.

Fringe mangrove forest types are mangroves exposed directly to the open sea, as opposed to riverine mangrove found in estuaries, or basin mangroves which occur in partially impounded depressions (Cintron and Novelli, 1984). The density of mangrove vegetation exerts a drag coefficient on tidal waters to protect the sediment from erosion (Mazda et al., 1995). When the fringing mangroves are degraded by human impact, then tidal forces can increase to cause coastal erosion (Furukawa and Wolanski, 1996; Mazda

et al., 1997; Massel et al., 1999). Coastal erosion also occurs with degradation in riverine mangroves (Mazda et al., 2002).

A collaboration between Japanese experts and SPREP has assessed vulnerability of small island countries to sea-level rise, including Fiji (Mimura, 1999). Mimura and Nunn (1998) used observation and interviews with elderly inhabitants of long-established coastal settlements, to suggest that beach erosion in most of Fiji became significant from some 40 years ago. The causes of this change are considered to be a combination of human-induced development and possibly sea-level rise, and have been exacerbated by inappropriate coastal protection. A GIS was applied for the Fiji case study to classify coastal zones in terms of vulnerability indexes (Mimura, 1999).

Inundation Effects on Mangroves

One major control on mangrove species zonation is their inundation preferences, hence rise in sea-level could cause stress to existing mangrove trees. Impoundment of mangroves for mosquito control in Florida mangroves provides several examples of prolonged inundation causing mangrove mortality (Brockmeyer et al., 1997).

Naidoo (1983) found that prolonged flooding resulted in lower ability of leaves to conduct water; an increase in stomatal closing; and, degeneration of chloroplasts in *Bruguiera gymnorrhiza*, leading to reduced rates of photosynthesis. When lenticels of aerial roots become inundated, oxygen concentrations in the plant fall dramatically (Scholander, 1955). If inundation is sustained, low oxygen conditions occur and mortalities follow.

Lahmann (1988) found that rates of litterfall in an impounded mangrove forest in Florida were reduced relative to natural fringe forest during flooded months. This indicates that the above ground net productivity of *Rhizophora* mangle is reduced by flooding, though phenology (such as the timing of flowering and fruiting) was not changed. Over several years of flooding survival of *Avicennia germinans* and *Laguncularia racemosa* seedlings was prevented, and *Rhizophora* mangle became more common, despite poor seedling establishment during flooded periods. The depth of flooding was not indicated in this study.

Ellison and Farnsworth (1997) grew *Rhizophora* mangle seedlings with a 16 cm increase in water level. They maintained normal tidal fluctuation around this raised mean, and found that growth slowed dramatically at the sapling stage, until after 2.5 years, plants were 10- 20% smaller than control plants.

Impacts on Mangrove Fauna

River discharge has long been recognized as one of the factors contributing to the high productivity of estuaries. Studies in tropical Australia have demonstrated that high river discharge can have a strong positive effect on the production of commercial and recreational coastal fisheries (Vance, et al., 1998; Longeragan, 1999). Hence changes in precipitation and runoff are likely to affect mangrove faunal distribution and abundance. Furthermore, the seasonal pattern of flow is equally, if not more important, than the magnitude of flow.

Climate change can be expected to change many physical parameters in Fijian nearshore waters, such as temperature, salinity, current and tidal patterns. The abundance and distribution of fish species in mangrove habitats can be altered by changes in freshwater inflow, water depth or temperature (Ley et al., 1999). Decline in mangrove area due to mortality in their present locations caused by sea-level rise, and lack of inland areas available for mangrove migration will cause a parallel decline in fisheries that use mangroves as nursery grounds or habitat.

The tuna fish catch in Fiji is going to be affected by climate change with vast potential economic consequences (Aaheim and Sygna, 2000). This study drew on the past impact of El Nino as an analogue for longer-term climate effects and concluded that climate change may result in a decline in the total tuna stock, and a migration westwards away from Fiji, causing decreased Fijian stocks.

Tropical Cyclones

Tropical cyclones occur in the period November to April, with greatest frequency during January and February (Fiji Meteorological Service website, February 2003). On average, some 10-15 cyclones per decade affect some part of Fiji, and 2-4 exert severe damage. The dominant north-west to south-east tracks gives some increased risk of damage in outlying north-west island groups. There has been an apparent increase in the incidence of cyclones in Fiji since the early 1990's (Sulu et al., 2002).

Damage in mangroves following cyclones is usually a narrow zone of coastal wave damage, and complete defoliation over the narrow area of cyclone paths (Jaffar, 1992). Large-scale flooding is frequently associated with tropical cyclone impacts. More damage to mangroves is caused by rapid sedimentation adjacent to rivers and landslide areas, mangroves being intolerant of sudden burial by sediments (Ellison, 1999b.)

Summary

Direct climate change impacts on mangrove ecosystems are likely to be less significant than the devastating effects of associated sea-level rise. Mangrove forests occupy an intertidal habitat, and are extensively developed on accretionary shorelines, where sediment supply determines their ability to keep up with sea-level rise. Mangroves of low relief islands in carbonate settings that lack rivers are likely to be the most sensitive to sea-level rise, owing to their sediment-deficit environments. Mangroves of low islands have further been identified as more vulnerable to climate change and sea level rise than those developed on deeper sediments of high islands because they are structurally poorer (Ward and Metz, no date).

It may be difficult to differentiate the observed changes from causes, where mangroves weakened by climate change related stress may apparently suffer mortality from another cause. Minor changes in ecological conditions in mangroves could weaken the trees and render them more susceptible to forest insect and disease pests that would normally not affect health trees (Kjerve and Macintosh, 1996).

Certain identification of climate change and sea-level rise effects on mangroves requires monitoring of biological and physical parameters at a network of locations using standard techniques, which can be achieved by a combination of onground and remote sensing techniques (Lucas et al., 2002). This would provide environmental managers with ecological data to allow early identification mangrove response to climate change.

Impacts of Climate Change on Inshore Coral Reefs

Global climate change has not been recognized as a major threat to coral reefs until recently. Direct anthropogenic stresses such as increased sediment loading, organic and inorganic pollution and overexploitation were until recently considered to be far more critical (Wilkinson and Buddemeier, 1994). With widespread coral mortality in the global bleaching events of 1997-8, including pristine and remote reefs, views on the threat of climate change to corals radically switched (Wilkinson, 1999).

This was confirmed by fears that increased CO_2 concentrations would change the balance between carbonate and biocarbonate ions in sea-water, reducing calcification rates of corals (Kleypas et al., 1999; LeClerq et al, 2002). While coral reef species have survived substantial climate and sealevel change events in the geological past, this time human impacts are undermining reef resilience (Hughes et al., 2003).

Other impacts of climate change on coral reefs are relatively insignificant. No significant effects of increased UVB radiation can be anticipated on coral reefs. Projected sea-level rise should have virtually no effect on coral reefs, except for allowing more room to grow, through the raising of the upper limit to coral growth (Wilkinson, 1999; McCarthy et al., 2001). However, coastal erosion with sea-level rise will result in sediment movement offshore, which could smother coral reefs.

The effect of increased CO_2 concentrations weakening coral skeletons and reducing the accretion of reefs is expected to be greater at higher latitudes (Kleypas et al., 1999). Hence a gradation in impact from north to south across Fiji could be expected.

Coral Bleaching in Fiji

Water temperature in Fiji regularly reaches the upper thermal limit for coral. Corals in such locations exist within 1 or 2°C of their upper thermal limit during summer months. When corals are exposed to higher than normal seawater temperatures during the warm season their algal symbiosis is disrupted, leading to the phenomenon known as bleaching. This physiological symptom of stress is followed by large-scale coral mortality if high water temperatures are sustained.

It is predicted that annual sea-surface temperatures will increase, which should increase the magnitude and frequency of bleaching events over the next 100 years (McCarthy et al., 2001). This would cause reefs to remain in early successional states, or shift to communities dominated by organisms other than corals, such as macro algae (Hoegh-Guldberg, 1999). Unprecedented rates of species turnover on coral reefs in the Caribbean following the 1998 bleaching event (Aronson et al., 2002) provide a picture of potential change in the future. The 2000 bleaching event in Fiji was the worst ever recorded (Sulu et al., 2002).

In Fiji, coral bleaching caused a massive mortality of coral algae, invertebrates and fish between Savusavu and Buca Bay in January 1999 related to extreme temperatures and runoff (Zann and Vuki, 2000). Coral bleaching occurred around Viti Levu and south of Vanua Levu February to June 2000, when sea surface temperatures remained above 28.3°C during La Nina conditions (Obura and Mangudhai, 2001). During this event, bleaching of corals also occurred on Taveuni, Ovalau and Kadavu (Vuki et al., 2002). Almost the entire Great Astrolabe Reef and North Astrolabe Reef was affected, with close to 100% mortality at some sites in the lagoon and leeward sides of the reefs.

Coral became overgrown by algal filaments, coralline algae, and a soft mat of microbial and algal filaments, representing a successional change from

Signs of coral bleaching

climax coral to pioneer algae. Lowest mortality occurred on the windward reef, where cooler oceanic water reduced impact. This should provide a source of larvae to allow recovery of the leeward reef areas (Obura and Mangudhai, 2001).

Monitoring by Greenforce at Yadua Island and Yaduatapu found hard coral cover of 30% at 5 m and 10 m depth, which after the 2000 bleaching event reduced to 14% at 5 m and 12% at 10 m. Subsequent recovery has been very slow at 5 m, but far better at 10 m depth (Sulu et al, 2002).

Nineteen reef locations were surveyed in eight geographic regions within the Fiji archipelago between mid April and early July 2000, to assess the geographic extent and intensity of Fiji's first recorded mass bleaching event. 64% of all scleractinian coral colonies surveyed were bleached (partially or fully, or recently dead from bleaching), and mass bleaching occurred in all regions surveyed except in the far north (north of Vanua Levu). Bleaching was most intense (>80% of colonies bleached) in southern and eastern sites (south and east from Viti Levu and Vanua Levu, Kadavu and Northern Lau), and lower in some western and one northern site(s). The geographic patterns in bleaching coincide with Fiji's position on the northwestern edge of an area of high sea surface temperatures (SSTs), and support the prediction based on SSTs that bleaching should be most severe in the south and east. Seawater temperatures exceeded expected summertime maximum for 5 months and peaked at 30-30.5°C between early March and early April 2000. The bleaching threshold for Fiji appears to be in the range of 29.5- 30°C. It was estimated that 10-40% of coral colonies had died from bleaching within four months of the onset of bleaching (Cumming et al., 2002).

It is apparent from the percentage losses of coral due to bleaching reviewed above were not total, despite the severity of the event. These surviving patches of resistance may be either due to an intrinsic, speciesor colony-specific physiological tolerance, or due to extrinsic environmental factors that afford some protection from bleaching conditions (West and Salm, 2003). Such environmental factors may be those that reduce temperature such as upwelling of cool water, or block radiation from reaching corals through reef topography or turbidity.

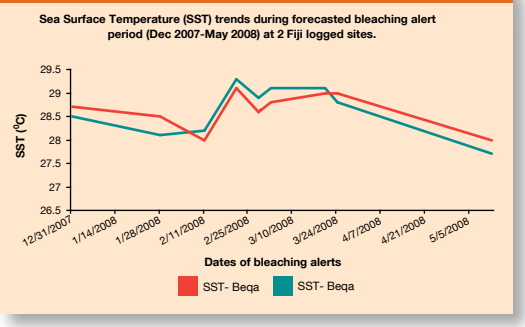
In massive *Porites*, Lough and Barnes (2000) demonstrate from locations throughout the inner GBR that there is a positive correlation between sea surface temperatures, coral calcification and annual coral extension rates. There was an associated decrease in coral density. Extension was highest and density lowest at inshore reefs where turbidity was highest, also noted by Scoffin et al. (1986) for Thai corals. This may be a growth response to greater availability of nutrients for coral growth in nearshore waters relative to offshore waters. This study concluded that as a result of global warming coral calcification rates will, at least initially, increase, with some evidence existing that this has already occurred.

Corals that are physiologically weak, with reduced defences are more prone to tissue injury by predators. These include predation by corallivorous gastropods, and the corallivorous seastar *Acanthaster* (crown of thorns). Once tissue injury to coral from crown of thorns has occurred, then coral mortality is more likely (Cumming, 2002). In Fiji, excavations of the sea urchin *E. matheaei* have caused massive changes

to the reef substratum associated with an increase in turf algae (Vuki et al., 2002).

Periodic storms such as cyclones when accompanied by heavy rains flush great quantities of accumulated materials from mangroves, with effect on downstream ecosystems such as inshore reefs (Ogden, 1988). Phytoplankton and benthic blooms are associated with runoff water. Outbreaks of the crown of thorns have been correlated with stirms on high pacific Islands, which may deliver pulses of nutrient rich runoff to the inshore reefs (Birkeland, 1982). Correlation of coral growth with runoff events has been demonstrated by Lough and Barnes (2000).

Figure: 6 SST trends at two Fiji reef sites



The data from the HOBO logger deployed at reefs adjacent to Tikina Wai mangroves illustrates similar SST trends at dates of bleaching alerts with a temperature range of 27.7-29.3 ^{0}C, a difference of 0.2-1.10^{0}C higher than normal. The Beqa reef, Fiji site for the NOAA's Coral Reef Watch Program from satellite data for both monitoring and assessment of coral bleaching. Alert levels are triggered when there is a 1^{0}C above the long-term monthly average temperature recorded over an extended period and coral bleaching is expected to occur.

Improving Resilience to Climate Change Effects

The above review demonstrates that mangroves and inshore reefs in Fiji are likely to demonstrate a sensitive response to climate change effects. Reduction of other stresses on coral reefs and mangroves will increase their resilience to climate change effects (Hansen and Biringer, 2003). Degraded areas if rehabilitated will also have increased resilience.

The review has found that there is little work to date on methodologies and projects that have designed an adaptation strategy to climate change effects for mangroves or coral reef systems. The majority of work to date has been focussed on assessment of impacts. Some inferences can be drawn however on how resilience of coral reefs and mangroves to climate change effects can be improved.

Improving Resilience in Coral Reefs

Coral reef conservation areas with reduced human impacts are supposed to provide habitats from which recruitment can spread following mortality events on reefs. While these are also subject to impact from coral bleaching, they will facilitate a partial recovery by reefs that are reconfigured and repopulated by a surviving subset of resistant species and genotypes (Hughes et al., 2003). Hence a change in choice of marine protected areas is appropriate, from the traditional choices of remote, pristine and special reefs, to those with higher survival rates recorded from bleaching events, and located where they can provide recruitment to damaged areas adjacent. On the Great Barrier Reef in Australia, Done et al. (2003) found that inshore reefs were more tolerant of elevated sea surface temperatures than reefs further offshore, perhaps due to greater acclimatisation to warmer waters.

Ward and Salm (2003) propose a new criteria to site selection for Marine Protected Areas of resilience to climate change, where areas of reefs show unexpected survival during bleaching events, either due to internal resilience in the corals or there are external factors operating that reduce the stress of warm water and radiation.

Reef monitoring in Fiji from accounts reviewed is fairly ad hoc, and not systematic or designed to indicate long term changes that may result from climate change effects. A systematic long-term monitoring program of representative or critical sites, in conjunction with existing research-based monitoring, would improve identification in Fiji of reefs responding to climate change effects.

Building Resilience in Mangroves

Similar to coral reefs, removal of other impacts on the health of mangrove ecosystems will improve their resilience to climate change and sea-level rise impacts.

Mangroves at a rising tide, Kubulau, Fiji

Improving Management and Planning

Resilience building in response to climate change involves revision of the design and management of protected areas. These should have buffer zones and corridors to aid species migration as environmental conditions change (Hansen and Biringer, 2003). In the case of mangroves, future migration areas for mangroves will be into the lowlands behind mangroves today. In Fiji these are lowland forests on the windward areas of large islands, or salt flats in the leeward areas of large islands. Unfortunately, the areas where mangroves will seek habitat with sea-level rise are those areas most favored by human development, the coastal lowlands. They are converted to other uses: agriculture, roads or coastal settlements. Conservation of buffer zones behind mangroves to anticipate landward migration with sea-level rise will improve future resilience of mangroves in Fiji.

A cross-sectoral task force or mangrove management committee needs to be strengthened in Fiji to facilitate and coordinate management, research and monitoring of the mangrove resource. Key organisations to be represented would include: the Ministries of Lands, Surveys, Natural Resources, Ministry of Fisheries, Ministry of Agriculture, Ministry of Health, Ministry of Education, Ministry of Tourism, USP Institute of Marine Resources, NGO's, and representatives of local communities and tribes. This is a mangrove management approach recommended by Hamilton and Snedaker (1984) and the SPREP Regional Wetland Action Plan (Idechong et al., 1995), and has been adopted by Fiji in the past, but needs to be made more effective. There is capacity for better use of traditiona community-based marine resource management systems (Veitayaki, 1977).

Mangrove Monitoring to Identify Climate Change Effects

Several expert groups have identified the need for a global monitoring system of mangrove response to climate change (UNEP-IOC-WMO-IUCN, 1991; UNEP 1994), but none to date has been implemented. In the South Pacific region, SPREP developed a Regional Wetland Action Plan, in which actions 3.3.1 and 3.3.5 call for development of a regional monitoring system for mangrove ecosystem health (Idechong et al., 1995). Such a regional monitoring networks would assist informed management with respect to climate change effects on mangroves.

Best practice for coastal monitoring of wetlands under threat from climate change and sea-level rise has been established in the Alligator Rivers Region of the Northern Territory, Australia (Finlayson and Eliot, 2001). This program has used the Ramsar Convention guidelines to define management objectives, the principal of which is to maintain ecological character or ecological integrity of the wetlands.

Wetland inventory, assessment and monitoring are distinguished as:

- Wetland inventory is the collection of information to describe the ecological character of wetlands.
- Wetland assessment is the identification of threats to wetlands.
- Wetland monitoring is collection of specific information for management purposes in response to hypotheses derived from assessment activities.

These authors stress that community and stakeholder involvement are an integral component of wetland management.

Wetland monitoring programs need to be of long time duration to be useful to wetland management (Finlayson and Eliot, 2001). In the case of sea-level rise and climate change impacts to mangroves, the later monitoring commences the poorer the baseline starting point will be in defining the ecosystem character before impacts commence.

Coastal monitoring programs are recommended to demonstrate the erosion expected with sea level rise, as reviewed in section *'Present Case Studies'* (Leatherman, et al, 2003).

Mangrove Rehabilitation to Benefit Inshore Reefs

Mangroves that are degraded are more likely to show impact from climate change effects than mangroves that are healthy. It is recognised in Fiji that while healthy mangroves cause sediment accretion and land building, degradation of mangroves can cause coastal erosion.

Mimura and Nunn (1998) reported from Nabila village on the west coast of Viti Levu, Fiji, an account from a long-time resident Timoci Tuwai. He said the foreshore was once covered with mangroves, but in the 1930's- 1940's the mangrove swamp was cleared. This was followed by coastal erosion, and now the shoreline is 10-15 m inland of where he remembered it.

On Ovalau, shoreline erosion at Naikorokoro became a problem 40 years ago perhaps about the time that the last of the mangroves fringing the village were cleared (Nunn, 1990). Increased sediment mobility as a result of the mangrove clearance probably contributed to the current lack of anything edible fro people to glean from the reef offshore.

At Natokalau shoreline erosion following mangrove clearance threatened the road. At Nukutocia mangroves were cleared to fuel a now closed pineapple factory, resulted in severe shoreline erosion.

On Moturiki, shoreline erosion and flooding has been caused at Nasauvuki by purposeful clearance of mangroves within the last 40 years of a mangrove area estimated at 75 000 m^2. By decree, new mangrove seedlings are pulled out still. In analysis of interviews with villagers around each island, Nunn (2000b) found that settlements that deliberately preserved their mangrove fringe report no landward movement of the shoreline in living memory, while those where mangroves were cleared found abrupt shoreline erosion.

As reviewed in section *'Sea-level Rise Impacts on Mangroves'*, coastal erosion will increase with sea-level rise, hence rehabilitation of mangroves will serve to protect shorelines from this threat. Mangrove replanting projects in Fiji have been piecemeal, but are known to have the potential to reduce the impacts of sea-level rise (Thaman, 1990).

Site Selection for Restoration

There are several issues for consideration in choice of a site for restoration.

Mangroves along the coastline of Kubulau, Vanua Levu

Value for money

Table 3 summarises the prioritisation mechanism currently used in choice or rehabilitation projects in natural resource management strategies in Australia. This prioritisation system places intact areas as highest priority for investment, and highly degraded reaches are lowest priority (LWRRDC, 1999). This is because large amounts of money can be spent trying to rehabilitate a type 5 site with limited success, while the same amount of investment can be used to protect type 1 sites or rehabilitate type 3 sites.

Type 2 sites may require a more significant rehabilitation effort, but being adjacent to areas of conservation significance can justify this expenditure. These sites are discussed in more detail in section 3.3.1.3 Benefits to adjacent ecosystems below.

Community and stakeholder support

In any rehabilitation project, it is necessary to engage the support of the local community or village that has traditional use of the mangrove area, and to engage the support of other interested stakeholders. These may include local government, tourism or fishing industry interests, local schools or churches, and relevant departments in the Fiji Government. There should be a consensus on what the mission or objective of the rehabilitation project is.

The mangrove replanting and conservation project at Namatakula and Navutulevu on the Coral Coast (Tamata et al., 1999) provide an excellent example where the communities had already indicated that replanting of mangroves along their shoreline would reduce erosion and improve fisheries, hence receptive of this British High Commission funded project. The project included community education, community involvement in the fieldwork and planting effort, and sharing of data collected.

Benefits to adjacent ecosystems such as inshore reefs

Degraded mangrove areas where rehabilitation would provide benefits to ecosystems offshore such as coral reefs or fish communities are identified as type 2 sites in Table 3 above. Intact mangrove areas are known to trap sediment, to promote clarity of offshore waters. They can also act as a trap for heavy metals or nutrientrich runoff. Sites where mangrove restoration would provide benefits to adjacent systems should be identified as a good choice for a rehabilitation project.

Whippy-Morris and Pratt (1998) in review of issues affecting coral reefs in Fiji provide several examples where health of coral reefs is affected by coastal or catchment disturbance. These include mangrove disturbance, coastal development such as Nadi Bay and Malolo Lailai, and tailings discharge form the Mount Kasi Gold Mine. Fish kills have also occurred in the Vitogo River, Lautoka, Labasa River, Labasa and Vatukoula due to toxic industrial waste escaping into river systems. Squires (1962) describes the effect of discharge from the Rewa River on coral communities offshore.

Table 3
Prioritisation of sites for rehabilitation

Highest

Lowest

Priority		Nature of Sites
1	**Conservation Areas**	These are the least disturbed sites, or near pristine. Channel structure and vehetation associations are relatively intact, and biodiversity is relatively high. Mangement strategies aim to maintain, or improve the current condition. These remnant or refuge areas provide a good base to work out from, into more degraded sections of the coast. A small amount of investment in conservation areas can ensure maintenance of these pristine sites. The mangroves of the Rewa delta are thought to be the most diverse in Fiji.
2	**Strategic Sites**	In general, strategic sites are sections of mangrove coast which may be sensitive to disturbance, triggering impacts which may have offshore consequences, such as sedimentation on coral reefs. Particular emphasis should be placed on areas where disturbances may threaten the integrity of conservation areas. Alternatively, where a mangrove area is in poor condition and lies between higher priority intact areas, there is significant likelihood of management success in rehabilitating the 'linking' mangrove area.
3	**High Recovery Reaches**	If a degraded mangrove area shows signs of natural recovery (i.e mangrove seedlings are establishing), there is high likelihood that management efforts can achieve a quick, visible success. While the 'do nothing' option may be viable in these areas, minimally invasive approaches will facilitate accelerated recovery. In some areas it may be possible to promote mangrove rehabilitation simply by restricting disturbance from the mangrove area. Are close to near pristine are tackled first, 'building outwards' to other sections on the coast.
4	**Moderate Recovery Reaches**	These mangrove areas have reasonable potential to recover and can be rehabilitated gat reasonable cost. Channel structure and vegetation associations require improvement, with gaps and disturbance, erosion. Invasive strategies are often required to change the character or behaviour of the area, such as active replanting of mangroves or protection from erosion.
5	**Low Recovery Reaches**	These mangrove areas have little natural recovery potential (i.e. There are signs of continued degradation eg. accelerated sedimentation or erosion). Invasive, physical intervention is required for these areas to recover. This is often expensive, with uncertain outcomes. Once destabilised, the most effective strategy may be to wait for the coastal system to regain some sort of balance before adoption of physical intervention strategies. In most instances of excess sedimentation, coastal rehabilitation should only continue once upstream areas have been rehabilitated and catchment wide sediment and vegetation management plans are implemented.

Agricultural expansion in the Waimanu catchment has increased suspended sediment in river runoff, causing progressive decline of inshore corals. In North Nadi Bay, the Vuda Point fringing reef has degraded over time due to river-borne sediment (Lovell, 1995). Such sites should be assessed to determine whether a mangrove rehabilitation project would stabilize sediment and improve estuarine water quality, and so benefit adjacent coral or fish communities.

Sites with Greater Threat from Sea-level Rise

Section *'Sea-level Rise Impacts on Mangroves'* reviews that the greatest threat of climate change to mangroves is from sea-level rise, particularly to low island or sediment deficit mangrove settings. Section 2.2 reviews that due to tectonic movement of islands, some areas of Fiji are likely to have higher rates of sea-level rise than others. Areas known to be subsiding include the North Coast of Viti Levu, Yasa Yasa Moala and Vanuabalavu. This raises an ethical dilemma with respect to site selection. Either, it best to choose a site likely to have a higher impact, and through the project hopefully demonstrate how resilience of mangroves to sea-level rise impacts can be improved. Or, a more conservative approach would be to select a site likely to have lower sea-level rise impacts, which would better ensure the long-term success of the project.

Replanting Techniques

Suitable rehabilitation methods involve the following steps:

- Remove the stress that caused mangrove decline
- Decide on the approach to reforestation, either natural regeneration, propagule/ seed planting, or seedling planting
- Consider issues of danger of genetic change to unique Fijian characteristics
- Issues of seed collection
- Wilding collection and transplanting
- Propagule/ Seed planting
- Nursery Practices
- Monitoring

Remove the Stress that Caused Mangrove Decline

Replanting of mangroves will only be successful if the stress that caused the mangroves to decline in the first place is removed. This may be over exploitation/ clearance by people, and or some other disturbance such a pollution or excess sedimentation.

Decide on the Approach to Reforestation

There are several approaches to mangrove reforestation that can be adopted.

a) Natural regeneration

This is a non-active technique that protects the mangrove area from the original stress, and allows natural regeneration to occur. This may mean stopping human usage of the degraded mangrove area for a period of not less than 5 years. The advantages of natural regeneration are that the resultant mangrove forest tends to be more natural, and it is less labour intensive.

b) Propagule/ Seed planting

This involves active planting of mature seeds in areas that are too degraded for natural regeneration to occur. This is usually due to lack of suitable propagules. If propagules are present but not establishing, then this is because the disturbance stress is still active.

c) Seedling planting

This involves active planting of seedlings in areas that are too degraded for natural regeneration to occur. The seedlings can be obtained either from wild sources elsewhere (wilding transplanting) or can be raised in a mangrove nursery.

Danger of Genetic Change of Unique Fijian Characteristics

Although a mangrove species may have a wide range internationally, areas of its range become genetically isolated and develop special varietal characteristics or ecological practices. This have been well demonstrated for the mangrove species *Avicennia marina* (Duke, 1992). The mangrove varieties across the Pacific islands have not yet been studied in any depth, but interesting differences have been noted. The *Rhizophora* mangle in Fiji is unique in flower structure from that which occurs in Hawaii, for example. It is important to preserve these genetically unique characteristics of species from island group to island group.

Coastal mangroves in the western part of Viti Levu

This means that mangrove seeds used for replanting should be harvested from a place as close as possible to where they will be replanted. Import of mangrove seeds or seedlings from another country should not occur. Transport of seeds between islands should not be permitted, for example, mangrove seeds from Vanua Levu should not be planted in Viti Levu, each island group must use seeds collected locally for planting.

Species Selection

As reviewed in the mangrove Ecology section above, of the mangrove species present in Fiji, four are fairly common (Table 4) and the others are rarer. It is a priority in rehabilitation to replant the four more common species, because this will ensure success of the replanting program. Concentration on rarer species will make the task more difficult, and these can be introduced when the rehabilitation has become better established.

Seed Collection

Rhizophora and *Bruguiera* seeds are viviparous (already germinated) so have to be replanted within a few weeks. They cannot be dried and stored like normal seeds, they do not remain viable because they are already germinated before they leave the parent tree. This is an adaptation mangroves have to their wet and saline habitat.

Excoecaria seeds are not viviparous, and several

Scientific Name	Fijian Name	Reasons for replanting priority
Rhizophora mangle Rhizophora stylosa	**Tiri**	Seaward zone - Both species are useful in shoreline protection, sediment stabilisation, and as fisheries habitat.
Bruguiera gymnorrhiza	**Dogo**	Landward zone - species forming extensive stands on wetter coasts, used indying tapa.
Excoecaria agallocha	**Sinu**	Landward zone.

Table 4
Mangrove species with high replanting priority in Fiji

occur in each fruit. The seeds retain their viability for about a month, and can either be sown directly onto suitable areas, or can be raised in nurseries.

Seeds for planting or for raising in nurseries must then be collected. This must be when they are ripe, which in Fiji is probably late summer (Jan-March). Mangrove phenology in Australia shows this to be the most common fruiting time at Fiji's latitude. If seeds are collected too young, they will not germinate (Hong, 1996).

Rhizophora stylosa seeds are ripe when a yellow ring develops at the top of the hypoycotyl, and the top swells. *Rhizophora* mangle hypocotyls are ripe when a (cotyledonary) collar or ring develops at the tip (Banus and Kolehmainen, 1975) and should be 20 cm long, evenly coloured, with a reddish-brown tip. *Bruguiera* seeds are ripe when the hypocotyl changes color from green to brown, they do not develop an abscission collar. If the hypocotyl does not come off from the parent tree with a slight pull, it is not ripe.

Seeds can either be collected from the tree, or beneath the tree. Seeds are usually in better condition if collected from the tree, with less physical damage or insect/ fungal infestation. They must be unblemished, free from insect attack, and handled carefully in transport. The seeds must no be allowed to dry out, but if kept in moist conditions this makes them vulnerable to insect or fungal attack. It is best to transport and store them in small horizontal bundles covered with banana leaves/ palm fronds or sacking. The baskets commonly woven in Fiji from palm fronds are ideal.

Rhizophora/ Bruguiera seeds must be handled gently, particularly the plumule (spike) at the top of the hypocotyl.

Excoecaria seeds should fall in late summer, and can be collected from the mangrove mud surface beneath the parent trees. They are <1 cm in size, a fused 3 seeded pod.

Wilding Collection and Transplanting

Advantages of this method are: seedlings can be collected at any time through the year; they are suitable for higher energy sites; and success rates are usually higher than planting seeds.

Mangrove seedlings for replanting can be collected from large, mature mangrove ecosystems where natural regeneration is occurring. The mangrove mud must be firm, and seedlings can only be taken from within the forest. This is because sediment is removed with the seedling, so in a narrow, degraded or sea margin source site then erosion and degradation of the source area may occur.

Seedlings chosen for transplanting should be 0.5-0.8 m tall, with a straight trunk, an intact growing tip, and several leaf pairs. Avoid old seedlings, with over 15 leaf scars on the trunk, and those already developed prop roots or side branches. Older seedlings are less likely to survive transplanting, probably due to root disturbance (Hamilton and Snedaker 1984).

Seedling collection is best done at low tide. Seedling removal is best done using a length of 100 cm diameter PVC pipe. This is slid over the seedling, and cut into the mud around the seedling and pushed to 20-25 cm depth. Then the pipe is twisted and the seedling with a plug of sediment removed from the ground. A little water poured down the pipe, and shaking, will remove the plug out of the corer.

During transportation the seedling plug should be protected from drying out, and wind.

Propagule/ Seed planting

Seeds or *Rhizophora* and *Bruguiera* can be planted by inserting the tip into the mud, so that 1/3 to 1/2 of the propagule length is buried. This must be done gently. Seed planting can only be done soon after the fruiting season, and mangrove seeds/ propagules cannot be stored for long.

Awareness raising of local resource use knowledge in the mangroves

Community mangrove monitoring to assess the status of their mangroves

Nursery Practices

Raising mangrove seedlings in nurseries before planting out can increase the survival and growth of mangrove planting. This allows the seedling to develop an healthy root system before planting. Propagules without woody thickening are more prone to crab attack (Chan, 1996). Another benefit of raising seedlings in nurseries, is that it provides an year- round supply for reforestation activities.

The propagule (seed) of *Bruguiera* is smaller than that of *Rhizophora*, so raising in nurseries will increase the planting success rate (Soemodihardjo et al., 1996). The seeds of *Excoecaria agallocha* are only 0.5 cm in diameter, so seedling raising in nurseries will greatly increase success of replanting.

Growing seedlings involves planting propagules in a mixture of sand and mangrove mud. Poly bags are best used, about 15 cm deep and 10 cm diameter, these can be easily relocated, and should have holes to allow drainage. The Ministry of Forestry nursery would be able to assist. Plastic containers with holes have also been used (Bohorquez, 1996). Seedlings should be watered once or twice a day with seawater mix. This suppresses fungal infections, and acclimatises the seedlings to saline conditions. Location of the nursery within a protected intertidal area means that watering occurs naturally, and the mangrove seedlings are better acclimatised to the mangrove conditions where they are to be planted. An upper intertidal area should be selected.

Walkways between seedling beds in the nursery are best made firm with wooden planks or matting for walking on. Excessive mud disturbance may cause silt deposition on seedling leaves. Seedling banks are best encased in wooden frames, to give them support at high tide.

To plant the small *Excoecaria* seeds, make a small indentation in the surface of the mud of the Poly bag with a finger tip, and drop the seed in, but do not cover the seed with mud (Siddiqi et al., 1993). Germination should occur in a few weeks. Seedlings should be raised in polybags for about 12 months, until seedlings reach a height of 30-50 cm. They were planted out with spacing of 1 m apart in Bangladesh, with 80% success after 12 months (Saenger and Siddiqi, 1993).

Site Preparation

If the site is infested with *Acrostichum* fern, then this has been found in replanting attempts elsewhere to be problematic (Field, 1996: 235). It will need to be cleared, by cutting. *Acrostichum* will compete with newly planted seedlings, and reduce their success (Soemodihardjo et al., 1996).

If there are dead trees on the site, then these will have to be removed. This is because as dead trees rot over time, they become loose and roll with tides and waves, and can crush replanted seedlings.

Planting Seedlings in the Swamp

Mangrove species tend to occur in zones according to micro-elevation and frequency of inundation. Therefore, it is best to replant with the species that used to grow in the zone, i.e. *Rhizophora* on the seaward margin, and *Bruguiera/ Excoecaria* on the landward margin. Air photographs can be used to show the for-

mer extent of mangroves, and the constituent zones.

Planting can be done merely by digging a hole, taking the plastic bag off, and placing the seedling in the hole. It is very important that the mud level in the polybag becomes the same level as the mud in the mangrove swamp- if the seedling is buried deeper it will die (Ellison, 1999b). In loose substrates footprints are easily used for making a hole, digging tools are rarely necessary in the mangrove environment. Seedlings should be clumped in open areas at 1 meter intervals, as this provides mutual protection. The area should be protected from fenced from pigs, as these will push over young seedlings in their foraging activities.

Monitoring

Once the initial planting has been completed, it is important to monitor the progress of propagules or transplants. Replacement of individuals that die will be necessary. Problems that may reduce success could be debris, pig disturbance, crabs, fungi attack or storms.

Acrostichum may have to be cleared, if it grows up to compete with the seedlings. If there is high seedling success rates, then replanted areas may need to be thinned after 5-7 years.

The benefits of mangrove rehabilitation to inshore fisheries and reefs would be best shown by a monitoring program. This should collect baseline data before rehabilitation commences, and should demonstrate improvement in water quality, reef cover and fisheries with progression of the mangrove rehabilitation project.

References cited

Note: website addresses are provided for convenience, but will suffer from web changes over time.

Aaheim, H. A. and L. Sygna, 2000. Economic impacts of climate change on tuna fisheries in Fiji Islands and Kiribati. Report 2000-04. CICERO, Oslo, Norway. http://www.cicero.uio.no/media/23.pdf

Aalbersberg, W., Thaman, B., Sauni, L., and Power, M. (2003). Proceedings of the Pacific Regional Workshop on Mangrove Wetlands, Protection and Sustainable Use. South Pacific Regional Environment Program, Apia, Western Samoa.

Agrawala, S., Ota, T., Risbey, J., Hagenstad, M., Smith, J., van Aalst, M., Koshy K., and Prasad, B., (2003). Development and Climate Change in Fiji: Focus on Coastal Mangroves. Organisation for Economic Co-operation and Development, Paris, COM/ENV/EPOC/DCD/DAC(2003)4/FINAL.

Anderson, S., Zepp, R., Machula, J., Santavy, D., Hansen, L., and Mueller, E., (2001). Indicators of UV Exposure in Corals and Their Relevance to Global Climate Change and Coral Bleaching. Human and Ecolocial Risk Assessment 7 (5), 1271-1282.

Aronson, R.B., Macintyre, I.G., Precht, W.F., Murdoch, T.J.T. and Wapnick, C.M. (2002). The expanding scale of species turnover events in coral reefs of Belize. Ecological Monographs 72, 233-249.

Ball, M.C., Cochrane, M.J., and Rawson, H.M. (1997). Growth and water use of the mangroves Rhizophora apiculata ans R. stylosa in response to salinity and humidity under ambient and elevated concentrations of atmospheric CO2. Plant, Cell and Environment 20, 1158-1166.

Ball, M.C. and Farquhar, G.D., (1984a). Photosynthetic and stomatal responses of two mangrove species, Aegiceras corniculatum and Avicennia marina, to long term salinity and humidity conditions. Plant Physiology, 74: 1-6.

Ball, M.C. and Farquhar, G.D., (1984b). Photosynthetic and stomatal responses of grey mangrove, Avicennia marina, to transient salinity conditions. Plant Physiology, 74: 7-11.

Banus, M.D., (1983). The effects of thermal pollution on red mangrove seedlings, small trees and mangrove reforestation. In Ogden, J.C. (Ed.) Coral reefs, seagrass beds and mangroves: Their interaction in coastal zones of the Caribbean. Unesco Reports in Marine Science 23, 114-127.

Banus M.D. & Kolehmainen S.E.(1975) Floating, rooting and growth of red mangrove (Rhizophora mangle L.) seedlings: Effect on expansion of mangroves in southwestern Puerto Rico. Proc. Int. Symp. on Biology and Management of Mangroves, Walsh G.E., Snedaker S.C. & Teas H.J.. eds., Vol. 1, Univ. Florida (Gainesville), p. 370-374.

Batibasaga A. and Korovulavula, J. (1996). Environment and Fisheries Impact Assessment of the Wairua Wreck, Daviqele Village- Nabukeluvu, Kadavu, 3 September 1996. Research Report No. 4. Fisheries Department, Ministry of Agriculture, Forest, Fisheries and Alta.

Blasco, F., Saenger, P. and Janodet, E. (1996). Mangroves as indicators of coastal change. Catena 27, 167-178.

Bohorquez, C., (1996). Restoration of mangroves in Colombia: a case study of Rosario's Coral Reef ational Park. In C. D. Field (Editor) Restoration of Mangrove Ecosystems. International Society for Magrove Ecosystems, Okinawa, Japan, pp. 189-196.

Brockmeyer, R.E. Jr., J.R. Rey, R.W. Virnstein, R.G. Gilmore and L. Ernest. (1997). Rehabilitation of impounded estuarine wetlands by hydrologic reconnection to the Indian River Lagoon, Florida (USA). Wetlands Ecology and Management 4(2): 93-109.

Brook, R.R., Basher, R.E., Bruce, J.P, Parsons, S.A., and Sullivan, M.E. (1993). The changing climate in Paradise. Feasibility study on climate monitoring and impacts in the South Pacific. Commonwealth of Australia, Bureau of Meteorology, 145pp.

Bruun, P. (1962). Sea level rise as a cause of shore erosion. Journal of the Waterways and Harbours Division, Proceedings of the American Society of Civil Engineers, 88, 117-130.

Bunt, J.S. (1996). Mangrove zonation: an examination of data from seventeen riverine estuaries in tropical Australia. Annals of Botany 78, 333-341.

Burns, W.C.G. (2000a). The possible impacts of climate change on Pacific Island State ecosystems. An occasional paper of the Pacific Institute for Studies in Development, Environment and Security, Oakland, CA.

Burns, W.C.G. (2000b). The impact of climate change on Pacific Island developeing countries in the 21st Century. In A. Gillespie and W.C.G. Burns (Eds.), "Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Islands States", Kluwer Academic Publishers, Dordrecht, pp. 233-250.

Canoy, M.J. (1975). Diversity and stability in a Puerto Rican Rhizophora mangle L. forest. In Walsh, G.E., Snedaker, S.C and Teas, H.J. (Eds.), Proceedings of an International Symposium on the Biology and Management of Mangroves, Univ. Florida, Gainesville.

Chan, H. T., (1996). Mangrove reforestation in Peninsular Malaysia: a case study of Matang. In C. D. Field (Editor) Restoration of Mangrove Ecosystems. International Society for Mangrove Ecosystems, Okinawa, Japan, pp. 64-75.

Cheeseman, J.M., Clough, B.F., cCarter, D.R., Lovelock, C.E., Ong, J.E., and Sim, R.G. (1991). The analysis of photosynthetic performance of leaves under field conditions: A case study using Bruguiera mangroves. Photosyn. Res. 29, 11-22.

Clark, D.J. and Eliot, I.G. (1983). Mean sea level and beach-width variation at Scarborough, Western Australia. Marine Geology 51, 251-267.

Clough, B.F., Andrews, T.J. & Cowan, I.R. (1982). Physiological processes in mangroves. In: Clough, B. F., (ed.), Mangrove ecosystems in Australia. Australian Institute of Marine Science & Australian National University, Canberra,. 193-210.

Cumming, R. (2002). Tissue injury predicts colony decline in reefbuilding corals. Marine Ecology Progress Series 242, 131-141.

Cumming, R. L., M.A. Toscano, E.R. Lovell, B.A. Carlson, N.K. Dulvy, A. Hughes, J.F. Koven, N.J., Quinn, H.R Sykes, O.J.S. Taylor, D. Vaughan, (2002). Mass coral bleaching in the Fiji Islands, 2000. In Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno and Suharsono (ed.).

Proceedings of the Ninth International Coral Reef Symposium, Bali. 23-27 Oct. 2000. Vol 2:1161-1169. http://orbitnet. nesdis.noaa.gov/orad/sub/sub_pdf/crbpub_9thicrscumming.pdf

Diez, J.J. (2000). A review of some concepts involved in the sea level rise problem. Journal of Coastal Research 16, 1179-1184.

Done, T.J., Turak, M., Wakeford, M., De'ath, G., Kininmonth, S., Wooldridge, S. Berkelmans, R., Van Oppen, M. and Mahoney, M. (2003). Testing bleaching resistance hypotheses fro the 2002 Great Barrier Reef bleaching event. Final Report from the Australian Institute of Marine Science to the State of Queensland Taskforce through the Department of Natural Resources and Mines.

Douglas, B.C., Kearney, M.S. and Leatherman, S.P. (2001). Sea level rise: History and consequences. Academic Press, New York, 228pp.

Duke, N. C. (1992). Mangrove floristics and biogeography. InTropical Mangrove Ecosystems, Eds. A. I. Robertson and D. M. Alongi, 63- 100. Washington DC, American Geophysical Union.

Duke, N. C., Ball, M. C. and Ellison, J.C. (1998). Factors influencing biodiversity and distributional gradients in mangroves. Global Ecology and Biogeography Letters, 7, 27-47.

Drodrolagi, P., Rarawa, B., Ledua, S., Ravitu, N. and Ratoki, T., (2003). Lady Maraia Road, Nabua. Fisheries Resource Assessment Report, 8-10 September 2003. Prepared by the Fisheries Resource Survey Team. Fisheries Department.

Finlayson, C.M., Davidson, N.C., Spiers, A.G., and Stevenson, N.J. (1999). Global wetland inventory- current status and future priorities. Marine and Freshwater Research 50, 717-727.

Ellison, A. and Farnsworth, E., 1997. Simulated sea level change alters anatomy, physiology, growth and reproduction of red mangroves. Oecologica 112, 435-446.

Ellison, J.C. (2003a). The value of mangrove ecosystems: Ecosystem services & functions. In Proceedings of the Pacific Regional Workshop on Mangrove Wetlands, Protection and Sustainable Use. South Pacific Regional Environment Program, Apia, Western Samoa, pp. 11-16.

Ellison, J.C. (2003b). Mangrove assessment and monitoring methodologies. In Proceedings of the Pacific Regional Workshop on Mangrove Wetlands, Protection and Sustainable Use. South Pacific Regional Environment Program, Apia, Western Samoa, pp 105-118.

Ellison, J.C. (2000). How South Pacific mangroves may respond to predicted climate change and sea level rise. In A. Gillespie and W.C.G. Burns (Eds.), "Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Islands States", Kluwer Academic Publishers, Dordrecht, pp. 289-301.

Ellison, J. C., (1999a). Present status of Pacific Island mangroves. In Marine/ Coastal Biodiversity in the Tropical Island Pacific Region: Volume II. Population, Development and Conservation Priorities, Eds L. G. Eldredge, J. E. Maragos and P. L. Holthus, Pacific Science Association/ East West Center, Honolulu. P. 3-19.

Ellison, J.C., (1999b) Impacts of sediment burial on mangroves. Marine Pollution Bulletin 37:420-426.

Ellison, J.C. (1998). Holocene stratigraphic records of vegetation change and sedimentation from the Ajkwa River Estuary mangroves, Irian Jaya. Report presented to P. T. Freeport Indonesia Company, 300 K Expansion Project, Tembagapura, Irian Jaya, Indonesia.

Ellison, J.C. (1997). Mangrove community characteristics and litter production in Bermuda, in B. Kjerfve, L.D. Lacerda, and E,S, Diop (Eds.), Mangrove Forests of the Latin America and Africa Regions, UNESCO, Paris, pp 5-17.

Ellison, J.C., 1995. Systematics and distributions of Pacific Island mangroves. In Marine and Coastal Biodiversity in the Tropical Island Pacific Region: Volume I. Species Systematics and Information Management Priorities, Maragos, J. E., Peterson, M. N. A., Eldredge, L. G., Bardach, J. E. and Takeuchi, H. F. Eds., East West Center, Honolulu, 59-74.

Ellison, J.C. (1993). Mangrove retreat with rising sea-level, Bermuda. Estuarine Coastal and Shelf Science, 37, 75-87.

Ellison, J.C., (1991). The Pacific palaeogeography of Rhizophora mangle L. (Rhizophoraceae). Botanical Journal of the Linnean Society 105, 271-284.

Ellison, J.C. (1989). Pollen analysis of mangrove sediments as a sea level indicator: Assessment from Tongatapu, Tonga. Palaeogeography, Palaeoclimatology, Palaeoecology, 74, 327-341.

Ellison, J.C. and D.R. Stoddart, (1991). Mangrove ecosystem collapse during predicted sea-level rise: Holocene analogues and implications. Journal of Coastal Research 7, 151-165.

Ellison, J.C. 2008. Long-term retrospection on mangrove development using sediment cores and pollen analysis. Aquatic Botany 89, 93-104.

Ellison, J.C., 2009a. Wetlands of the Pacific Island region. Wetlands Ecology and Management 17: 169-206.

Ellison, J.C. 2009b. Geomorphology and sedimentology of mangrove swamps. In Eric Wolanski, Don Cahoon and Gerardo M. E. Perillo (Eds.) Coastal Wetlands: an Ecosystem Integrated Approach. Elsevier Science, Amsterdam, pp. 564-591.

Evans, N. 2006. Natural resources and the environment in Fiji : a review of existing and proposed legislation. IWP-Pacific Technical Report (International Waters Project), no. 21. Apia, Samoa, 56 p.

FAO (2003) Status and trends in mangrove area extent worldwide. In Wilkie ML, Fortuna S, editors. Forest Resources Assessment Working Paper No. 63. Rome: Forest Resources Division, FAO.
http://www.fao.org/docrep/007/j1533e/j1533e00.HTM

Farnsworth, E. J., Ellison, A. M. and Gong, W. K., (1996). Elevated CO2 alters anatomy, physiology, growth and reproduction of red mangrove (Rhizophora mangle L.). Oecologia 108: 599-609.

Field, C. D., (1996). General guidelines for the restoration of mangrove ecosystems. In C. D. Field (Editor) Restoration of Mangrove Ecosystems. International Society for Magrove Ecosystems, Okinawa, Japan, pp. 233-250.

Fiji Mangrove Management Committee (1986). Fiji. In Mangroves of Asia and the Pacific: Status and Management. Technical Report of the UNDP/UNESCO Research and Training Pilot Programme in Mangrove Ecosystems in Asia and the Pacific (RAS/79/002). Quezon, Manila, pp. 281-298.

Fiji Meteorological Service (2003) website accessed February 2003. www.met.gov.fj

Finlayson, C.M. and Eliot, I. (2001). Ecological assessment and monitoring of coastal wetlands in Australia's wet-dry tropics: A paradigm for elsewhere? Coastal Management 29, 105-115.

Finlayson, C.M., Davidson, N.C., Spiers, A.G. and Stevenson, N.J. (1999). Global wetland inventory: current status and future priorities. Marine Freshwater Research 50, 717-727.

Fiji's First Communication under the United Nations Framework Convention on Climate Change. PICCAP, Suva.

Fong, G., (1994). Case study of traditional marine management system: Sasa village, Macuatu Province, Fiji. FAO Field Report No. 94/1, FAO, Rome, 85pp.

Gilman, E., Ellison, J., Duke, N.C., Field, C. (2008) Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany 89, 237-250.

Ghazanfar, S.A., Keppel, G. and Khan, S. (2001). Coastal vegetation of small islands near Viti Levu and Ovalau, Fiji. New Zealand Journal of Botany 39, 587-600.

Hall, P., 2006. What the South Pacific Sea Level and Climate Monitoring Project is Telling Us. Briefing at the Pacific Climate Change Discussions at AusAID. http://www.bom.gov.au/pacificsealevel/

Hamilton, L. S. and Snedaker, S. C., Eds. (1984). Handbook for mangrove area management. Honolulu: East-West Center, IUCN and UNESCO, 123pp.

Hansen, L.J. (2003). Increasing the resistance and resilience of tropical marine ecosystems to climate change. In L.J. Hansen, J.L. Biringer, J.R. Hoffmann (Eds). (2003). Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. Pages 157-177. Published by Martin Hiller. http://www.panda.org/news_facts/publications/climate_change/pu blication.cfm?uNewsID=8678&uLangId=1

Hansen, L.J. and Biringer, J. (2003). Building resistance and resilience to climate change. In L.J. Hansen, J.L. Biringer, J.R. Hoffmann (Eds). (2003). Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems. Pages 9-14. Published by Martin Hiller. http://www.panda.org/news_facts/publications/climate_change/pu blication.cfm?uNewsID=8678&uLangId=1

Hansen, A., Neilson, R., Dale, V., Flather, C., Iverson, L., Currie, D., Shafer, S., Cook, R., and Bartlein, P. (2001). Global change in forests: responses of species, communities and biomes. Bioscience 51, 765- 779.

Harvey, N. and Mitchell, B. (2003). Monitoring sea-level change in Oceania. Tiempo 50, 1-6.

Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. Marine Freshwater Research 50, 839-866.

Hong, P. N. (1996). Restoration of mangrove ecsystems in Vietnam: a case study of Can Gio District, Ho Chi Minh City. In C. D. Field(Editor) Restoration of Mangrove Ecosystems. International Society for Mangrove Ecosystems, Okinawa, Japan, pp. 76-96.

Hoffman, T.C. (2002). Coral reef health and effects of socio-economic factors in Fiji and Cook Islands. Marine Pollution Bulletin 44, 1281- 1293.

Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A. and Maskell, K. Eds. (1996). Climate Change 1996. The Science of Climate Change. Cambridge University Press, Cambridge, 572pp.

Hughes, L. (2003). Climate change and Australia: projections and impacts. Austral. Ecology 28, 423-443.

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nystrom, M., Palumbi, S.R., Pandolfi, J., Rosen, B., and Roghgarden, J. (2003). Climate change, human impacts and the resilience of coral reefs. Science, 301, 929- 933.

Hunt, C. (1999). Fiji's fisheries: their contribution to development and their future. Marine Policy 23, 571-585.

Idechong, N., Ellison, J. and Jaensch, R., 1996. A Draft Regional Wetlands Action Plan for the Pacific Islands. International Coral Reef Initiative Pacific Regional Workshop Report (Suva, Fiji, 27 Nov-1 Dec 1995), p. 116-134. South Pacific Regional Environment Programme, Apia.

Intergovernmental Panel on Climate Change (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Summary for Policy Makers and Technical Summary of the Working Group II Report. Cambridge University Press, Cambridge.

Intergovernmental Oceanographic Commission (1990). UNEP-IOC-WMO-IUCN Meeting of Experts on a Long-Term Global Monitoring System of Coastal and Near Shore Phenomena Related to Climate Change. Intergovernmental Oceanographic Commission Report of Meetings of Experts and Equivalent Bodies 61.

Intergovernmental Oceanographic Commission (1991). UNEP-IOCWMO- IUCN Meeting of Experts on a Long-Term Global Monitoring System of Coastal and Near Shore Phenomena Related to Climate Change, Pilot Projects on Mangroves and Coral Reefs.

Jaffar, M. 1992. Country Report on Mangrove ecosystem in the republic of Fiji. Proceedings Seminar and Workshop on integrated research on man-

grove ecosytems in Pacific islands region II. ed. In T. Nakamura. Tokyo: Japan International Association for Mangroves.

Jennings, S.and Polunin, N.V.C., (1996). Effects of fishing effort and catch rate upon the structure and biomass of Fijian reef communities. Journal of Applied Ecology 33, 400-412.

Kleypas, J.A., Buddemeir, R.W., Archer, D., Gattuso, J.P., Langdon, C. and Opdyke, B.N. (1999). Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284, 118-120.

Kjerve, B. and Macintosh, D,J., (1996). Climate change impacts in mangrove ecosystems. In Proceedings of mangrove Ecosystems Studies in Latin America and Africa. UNESCO, Niteroi, Brazil.

Ladd, H. S. 1965. Tertiary fresh-water mollusks from Pacific Islands. Malacologia 2: 189-197.

Lahmann, E.J., 1988. Effects of different hydrological regimes on the productivity of Rhizophora mangle L. A case study of mosquito control impoundments at Hutchinson Island, Saint Lucie County, Florida. Ph.D. dissertation, University of Miami, 149 pp.

Lal, P. N. (1990a). Ecological economic analysis of mangrove conservation: a case study from Fiji. Mangrove Ecosystems Occasional Papers No. 6. UNDP/UNESCO Regional Project for Research and its Application to the Management of the Mangroves of Asia and the Pacific (RAS/86/120).

Lal, P.N. (1990b). Conservation of conversion of mangroves in Fiji: An ecological economic analysis. Environment and Policy Institute, East-West Center, Occasional Paper 11.

Lal P. (1984). Mangrove ecosystem- Fisheries associated with mangroves and their management. In Productivity and Processes in island ecosystems. UNESCO Report in Marine Science, Paris.

Lal, P.N., Swamy, K. and Singh, P. (1983). Mangroves and secondary productivity: Fishes associated with Wairiki Creek, Fiji. In Lal, P.N. (Ed.), Proceedings of an Interdepartmental Workshop, 24 February 1983, Suva, Fiji. Technical Report No. 5, Fisheries Division, Fiji.

Latham, M. (1979). The Natural environment of Lakeba. In Brookfield H.C., Latham, M., Brookfield, M., Salvat, B., McLean, R.F., Bedford, R.D., Hughes, P.J. and Hope, G.S. (Eds.) Lakeba: Environment change, population dynamics and resource use.

Population and environment project on the Eastern Islands of Fiji: Fiji Island Reports 5, UNESCO/UNFPA, Canberra. Pp 13-64.

Leatherman, S.P., Douglas, B.C. and LaBrecque, J.L. (2003). Sea level and coastal erosion require large-scale monitoring. Eos 84 (2), 15-16.

Leatherman, S.P., Zhang, K. and Douglas, B.C. (2000). Sea level rise shown to drive coastal erosion. Eos Trans., American Geophysical Union 81, 55-57.

Leatherman, S.P., 1989. Response of sandy beaches to sea level rise. In Scott, D.B., Pirazzoli, P.A. and Honig, C.A., (Editor), Late Quaternary Sea-Level Correlation and Applications. Kluwer, Dordrecht, 57-69.

Leatherman, S.P., 1987. Beach and shoreface response to sea-level rise: Ocean City, Maryland, U.S.A. Prog. Oceanogr., 18, 139-149.

LeClerq, N., Gattuso, J.-P., and Jaubert, J. (2002). Primary production, respiration, and calcification of a coral reef mesocosm under increased partial CO2 pressure. Limnology and Oceanography 47, 558-564.

Ley, J.A., McIvor, C.C. and Montague, C.L. (1999). Fishes in mangrove prop-root habitats of Northeastern Florida Bay: Distinct assemblages across an estuarine gradient. Estuarine, Coastal and Shelf Science 48, 701-723.

Ley, J.A., Halliday, I.A., Tobin, A.J., Garrett, R.N., and Gribble, N.A. (2002). Ecosystem effects of fishing closures in mangrove estuaries of tropical Australia. Marine Ecology Progress Series 245, 223-238.

Ley, J.A. and McIvor, C.C. (2002). Linkages between estuarine and reef fish assemblages: Enhancement by the presence of well developed mangrove shorelines. In Porter, J.W. and Porter, K.G. (Eds.) The Everglades, Florida bay, and Coral Reefs of the Florida Keys. An Ecosystem Sourcebook. Boca Raton, CRC Press, pp. 539-562.

Linton, D.M. and Warner, G.F. (2003). Biological indicators in the Caribbean coastal zone and their role in integrated coastal management. Ocean & Coastal Management 46, 261-276.

Loneragan, N.R. (1999). River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. Australian Journal of Ecology 24, 431-441.

Lough, J.M. and Barnes, D.J. (2000). Environmental controls on growth of the massive coral Porites. Journal of Experimental Marine Biology and Ecology 245, 225-243.

Lovell, E.R. (1995). Preliminary biological survey of the coral reefs along north Nadi Bay to Vuda Point, Ba. In: A Marine Survey of Vuda Point, Ba Province, Viti Levu by Environmental Consultants (Fiji) Ltd.

Lovell, E.R. (2000?). Status Report: Collection of coral and other benthic reef organisms fro the marine aquarium and curio trade in Fiji. Report for the World Wide Fund for Nature, Suva, Fiji.

Lovelock, C.E., Clough, B.C, and Woodrow, I.E. (1992). Distribution and accumulation of ultraviolet-radiation-absorbing compounds in leaves of tropical mangroves. Planta 188, 143-154.

Lucas, R.M., Ellison, J.C., A. Mitchell, B. Donnelly, C. M. Finlayson, and A.K. Milne. (2002) Use of Stereo Aerial Photography for Assessing Changes in the Extent and Height of Mangrove Canopies in Tropical Australia. Wetlands Ecology and Management 10, 159-173.

LWRRDC (1999). Riparian Land Management Technical Guidelines. Part A: Principles of Sound Management. Land and Water Resources Research and Development Corporation, Canberra.

Madronich, S., McKenzie, R.L., Bjorn, L.O. and Caldwell, M.M., (1998). Changes in biologically active ultraviolet radiation reaching the earth's surface. J. Photochem, Phytobiol. B. – Biol. 46, 5-19.

Maharaj, R.J. N. (2000) In Mimura, H. Yokoki, (Eds.), Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaption in the Asia-Pacific Region. Kobe, Japan, 14-16 November 2000.

Massel, S. R., Furukawa, K., and Brinkman, R.M., 1999, Surface wave propagation in mangrove forests. Fluid Dynamics Research 24, 219-249.

Mayer, A.G. (1924). Structure and ecology of Samoan reefs. Publ. Carnegie Institute 340, 1-25.

Mazda, Y., Kanazawa, N., and Wolanski, E., 1995. Tidal asymmetry in mangrove creeks. Hydrobiologia 295, 51-58.

Mazda, Y., Magi, M., Kogo, M., and Hong, P.N., (1997). Mangroves as a coastal protection from waves in the Tong King Delta, Vietnam. Mangroves and Salt Marshes 1(2), 127-135.

Mazda, Y., Magi, M., Nanao, H., Kogo, M., Miyagi, T., Kanazawa, N., and Kobashi, D. (2002). Coastal erosion due to long-term human impact in mangrove forests. Wetlands Ecology and Management 10, 1-9.

McCarthy, J.J., Canziani, O.F., Learty, N.A., Dokken, D.J. and White, K.S. (Eds.) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Intergovernmental Panel on Climate Change, Geneva and Cambridge University Press, Cambridge, and New York, 1032pp.

McCook, L.J. (1999). Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. Coral Reefs 18, 357-367.

Meehl, G.A., (1997). Pacific region climate change. Ocean and Coastal Management 37, 137-147.

Mimura, N. (1999). Vulnerability of island countries in the South Pacific to sea level rise and climate change. Climate Research 12, 137-143.

Mimura N. and Nunn, P. D., 1998. Trends of beach erosion and shoreline protection in rural Fiji. Journal of Coastal Research 14, 37- 46.

Morrison, R.J., Narayan, S.P. and Gangaiya, P. (2001). Trace element studies in Laucala Bay, Suva, Fiji. Marine Pollution Bulletin 42, 397- 404.

Morrison and Naqasima, (1999). Fiji's Great Astrolabe Lagoon: baseline study and management issues for a pristine marine environment. Ocean & Coastal Management 42, 617-636.

Mosley, L.M. and Aaldersberg, G.L. (no date, probably 2003). Nutrient levels in sea and viver water along the 'Coral Coast' of Viti Levu, Fiji. Unpublished paper.

Mumby, P.J., Edwards, A.J., Arias-González, J.E., Lindeman, K.C., Blackwell, P.G., Gall, A., Gorczynska, M.I., Harborne, A.R., Pescod, C.L., Renken, H., Wabnitz, C.C.C. and Llewellyn, G. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427, 533 - 536 (05 February 2004).

Naidoo, G., 1983. Effects of flooding on leaf water potential and stomatal resistance in Bruguiera gymnorrhiza. New Phytologist, 93: 369-373.

Nagelkerken, I; Roberts, C.M., Van der Velde, G., Kleijnen, S; Dorenbisch, M., van Riel, M.C., De la Moriniere, E. and Neinhuis, (2003). How important are mangroves and seagrass beds for coral reef fish? The nursery hypothesis tested on an island scale. Marine Ecology Progress Series 244, 299-305.

Nagelkerken, I; Kleijnen, S; Klop, T; Van den Brand, RACJ; De la Moriniere, EC; Van der Velde, G. (2001). Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: A comparison of fish faunas between bays with and without mangroves/seagrass beds. Marine Ecology Progress Series 214, 225-235.

Nunn, P.D. (2000a). Significance of emerged Holocene corals around Ovalau and Moturiki islands, Fiji, southwest Pacific. Marine Geology 163, 345-351.

Nunn, P.D. (2000b). Coastal changes over the past 200 years around Ovalau and Moturiki Islands, Fiji: implications for coastal zone management. Australian Geographer 31, 21-39.

Nunn, P. D. (1998). Sea-level changes over the past 1,000 years in the Pacific. Journal of Coastal Research 14(1), 23-30.

Nunn, P.D. 1994 Oceanic Islands. Oxford, Blackwell. 418 pp.

Nunn, P. D. (1990a). Potential impacts of projected sea level rise on Pacific Island States (The Cook Islands, Fiji, Kiribati, Tonga and Western Samoa): A Preliminary Report. In Pernetta J.C. and Hughes, P.J. (Eds.) Implications of expected climate changes in the South Pacific Region: An Overview. UNEP Regional Seas Reports and Studies no. 128, 127-148.

Nunn, P. D. (1990b). Recent coastline changes and their implications for future changes in The Cook Islands, Fiji, Kiribati, The Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa. In Pernetta J.C. and Hughes, P.J. (Eds.) Implications of expected climate changes in the South Pacific Region: An Overview. UNEP Regional Seas Reports and Studies no. 128, 149-160.

Nunn, P. D. (1990c). Coastal processes and landforms of Fiji: Their bearing on Holocene sea-level changes in the south and west Pacific. Journal of Coastal Research 6(2), 279-310.

Nunn, P. D. (1988). Potential impacts of projected sea level rise on Pacific Island States (The Cook Islands, Fiji, Kiribati, Tonga and Western Samoa): A Preliminary Report. In: Potential impacts of greenhouse gas generated climatic change on Pacific Islands States of the SPREP region. Prepared by a task team of the Association of South Pacific Environmental Institutions. Split, Yugoslavia, 3-7 October, 1988. pp.53-74.

Nunn, P.D. and Mimura, N. (1997). Vulnerability of South Pacific Nations to Sea Level Rise. Journal of Coastal Research, Special Issue No. 24, 134-151,

Nunn, P.D., Ollier, C., Hope, G., Rodda, P., Omura, A., and Peltier, W.R. (2002). Late Quaternary sea-level and tectonic changes in northeast Fiji. Marine Geology 187, 299-311.

Nunn, P.D. and Peltier, W.R. (2001). Far-field test of the ICE-4G model of global isostatic response to deglaciation using empirical and theoretical Holocene sea-level reconstructions for the Fiji Islands, southwest Pacific. Quaternary Research, 55, 203-214.

Obriant, M. P (2003). UV Exposure of Coral Assemblages in the Coral Keys. Report on US EPA Project. http://cfpub.epa.gov/si/osp_sciencedisplay.cfm?dirEntryID=75671 &ActType=project&kwords=Global%20Change

Obura, D. and Mangubhai, S. (2001). Marine biological survey of the Kadava Ono Tinika, Fiji (Great and North Astrolabe Reefs). World- Wide Fund for Nature- South Pacific Programme, Suva, Fiji.

Ogdes, J.C. and Gladfelter, E.H. (Eds.) (1983). Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean. UNESCO Report in Marine Science 23.

O'Grady, A.P., McGuinness, K.A. and Eamus, D. 1996. The abundance and growth of Avicennia marina and Rhozophora stylosa in the low shore zone of Darwin Harbour, Northern Territory. Australian Journal of Ecology 21: 272-279.

Pacific Islands Climate Change Assistance Program & Fiji Country Team (2003). Climate Change: The Fiji Islands Response. Fiji's Firs Communication under the United Nations Framework Convention on Climate Change. PICCAP, Suva.

Parliament of Fiji (2002). "Rebuilding Confidence for Stability and Growth for a Peaceful, Prosperous Fiji". Strategic Development Plan 2003-2005. Parliamentary Paper No. 72 of 2002, November 2002, Fiji Government Printing Department.

Pillai, G. (1985). Mangrove of Fiji their uses and management. In Field C. D., and Dartnall, A. J., eds., Mangrove Ecosystems of Asia and the Pacific, pp. 150-160. Australian Institute of Marine Science, Townsville.

Pirazzoli, P. A. 1986. Secular trends of relative sea-level (RSL) changes indicated by tide-gauge records. Journal of Coastal Research 1, 1- 126.

Raj, U. and Seeto, J. (1982). Report on an investigation of Saweni Bay and coastal environment for an environmental impact statement. Report, Institute of Marine Resources, USP, Suva.

Raj, U., Vodonivalu, Seeto, J., Hirta, H. and Iwakiri, S. (1984). Flora and fauna of mangroves in Rewa delta Fiji. In Prompt report of the first scientific survey of the South Pacific. Kagoshima University, Japan, pp. 149-155.

Richmond, T. de A., and Ackermann, J. M. (1975). Flora and fauna of mangrove formations in Viti Levu and Vanua Levu, Fiji. In Walsh, G., Snedaker, S. and Teas, H. (eds.), Proceedings of International Symposium on Biology and management of Mangroves. East-West Center, Honolulu, pp. 147-152.

Ross, M.S., O Brien J.J. and Sternberg, L.D., 1994. Sea level rise and the reduction of pine forests in the Florida keys. Ecological Applications, 4, 144.

Roy P and Richmond 1985 A map of the recent (holocene) geology of the Rewa delta. CCOP/ SOPAC Spec Publ, Suva. Saintilan, N. (1997). The landward transgression of mangroves into saltmarsh in New South Wales, in Bliss, E. (Ed.) Islands; economy, society and environment; conference proceedings, New Zealand Geographical Society Conference Series, 19, pp.396-399.

Saenger, P., Hegerl, E.J., and J.D.S. Davie (Eds.) (1983) Global status of mangrove ecosystems. Commission on Ecology Papers No. 3, IUCN, Gland.

Solomon, S., D. Qin, M. Manning, R.B. Alley, T. Bernsten, N.L. Bindoff, Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P. Whetton, R.A. Wood

Scholander, P.F., Hammel, H.T., Hemmingsen, E. and Garey, W., 1962. Salt balance in mangroves. Plant Physiology, 37: 722-729.

Schlacher, T.A., Newell, P., Clavier, J., Schlacher-Hoenlinger, M.A., Chevillon, C. and Britton, J. (1998). Soft-sediment benthic community structure in a coral reef lagoon- the prominence of spatial hererogeneiry and 'spot endimism'. Marine Ecology Progress Series 174, 159-174.

Schwartz, M.L. (1967). The Bruun theory of sea level rise as a cause of shore erosion. J. Geol., 75, 76-92.

Scoffin, T.P. (1986). Banding in coral skeletons from Pulau Seribu as revealed by X-rays and U/V light analyses. In: Brown, B.E. (Ed.) Human induced damage to coral reefs: Results of a regional UNESCO (COMAR) Workshop with Advance Training. UNESCO Reports in Marine Science 40, 126-134.

Scott, D. A. 1993. A Directory of Wetlands in Oceania. Slimbridge: International Waterfowl and Wetlands Research Bureau and Kuala Lumpar: Asian Wetland Bureau.

Semeniuk, V., 1980. Mangrove zonation along an eroding coastline in King Sound, North-Western Australia. Journal of Ecology, 68: 789- 812.

Siddiqi, N. A., Islam, M. R., Khan, M. A. S. and Shahidullah, M., (1993). Mangrove Nurseries in Bangladesh. ISME Mangrove Ecosystems Occasional Papers 1, Okinawa.

Singh, B. 1994. Fiji. In Jaensch, R.P. (ed.) 1994. Wetland Conservation in the Pacific Islands Region. Proceedings of a workshop on wetland protection and sustainable use in Oceania, Port Moresby, Papua New Guniea, 6-10 June 1994. Wetlands International- Asian Wetland Bureau, Asia Pacific, Canberra, Publication No. 118, 40-51.

Smith, Thomas J. III. (1992). Forest structure. In Robertson, A.I. and Alongi, D.M. Alongi (eds.), Tropical Mangrove Ecosystems. Coastal and Estuarine Studies 41, American Geophysical Union, Washington DC.

Snedaker, S. C., (1995). Mangroves and climate change in the Florida and Caribbean region: scenarios and hypotheses. Hydrobiologia, 295, 43-49.

Soemodihardjo, S., Wiroatmodjo, P. Mulia, F. and Harahap, M. K., (1996). Restoration of mangroves in Indonesia: a case study of Tembilahan, Sumatra. In C. D. Field (Editor) Restoration of Mangrove Ecosystems. International Society for Magrove Ecosystems, Okinawa, Japan, pp.

Spalding M., Blasco F., Field C., 1997.World Mangrove Atlas. International Society for mangrove Ecosystems, Okinawa, Japan, 178 p.

Spalding, M.D., C. Ravilious and E.P. Green , 2001, World Atlas of Coral Reefs. Prepared at the UNEP World Conservation Monitoring Centre. University of California Press,Berkeley,USA.

SPREP, (1998). Research Shows Major Change in Pacific Climate. SPREP Press Release, August 6th 1998.

Squires, D.F. (1962). Corals at the mouth of the Rewa River, Viti Levu, Fiji. Nature 20, 115-126.

Stern, W.L. and Voight, G.K., 1959. Effect of salt concentration on growth of red mangrove in culture. Botanical Gazette, 131: 36-39.

Stewart, R.W., Kjerfve, B., Milliman, J. and Dwivedi, S.N. (1990). Relative sea-level change: a critical evaluation. UNESCO Reports in Marine Science 54, 1-22.

Sulu, R., Cumming, R., Wantiez, L., Kumar, L., Mulipola, A., Lober, M., Sauni, S., Poulasi, T., and Pakoa, K. (2002). Status of coral reefs in the southwest Pacific to 2002: Fiji, Nauru, New Caledonia, Samoa, Solomon Islands, Tuvalu and Vanuatu. In Wilkinson, C. (Ed.). Status of Coral Reefs of the World: 2002. GCRMN, Australian Institute of Marine Science, Townsville, pp. 181-201.
www.aims.gov.au/pages/research/coral-bleaching/scr2002/scr-00.html

Swart, Ram 1992. Country Report Fiji. In Nakamura, T. (Ed.) In Proceedings seminar and Workshop on integrated research on mangrove ecosystems in Pacific Islands Region I, pp. 90-135. Tokyo, Japan International Association for Mangroves. On behalf of the Fiji Mangrove Management Ctte.

Sykes, H. (1999). Waitabu Marine Life Follow-up Survey. Report prepared for Ministry of Foreign Affairs and Trade, NZODA Ecotourism Programme, Fiji Native Land Trust Board and Waitabu Village and Vanua Bouma.

Tamata, B.R., Wilson, L. and Ram, N. 1999. Report on the mangrove replanting and conservation project at Namatakula and Navutulevu. Institute of Applied Science Environmental Report No. 98, University of the South Pacific, Suva.

Terry, J.P., Garimella, S., and Kostaschuk, R.A. (2002). Rates of floodplain accretion in a tropical island river systems impacted by cyclones and large floods. Geomorphology 42, 171-182.

Thaman, B, (1998). The importance of mangrove resources to rural and urban Fijian Villages: Cases studies of Daku, Nadoria, and Sawa Villages and Kinoya and Tamavua-I-Wai peri-urban settlements, Fiji Islands. Unpublished M.Sc. thesis. James Cook University, Townsville.

Thaman, R.R. (1990). Coastal restoration and agroforestry as immediate ameliorative measures to address global warming and to promote sustainable habitation of low-lying coastal areas. In Streets, D,G, and Siddiqi T.A. (Eds.) Responding to the threat of global warming: options for the Pacific and Asia. Argonne National Laoratory, Argonne, pp. 4.33-4.57.

Thaman, B. and Naikatini, A. (2003). Report on the mangrove flora and fauna surveys conducted within Lomaiwai Reserve, Bole Reserve, Tikina Wai, Nadroga. Report produced by the IAS, USP for WWF?

Thaman, B., Vunisea, A., Naikatini, A., and Guanavinaka, T. (2003). Fiji. In Proceedings of the Pacific Regional Workshop on Mangrove Wetlands, Protection and Sustainable Use. South Pacific Regional Environment Program, Apia, Western Samoa, pp 127-140.

Tomlinson, P. B. 1978. Rhizophora in Australasia- some clarification of taxonomy and distribution. Journal of the Arnold Arboretum 59: 156-169.

Tyagi, A.P. (2001). A comparison of flowering and propagule setting in mangroves of Fiji in a normal and drought year. Paper presented to the International Symposium on Mangroves, 9-12 July 2001, in Tokyo, Japan.

Tyagi, A.P. and Pillai, G. (1996). Final report on research project: Cytogenetics and reproductive biology of mangroves in Fiji. USP Library-PIM RC4/96/4.1a, 9pp.

UNEP, (1994). Assessment and Monitoring of Climatic Change Impacts on Mangrove Ecosystems. UNEP Regional Seas Reports and Studies No 154, 62pp.

Veitayaki, J. (1997). Traditional marine resource management practices used in the Paciic Islands: An agenda for change. Ocean and Coastal Management 37, 123-136.

Veitayaki, J. and South, G.R. (2001). Capacity building in the marine sector in the Pacific Islands: the role of the University of the South Pacific's Marine Studies Programme. Marine Policy 25, 437-444.

Vance, D.J., Haywood, M.D.E., Heales, D.S., Kenyon, R.A., and Loneragan, N.R. (1998). Seasonal and annual variation in abundance of postlarval and juvenile banana prawns Penaeusmerguiensis and environmental variation in two estuaries in tropical northeastern Australia: a six year study. Marine Ecology Progress Series 163, 21-36.

Vuki, V., Naqasima, M. and Vave, R. (2002) Status of Fiji's coral reefs. Global Coral Reef Monitoring Network (GCRMN) Report. http://www.reefbase.org/pdf/GCRMN_2000_FJI.pdf

Vuki, V.C., Zann, L.P., Naqasima, M. and Vuki, M. (2002). The Fiji Islands. In Sheppard, C.R.C. (Ed.) Seas at the Millenium: An Environmental Evaluation. Permagon, Amsterdam, pp. 751-7642.
Ward, J.D. and Metz, W.D. (2002). Mangrove forests as modifiers of the impacts of climate change on high islands and atolls of the South Pacific: Mobilizing people and governments to act (ATOLLS). Pacific Island Regional Forestry Program, 6 page report downloaded from www.spcforests.org/Library/Mangroves/atolls/atolls.htm

Watling, D., (1985). A mangrove management plan for Fiji. Government Press, Suva. 67 pp.

Watkins, D. (1999) Review of wetland inventory information in Oceania. In Finlayson, C.M. and Spiers, A.G. (Eds.) Global review of wetland resources and priorities for wetland inventory. Supervising Scientist Report 144/ Wetlands International Publication 53, Supervising Scientist, Canberra, pp. 493-520.

Whippy-Morris, C., Korovulavula, J., Yakub, N. and Qauqau, A. (2001). Rokobili Terminal Fisheries Assessment Report. Fisheries Department, Ministry of Fisheries and Forests, Fiji.

Whippy-Morris, C. and Pratt, C. (Eds.) (1998). Fiji Biodiversity Strategy and Action Plan. Marine Biodiversity Technical Group Report.

Wilkinson, C.R. and Buddemeier, R.W. (1994). Global climate change and coral reefs: implications for people and reefs. Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on Coral Reefs. IUCN, Gland, Switzerland, 124pp.

Wilkinson, C.R., (1999). Global and local threats to coral reef functioning and existence: review and predictions. Marine Freshwater Research 50, 867-878.

West, J.M. and Salm, R.V. (2003). Resistance and resilience to coral bleaching: Implications for coral reef conservation and management. Conservation Biology 17, 956-967.

Wolanski, E. and Chappell, J. (1996). The response of tropical Australian estuaries to a sea level rise. Journal of Marine Systems 7, 267-279.

Wood, W.L. (1991). Living on the edge: A Great Lakes dilemma. Symposium on Coastal Erosion Zone Management, AAAS Abstracts with Programmes, Washington D.C.

Woodroffe, C. D., (1995). Response of tide dominated mangrove shorelines in Northern Australia to anticipated sea-level rise. Earth Surface Processes and Landforms, 20, 65-85.

Woodroffe, C. D. and Mulrennan, M. E., (1993). Geomorphology of the Lower Mary River Plains, Northern Territory. North Australia Research Unit, Darwin, 152pp.

Yakub, N. (2002a). Proposed reclamation for Fiji Sports Council, Laucala Bay: Fisheries Assessment Survey. Ministry of Fisheries and Forests, Fiji, Fisheries Department. March 2002.

Yakub, N. (2002b). Fisheries Assessment Survey Report: Turtle Island Jetty Reclamation. Report, Ministry of Fisheries and Forests, Fisheries Department. April, 2002.

Yakub, N. (2002c). Fisheries Assessment Survey Report: Turtle Airways Base Jetty, Newtown, Nadi. Ministry of Fisheries and Forest,s Fisheries Department. April, 2002.

Zann, L.P. (1992). The state of Fiji's marine environment, Natural Environmental management Project Report. TA No 1206 Dept. of Town and Country Planning, Govt of Fiji, IUCN.

Zann, L.P. and Vuki, V. (2002). The southwestern Pacific Islands Region. In Sheppard, C.R.C. (Ed.) Seas at the Millenium: An Environmental Evaluation. Permagon, Amsterdam, pp. 705-722.

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