



Impacts of Projected Climate Change on Mangrove and Coastal Ecosystems and Community Livelihoods in

- Solomon Islands
- Vanuatu
- Fiji
- Tonga
- Samoa

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List of Abbreviations

AOGCM	Atmospheric-ocean general circulation model
AR4	(IPCC) Fourth Assessment Report (2007)
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BOM	Bureau of Meteorology (Australia)
CGPS	Continuous Global Positioning System
COSPPac	Climate and Oceans Support Program in the Pacific
GCM	Global climate model
ICCAI	International Climate Change Adaptation Initiative
IPCC	Intergovernmental Panel on Climate Change
IUCN ORO	International Union for Conservation of Nature Oceania Regional Office
MESCAL	Mangrove Ecosystems for Climate Change Adaptation and Livelihoods
PCCSP	Pacific Climate Change Science Program
PMI	Pacific Mangroves Initiative
PSLM	Pacific Sea Level Monitoring (formerly known as SPSLCMP)
SEAFRAME	Sea Level Fine Resolution Acoustic Measuring Equipment
SimCLIM	SimCLIM Open Framework Modelling System
SOPAC-SPC	Applied Geoscience and Technology Division of the Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
SPSLCMP	South Pacific Sea Level and Climate Monitoring Project (now known as PSLM)
UNCBD	United Nations Convention on Biological Diversity
UNFCCC	United Nations Framework Convention on Climate Change

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1 Introduction

The Mangrove Ecosystems for Climate Change Adaptation and Livelihoods (MESCAL) project is a four-year project (2010-2013) funded by the German Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). It is one of the projects under the umbrella of the Pacific Mangroves Initiative (PMI). MESCAL is managed by the International Union for Conservation of Nature – Oceania Regional Office (IUCN ORO) and has an overarching goal to increase the climate change resilience of Pacific Islanders as well as improve their livelihoods through selected capacity support in adaptive co-management and restoration of mangroves and associated ecosystems in five countries: Fiji, Samoa, Solomon Islands, Tonga and Vanuatu.

2 Rationale

The overall goal of the MESCAL project is to increase the climate change resilience and livelihoods of the five pilot countries (Solomon Islands, Vanuatu, Fiji, Tonga and Samoa) by improving knowledge and management capacity of their mangrove and associated coastal ecosystems. Much of the project's groundwork in the pilot countries centres on baseline assessment on the current status of mangrove and associated resources. While it would have ideal for the countries to also produce climate change projections at the national or even demonstration site level, limitations in time, funds and modelling skills meant that this task was beyond the current scope of the project.

The first of the overall MESCAL project's four outcomes is to produce national baseline information about climate change scenarios, use and values of mangroves and associated ecosystem. This review aims to identify recent climate change projections (particularly sea level) and assess their likely impacts on mangroves and associated ecosystems and community livelihoods for the five MESCAL pilot countries.

3 National-level Climate Change Projections

Climate change projection using global climate models (GCMs) for small islands in the Pacific and elsewhere in the world poses a great challenge to researchers because the resolution of the models are generally not fine enough to distinguish small land areas from the sea surface (IPCC, 2007). As a result, projections for small islands are usually associated with some degree of uncertainty. The efforts of regional climate research organisations in the Pacific have contributed to improving the way that models simulate climatic changes in small islands and thereby reducing uncertainties associated with large-scale global models.

3.1 SimCLIM Open Framework Modelling System (SimCLIM)

The SimCLIM Open Framework Modelling System (SimCLIM) is a versatile and user-friendly climate modelling software package that uses observed data with combined atmospheric-ocean general circulation models (AOGCMs) to produce climate projections. The system can be customised for individual countries to projection outputs from the scale of the whole country to specific sites (UNFCCC, 2013). This high spatial resolution feature can be particularly valuable for adaptation planning in Pacific island countries that have their islands geographically scattered and exhibiting slightly different climate regimes.

Several of the MESCAL pilot countries including Solomon Islands, Vanuatu and Tonga previously held software licences for customised versions of SimCLIM and also received training in running the model; however, the licences have since expired without any national-level projections being made. The MESCAL project had originally proposed to use SimCLIM to generate sea level projections for its demonstration sites. With the publication of projections by the Pacific Climate Change Science Program (PCCSP), which will be further discussed in the next section, there is a preference for government agencies to use this source in their decision making and reporting. The cost of maintaining the software licence is also a likely factor in discouraging countries from using SimCLIM to generate their own projections.

3.2 Pacific Climate Change Science Program (PCCSP)

The PCCSP aims to assist 14 Pacific Island Countries and East Timor in improving their decision-making capacities in adaptation planning by developing national-level climate change projections. The program is the Pacific regional component of a larger Australia-funded International Climate Change Adaptation Initiative (ICCAI) which has an overall goal of helping vulnerable countries in the Asia-Pacific region to meet their priority adaptation needs (BOM and CSIRO, 2011f).

The findings of the program were presented as an interactive online tool, the Pacific Climate Futures (<http://www.pacificclimatefutures.net>), which allows users to explore the projections for ten climate variables, three IPCC greenhouse gas emission scenarios and for the three time periods of 2030, 2055 and 2090 for each of the 15 countries.

Coastal ecosystems, including mangroves, are found at the interface between land and sea and are thus affected by both land and sea surface temperatures. These two temperatures, together with sea level are among the key climate variables to affect the health of mangrove ecosystems and will therefore be assessed in this review.

3.3 Pacific Sea Level Monitoring (PSLM)

The Pacific Sea Level Monitoring (PSLM) project was known as the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) until 2010 when it was absorbed under the umbrella of the Climate and Oceans Support Program in the Pacific (COSPPac). It aims to provide an accurate long-term record of sea levels in the Pacific region for scientific research purposes and to better inform decision making in national development and planning processes (SOPAC-SPC, 2013). The project uses a highly sensitive Sea Level Fine Resolution Acoustic Measuring Equipment (SEAFRAME) to record sea level and several other ‘ancillary’ variables including air and water temperatures, wind directions and speed and atmospheric pressure.

The map in Figure 3.1, below, presents the sea level trends for all of the PSLM stations, with MESCAL pilot countries labelled in yellow. The trends are calculated as the average annual change in sea level from the time the station was installed in the respective countries until the end of 2010 (BOM, 2010a).

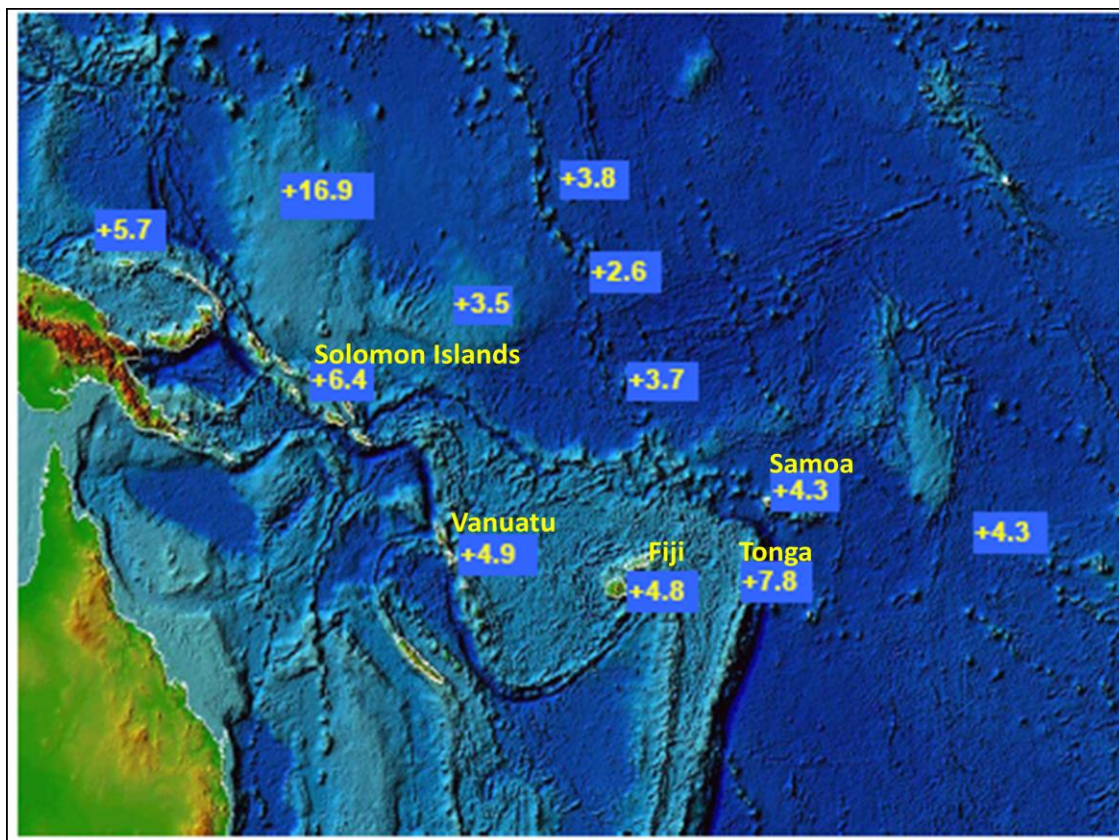


Figure 3.1: Map of Pacific region showing net sea level trends (in mm/year) for different countries (BOM, 2010a).

While the sea level trends recorded by PSLM are not technically ‘projections’ for future trends, it does provide an understanding of the current rate of sea level change for the specific countries being monitored. Furthermore, future sea levels could be estimated by way of linear extrapolation of the current observed trends. This is a simplistic method to derive future sea levels in the absence of modelled projections; however, the rate of sea level change is actually non-linear. The effect of seasonal climate variability will become smaller and reliability of long term trends will improve as the length of data record increases (BOM, 2010a). Station information, as well as the current observed sea level trends and linearly extrapolated sea levels of the five MESCAL pilot countries are shown in Table 3.1, below.

Table 3.1: Sea level trend in MESCAL pilot countries (BOM, 2010a).

Country	Location	Installed	Years of data	Net sea level trend (mm/yr) as of Dec '10	Sea level (mm) extrapolated to 2100
Solomon Islands	Honiara	28/07/1994	16	6.4	678.4
Vanuatu	Port Vila	15/01/1993	18	4.9	529.2
Fiji	Lautoka	23/10/1992	18	4.8	518.4
Tonga	Nuku'alofa	21/01/1993	18	7.8	842.4
Samoa	Apia	26/02/1993	18	4.3	464.4

4 Global Climate Projections

Global temperature is projected to rise between 1.8°C under B1 (the most conservative of the Intergovernmental Panel on Climate Change or IPCC’s carbon emission scenarios) and 4.0°C under A1FI (the most extreme scenario), with an average of 2.9°C (IPCC, 2007). The trend for the Pacific would be smaller due to the high thermal capacity of the ocean acting to regulate extreme temperature changes.

The global rate of sea level rise was estimated to be around 1.7 mm/yr over most of the 20th century and under a range of carbon dioxide emission scenario assessed in IPCC’s Fourth Assessment Report (AR4), the rate was projected to range between 0.18 - 0.59 m (average of 3.8 mm/yr) by the end of the 21st century (IPCC, 2007).

Subsequent studies since 2007 have found that this projection was overly conservative and that new evidence suggesting sea level rise of at least 1 m was more likely (Hansen et al., 2011, Vermeer and Rahmstorf, 2009, Pfeffer et al., 2008). One of the most recent studies even suggested a long-term rise of about 2 m for every degree of warming after 2100 (Levermann et al., 2013). Levermann et al.’s study combined paleo-climatic evidence with extensive model simulations built around the dynamics of thermal expansion, major glaciers and the Antarctic and Greenland ice sheets. These are the four main contributors to long-term global sea level rise and

accurately modelling their behaviour produces projections that can closely reflect their true impact on global sea level. IPCC, themselves, noted that their assessments had not taken into account the effect of the melting ice sheets and thus produce much lower sea level rise projections (IPCC, 2007).

This further demonstrates the importance of reliable scientific information in projecting future climate, especially for the Pacific region. With the next IPCC assessment expected in 2014 and the improved climate modelling capabilities, it is anticipated that updated projections would contribute to better inform national and local decision-making processes.

5 Climate Change Impacts

The effects of sea level rise on the livelihoods of Pacific communities over the past 200 years have been related mostly to changes in the coastal environments. These changes brought about scarcity in marine food sources, coastal flooding and erosion and saltwater intrusion into groundwater sources (Nunn, 2013). The current changing environment and climate cause the same physical effects on today's communities; however, the impacts are multiplied due to the increased populations that these areas support.

Mangroves and associated coastal ecosystems perform numerous functions that are important to coastal communities that live close to them and for countries as a whole. These include but are not limited to the following:

- Supporting traditional practices – communities utilize mangrove ecosystems as a source of traditional medicines, fuel wood, building material and natural dyes (Gilman et al., 2006, SPREP, 2009).
- Food security – coastal communities are often dependent on these areas to provide food such as fish, shellfish, crustaceans, etc. (Gilman et al., 2006, SPREP, 2009).
- Coastline protection – the mangrove root system is well adapted to trapping sediment and breaking down the energy of strong winds and waves (Gilman et al., 2006, McIvor et al., 2012).
- Wildlife spawning ground, nursery and habitat – the calm and nutrient rich environment in the mangrove forests provide a safe and stable habitat for marine life (Gilman et al., 2006). Up to 80% of global fish catch utilises mangrove ecosystem services in one form or another (Polidoro et al., 2010).
- Improve coastal water quality – the roots of mangroves reduce water flow and allow suspended sediment and other pollutants to settle, effectively filtering the water before they reach the seagrass beds and coral reefs. Much of the nutrient is also retained, preventing eutrophication of coastal waters (Mumby et al., 2004, Ewel et al., 1998).

- Supporting connected coastal ecosystems including seagrass bed and coral reefs – the vegetative detritus from mangroves are transferred as nutrients to these connected ecosystems (Gilman et al., 2006, SPREP, 2009).
- Carbon storage – mangroves around the world, including associated soils, could sequester about 22.8 million metric tons of carbon each year (Giri et al., 2011) and provide at least 10% of the ocean's global organic carbon supply (Polidoro et al., 2010).
- Education, research and recreation – mangrove areas are easily accessible and ideal for environmental education and awareness, scientific research and also has potential to be developed into ecotourism areas (Gilman et al., 2006).

5.1 Impacts on ecosystems

Mangroves are found in the inter-tidal zones of the tropical and sub-tropical regions of the world and geographically distributed between 30°N and 30°S latitude, with the belt between 5°N and 5°S containing the densest systems (Giri et al., 2011). Temperature is the main controlling factor for mangrove distribution and limited mangrove areas can be found extending into the latitudinal limits of 32°N and 40°S (Stuart et al., 2007). The 20°C isotherms for both winter water and air temperatures restrict latitudinal mangrove distribution. Horizontal distribution is controlled by tidal inundation, with mangroves mostly found from mean sea level to highest spring tide mark (Alongi, 2009). Tidal inundation also dictates mangrove species zonation (Ellison, 2000). Within these broad geographical demarcations, the local diversity and extent of mangrove forests are affected by variables including temperature, rainfall and level of shelter from wind and wave action (NTG, 2002).

5.1.1 Temperature effect

Mangroves are found to be most productive within the temperature range of 15 - 25°C (Hutchings and Saenger, 1987). Thermal stress starts to affect the roots and seedlings at about 35°C and at 38 – 40°C, the leaves stop photosynthesizing (Clough et al., 1982, Andrews et al., 1984).

Projected increase in atmospheric temperature and carbon dioxide could increase mangrove productivity, alter their phenological patterns and expand their range into higher latitudes where low temperatures previously would not have allowed them to survive (Ellison, 2000). Mangroves are naturally well adapted to daily fluctuations in water and atmospheric temperature. In the tropical Pacific, where seasonal temperature varies little, mangroves are likely to have the capacity to adapt to temperature changes.

Increase in temperature alone seems to have an overall positive effect on mangrove trees. Unfortunately, the impact of climate change is not limited to changes in only temperature. Other associated impact has largely negative effects.

5.1.2 Relative sea level effect

Gilman et al. (2006) presents four generalised mangrove response scenarios to sea level change:

- a. Stable sea level, where mangrove margins remain in place (Figure 5.1A)
- b. Sea level fall, where the landward and seaward margins both migrate seaward (Figure 5.1B)
- c. Sea level rise without landward obstruction (by artificial structures such as roads, buildings and seawalls), where landward and seaward mangrove margins both migrate landward (Figure 5.1C)
- d. Sea level rise with landward obstruction, where landward migration is not possible and seaward margin continues to erode (Figure 5.1D). Under this scenario, the 'coastal squeeze' effect forces mangroves to get progressively narrower with severity of sea level rise (Alongi, 2009).

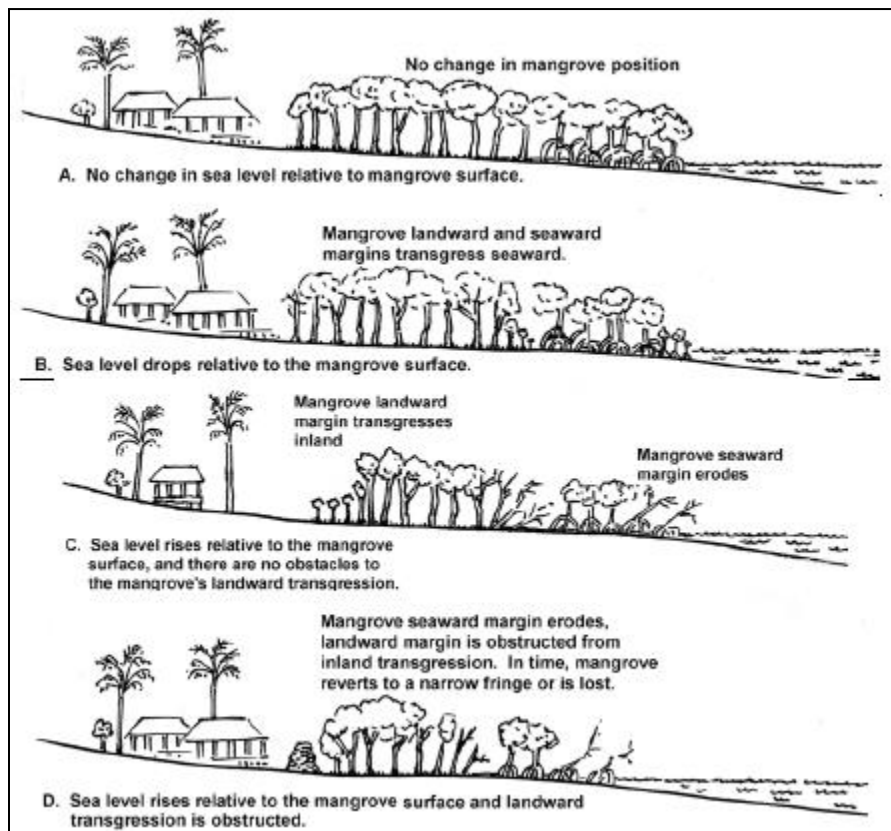


Figure 5.1: Generalised mangrove response to changing sea level (Gilman et al., 2006).

5.1.3 Sedimentation effect

The rate of sedimentation also has a large influence on the response of mangroves to rising sea levels. The two predominant settings where mangroves are found in the Pacific are the river deltas and estuarine areas of high volcanic islands and the bays, lagoons and reef flats most commonly found on low islands (Ellison, 2000). In addition to sediment accumulation from vegetative detritus breakdown, the delta and estuarine mangroves also receive significant sediment load from terrestrial sources. Low island mangroves, however, rely solely on detritus and naturally have a much lower rate of sedimentation. Consequently, they are also much more susceptible to sea level rise. Low island mangroves are able to keep up with and adapt to the effects of rising sea level as long as the rate of increase does not exceed 12 cm per 100 years (Ellison, 1989, Ellison, 1993) and for high island mangroves, not exceeding a rate of 45 cm per 100 years (Ellison and Stoddart, 1991).

Mangroves are known to have historically adapted to fluctuations in sea level (Alongi, 2008, Erwin, 2009, Fiu et al., 2010), however, their capacity to continue doing so, especially under the additional human-induced stresses such as urbanisation, pollution and overharvesting, is less certain.

5.2 Impacts on livelihoods

Mangroves and associated coastal ecosystems provide goods and services which contribute to the welfare of local and national communities but they continue to be threatened by degradation and environmental change. More than 70% of the inhabitants of the Pacific islands live in the coastal zones (SPREP, 2012) and the impact of a changing climate is already taking a toll on many of these communities.

The most immediate impact on community livelihoods will be food security. Saltwater intrusion into coastal soils and groundwater sources could severely reduce the yield of crops and food trees. The projected rise in atmospheric and sea surface temperature could increase heat stress on mangroves and near-shore marine food supply and also reduce their yield. Depending on the severity of the event, coral reefs would also be susceptible to bleaching which could reduce the supply of reef fishes. These will all lead to local shortage of food supply. Marine food makes up a significant part of the diets of coastal communities. Nunn (2013) estimates that by the middle of the 21st century, many Pacific island coastal communities would no longer have the capacity to meet local demands for food and they would also be unlikely to have the financial means to purchase food regularly from the shops.

Subsistence farmers and fishermen in the coastal communities often supplement their household income by selling excess catch and crops. There is also likely to be a loss in income when there is reduced yield in crops and marine food supplies.

If the community affected also relies on groundwater as a primary freshwater source, then saline intrusion also has the additional impact of reducing the community's water security by making the brackish groundwater unsuitable for human consumption. Sometimes, the communities have limited alternative drinking water options and continue to use this brackish water, which may cause sanitation and health issues (Lal et al., 2009).

When early settlers voyaged across the Pacific, it was the coastal environment of the islands that attracted them to come ashore and settle. Since then, the coastal ecosystems have supported a wide range of traditional practices (Nunn, 2007). These practices are in danger of being lost as the risk of coastal ecosystems degradation increases. An estimated 35% of the world's mangroves have been lost between 1980 and 2000. The rate of annual decline continues at about 2.1%, which is almost three times the 0.8% annual rate of tropical terrestrial forest loss (Gilman et al., 2006). The rate for the most of the Pacific is more uncertain due to limited baseline studies and lack of standardised monitoring procedures. The variation in estimation of mangrove coverage by different researchers is probably a reflection of the different methods used in baseline resources assessment.

Gilman et al. (2006) estimates the economic value of mangrove ecosystems across the Pacific to be between USD 200,000 – 900, 000 per hectare. The specific national value in different countries and areas will most likely vary according to their respective national and local circumstances. For example, mangrove areas of higher national importance, such as for ecotourism, will be valued more than those in remote uninhabited areas. Despite the large range in value, this estimate provides a guide, especially to countries that have not carried out any previous valuation to the benefits of preserving and the cost of losing these resources. Economic valuation of mangrove ecosystem services and resources are being finalised for Vanuatu, Fiji and Samoa as part of their national MESCAL project objectives.

National level climate projections and sea level trends for each of the five MESCAL pilot countries and their impacts on national and local coastal community livelihoods are discussed in the sections that follow.

6 Solomon Islands

MESCAL Solomon Islands is implemented locally by the Environment Conservation Division under the Ministry of Environment, Climate Change, Disaster Management and Meteorology.

6.1 Mangrove distribution and demonstration site

There is approximately 602.52 km² of mangrove forests distributed throughout the Solomon Islands, which is the second largest area in the Pacific region, after Papua New Guinea (Spalding et al., 2010). Significant mangrove coverage can be found on the following islands:

- a) Shortland Islands
- b) Choiseul
- c) New Georgia
- d) Santa Isabel
- e) Malaita
 - a. Maramasike Passage**
- f) Rennell

The project's demonstration site is Maramasike Passage, a narrow channel separating the larger island of Malaita from the smaller South Malaita. The site contains one of the largest stands of mangrove in Solomon Islands but overharvesting by local communities and expansion of nearby logging activities is putting this area at increasing risk of degradation. Figure 6.1, below, shows a map of Solomon Islands and the location of the demonstration site.

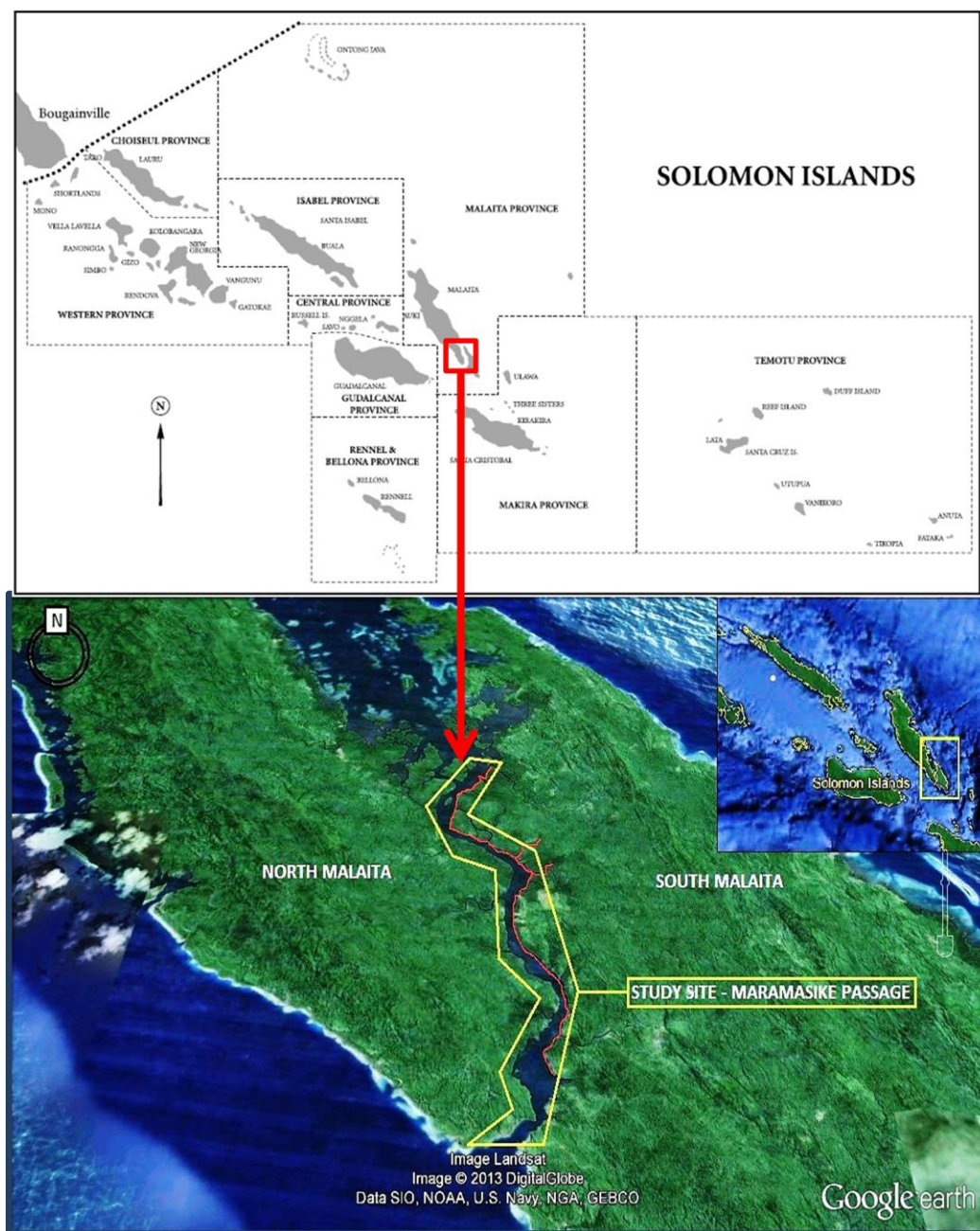


Figure 6.1: Map of Solomon Islands and Maramasike Passage (Central Bank of Solomon Islands, 2012, Tafea, 2013).

6.2 PCCSP

Both annual sea and air temperatures have been projected with high confidence to continue increasing over the 21st century for the Solomon Islands, as has sea level, with moderate confidence (BOM and CSIRO, 2011c). These projections are presented in detail in Table 6.1, below.

Table 6.1: PCCSP climate projections for Solomon Islands (BOM and CSIRO, 2011c).

	Emission scenario	Year			Confidence level
Variable		2030	2055	2090	
Annual surface air temperature (°C)	Low (B1)	+0.6 ± 0.4	+1.1 ± 0.4	+1.5 ± 0.6	High
	Mid (A1B)	+0.8 ± 0.4	+1.4 ± 0.5	+2.3 ± 0.8	High
	Hi (A2)	+0.7 ± 0.3	+1.4 ± 0.4	+2.7 ± 0.6	High
Annual sea surface temperature (°C)	Low (B1)	+0.6 ± 0.4	+0.9 ± 0.3	+1.3 ± 0.5	High
	Mid (A1B)	+0.7 ± 0.3	+1.2 ± 0.3	+2.0 ± 0.6	High
	Hi (A2)	+0.7 ± 0.4	+1.3 ± 0.5	+2.5 ± 0.6	High
Annual mean sea level (cm)	Low (B1)	+9 (4–14)	+18 (10–26)	+31 (17–45)	Moderate
	Mid (A1B)	+9 (5–14)	+19 (8–30)	+38 (19–58)	Moderate
	Hi (A2)	+9 (4–15)	+19 (8–30)	+40 (20–60)	Moderate

Surface air temperature for the Solomon Islands is projected to range from 1.5°C to 2.7°C (average of 2.1°C) higher than the 1990 baseline by 2090, while sea surface temperature is expected to be between 1.3°C and 2.5°C (average of 1.9°C) higher. Sea level rise is projected to range from 17 cm to 60 cm (average of 38.5 cm) compared to the 1990 baseline.

6.3 PSLM

Solomon Islands' SEAFRAME station, which is located in Honiara, on the island of Guadalcanal, was installed in 1994. A Continuous Global Positioning System (CGPS) was also installed in 2008 to measure the effect of vertical tectonic land movement (BOM, 2010c). The Maramasike Passage is located about 157 km east of the station, between the islands of Malaita and South Malaita.

The annual mean sea level rise for Solomon Islands, between 1994 and 2010, is calculated to be 6.4 mm per year (Table 3.1), after the effects of atmospheric pressure and tectonic movement have been removed. This is the second fastest trend in sea level rise, after Tonga, among the five MESCAL pilot countries. The linearly extrapolated sea level to the year 2100 for Solomon Islands is 678.4 mm above mean sea level. Between the installation of the Honiara SEAFRAME station in 1994 and the end of 2010, the station has recorded 16 years of data.

6.4 Threats to community livelihoods

Atmospheric temperature in the Solomon Islands is fairly consistent throughout the year. With monthly means around 26°C to 27°C, there is little variation even between the wet and dry seasons (BOM and CSIRO, 2011c). These temperatures are around the upper margin of the ideal temperature range for mangrove growth. Average projected temperature rise in both the sea and air is around 2°C but could be as high 2.7°C for the air and 2.5°C for the sea surface. Even under the highest temperature rise projections for the 21st century (Table 6.1), it would still be well below the 35°C when mangroves start to experience thermal stress.

The mangroves in Maramasike Passage are of the type found in a high island setting. Fortunately, PCCSP's projection average of 38.5 cm sea level rise by 2090 is still within Ellison and Stoddart's 45 cm per 100 year sustainable rate of sediment replenishment (1991) for mangroves in this setting. However, if the upper range of the projections (sea level rise of 60 cm according to PCCSP and the linearly extrapolated rise of 68 cm according to PSLM) were to eventuate, it would then mean that Solomon Islands' mangrove coverage would become severely diminished or totally lost by the end of this century.

This outlook is in agreement with Duke et al. (2007), who suggested losses of 30-40% of coastal wetlands and possibly of all mangrove forests by 2100, which will severely disrupt the supply of ecosystem goods and services previously mentioned. Coastlines would be at risk of being rapidly eroded, the coastal waters would be subjected eutrophication and the heavy sediment load in estuarine waters would cause the health of coral reefs and seagrass beds to deteriorate. The organic matter, which would otherwise have been the primary food supply for fauna in these associated ecosystems, would no longer be available. Biodiversity in coastal wetlands in general would be severely reduced.

In addition to these local effects on the ecosystems, the loss of mangroves would release large amounts of carbon stored in the soils and further increase atmospheric CO₂ concentration (Chmura et al., 2003).

Apart from climate-related threats to the mangrove and associated coastal ecosystems, human-induced threats also play an increasing role in endangering these resources.

The biggest anthropogenic threats to mangrove ecosystems in Solomon Islands include overfishing, overharvesting of fruits for food and trees for firewood and constructing houses and boats, conversion of land for coastal developments, residences and agriculture and as loading areas or "log ponds" for logging activities. Much of the mangrove fruit, crustaceans and mollusc sold at the Honiara market are sourced from the Maramasike Passage. This provides an important source of income for communities living near mangrove areas and the practice is likely to continue as long as there is demand and resources are available. Despite the unsuitability of coastal areas for agriculture, they are still being converted by communities for small scale cash cropping (Government of Solomon Islands, 2011). The forestry and logging sector was worth

SB\$ 502 million in 2011 (equivalent to about US\$ 68.8 million in 2013 values) and is the second largest contributor, after the mining sector, to the year's total national income (Central Bank of Solomon Islands, 2012). As long as this industry is given precedence at the national level, its associated impacts on mangrove ecosystems are also likely to continue.

As the sea level continues to rise and shorelines continue to retreat, it is yet to be known whether the coastal ecosystems will be able to adapt to the rate of climatic change. For a remote site like Maramasike, it is not the local community's resource consumption that is threatening the welfare of the ecosystem, but rather the demand for goods and services that these ecosystems can provide at the regional and national levels that have driven the communities to overexploit the resources. It is difficult to establish whether or not the rate of resources harvest is sustainable at Maramasike due to lack of monitoring information. Given the high regional demand, the likelihood is that it is not and eventually the Maramasike communities will face shortages of local food supplies and decrease in the income associated with it.

Pauki suggests (2009) that long term welfare of these ecosystems can only be protected if the local communities are provided with opportunities to gain monetary benefits by preserving their natural conditions rather than exploiting the resources. One way could be support in the establishment and operation of eco-tourism ventures by local communities.

Mangroves in the Solomon Islands are protected from commercial exploitation and export under the Forest and Timber Resources Utilisation Act (1970) but this has had little effect on the preservation of mangrove resources (FAO, 2007) from being locally overharvested. A review of current legislations under the MESCAL project will aim to facilitate the formulation of a framework which would guide policy makers to take the necessary measures to ensure the protection of these ecosystems.

7 Vanuatu

MESCAL Vanuatu is implemented locally by the Department of Environmental Protection and Conservation under the Ministry of Lands, Natural Resources, Geology, Energy and Environment.

7.1 Mangrove distribution and demonstration sites

There is approximately 20.5 km² of mangrove forests distributed throughout the islands of Vanuatu (Spalding et al., 2010) and their occurrence is known in the following islands:

- a) Hui
- b) Ureparapara
- c) Vanua Lava
- d) Mota Lava
- e) Santo Island
- f) Malekula
 - a. Port Stanley
 - b. Crab Bay and Amal Area**
 - c. Port Sandwich
 - d. Maskelynes
- g) Epi
- h) Emae
- i) Efate
 - a. Eratap**
 - b. Tounaliu
- j) Tanna
- k) Aniwa

The Crab Bay-Amal demonstration site is located along the northeast coast of Malekula Island. The site was also the demonstration site for a previous conservation project in 2002, which helped the communities in the area in establishing the Amal-Krab Bay Tabu Eria for better monitoring and management of their marine resources (Hickey, 2006). The other demonstration site is the Eratap Lagoon on the southeast coast of Efate, an area that is increasingly threatened by the expansion of coastal developments. The Crab Bay-Amal site demonstrates the value of sustainable local resource management after a period of exploitation while the Eratap site illustrates an ecosystem at increasing risk of degradation. Figure 7.1, below, shows Vanuatu's mangrove distribution and the mapped demonstration sites.

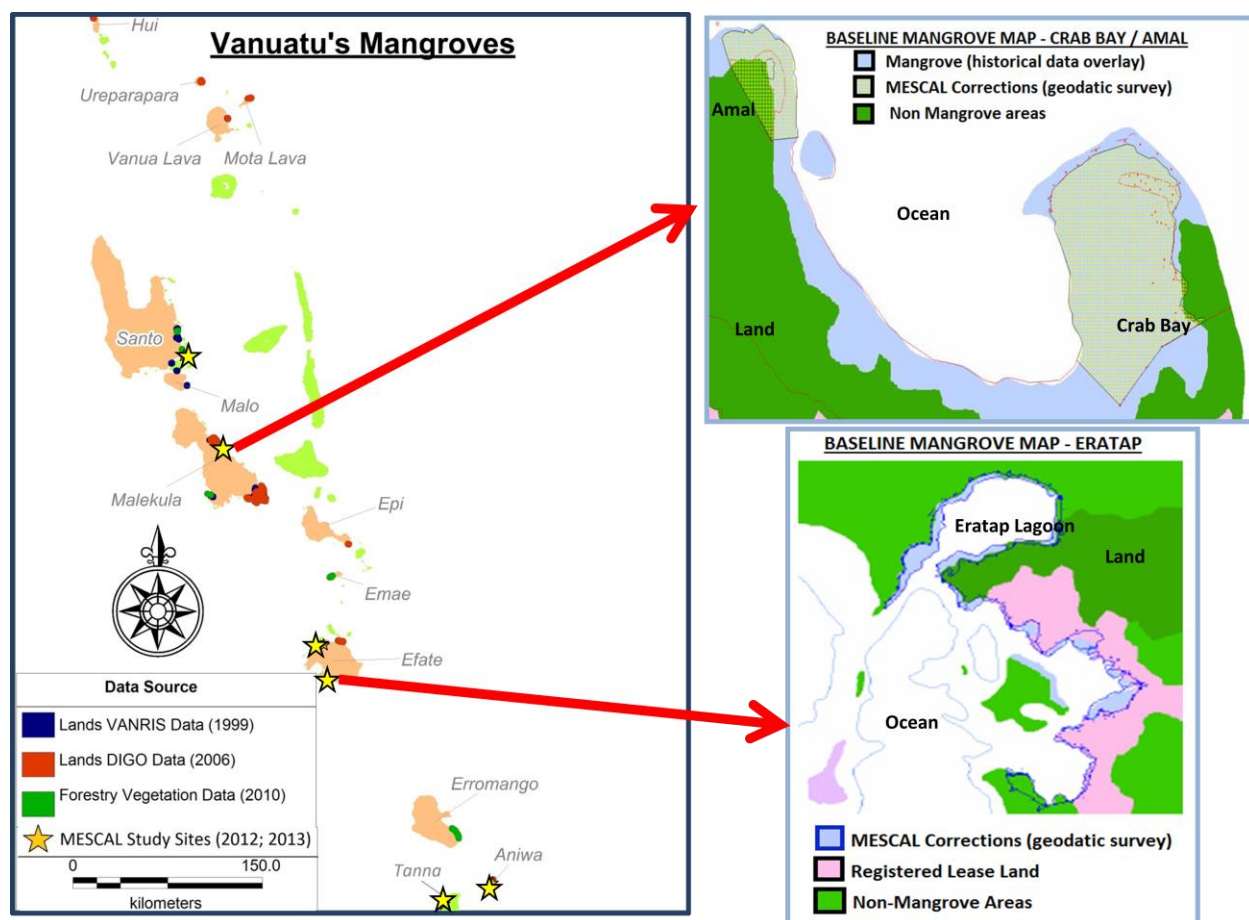


Figure 7.1: Vanuatu mangrove distribution (left) and MESCAL Vanuatu demonstration sites (Baereleo, 2013).

7.2 PCCSP

For Vanuatu, both the surface air and sea surface temperatures have been projected with high confidence; and sea level, with moderate to high confidence, to continue increasing over the 21st century (BOM and CSIRO, 2011e). These projections are presented in detail in Table 7.1, below.

Table 7.1: PCCSP climate projections for Vanuatu (BOM and CSIRO, 2011e).

	Emission scenario	Year			Confidence level
Variable		2030	2055	2090	
Annual surface air temperature (°C)	Low (B1)	+0.6 ± 0.4	+1.0 ± 0.5	+1.4 ± 0.7	High
	Mid (A1B)	+0.7 ± 0.4	+1.4 ± 0.6	+2.2 ± 0.9	High
	Hi (A2)	+0.6 ± 0.3	+1.4 ± 0.3	+2.6 ± 0.6	High
Annual sea surface temperature (°C)	Low (B1)	+0.6 ± 0.4	+0.9 ± 0.5	+1.3 ± 0.5	High
	Mid (A1B)	+0.6 ± 0.3	+1.2 ± 0.5	+2.0 ± 0.7	High
	Hi (A2)	+0.6 ± 0.4	+1.3 ± 0.4	+2.5 ± 0.6	High
Annual mean sea level (cm)	Low (B1)	+10 (5–16)	+19 (10–27)	+32 (17–47)	Moderate
	Mid (A1B)	+10 (5–16)	+20 (8–31)	+40 (20–59)	Moderate
	Hi (A2)	+10 (3–17)	+19 (7–31)	+42 (21–63)	Moderate

Surface air temperature for Vanuatu is projected to range from 1.4°C to 2.6°C (average of 2.0°C) higher than the 1990 baseline by 2090, while sea surface temperature is expected to be between 1.3°C and 2.5°C (average of 1.9°C) higher. Sea level rise is projected to range from 17 cm to 63 cm (average of 40 cm) compared to the 1990 baseline.

7.3 PSLM

Vanuatu's SEAFRAME station, which is located in Port Vila on the island of Efate, was installed in 1993. A Continuous Global Positioning System (CGPS) was also installed in 2002 to measure the effect of vertical tectonic land movement (BOM, 2010e). One of MESCAL Vanuatu's two demonstration sites, Eratap, is located on the same island, less than 5 km southeast of the station. The other site, Crab Bay-Amal is located about 192 km north northwest of the station, on the island of Malekula. Since there is only one tide gauge, the sea level trend for Vanuatu will be applied to both sites.

The annual mean sea level rise for Vanuatu, between 1993 and 2010, is calculated to be 4.9 mm per year (Table 3.1), after the effects of atmospheric pressure and tectonic movement have been removed. The linearly extrapolated sea level for Vanuatu to the year 2100 is 529.2 mm above mean sea level. Between the installation of the Port Vila SEAFRAME station in 1993 and the end of 2010, the station has recorded 18 years of data.

7.4 Threats to community livelihoods

Vanuatu's mean monthly temperature ranges from about 23°C in July/August, when it is the coolest, to about 27°C during January/February, when it is the warmest (BOM and CSIRO, 2011e). These temperatures border on the upper range of the mangrove's ideal temperatures. Even under the highest temperature rise projections for Vanuatu for the 21st century (Table 7.1), it would still be well below the 35°C when mangroves start to experience thermal stress.

MESCAL Vanuatu's demonstration sites are both located within bays (Figure 1.1). PCCSP's projection average of 40 cm sea level rise by 2090 (from a range of 17 – 63 cm), as well as the linearly extrapolated rise of 53 cm by 2100, from Vanuatu's current rate recorded by PSLM, have already exceeded Ellison and Stoddart's 12 cm per 100 year sustainable rate of sediment replenishment (1991) for this type of mangrove setting. This consequently indicates that Vanuatu's mangrove coverage could become severely diminished or totally lost by the end of this century, and in agreement with the outlook presented by Duke et al. (2007).

Apart from climate-related threats to the mangrove and associated coastal ecosystems, human-induced threats also play an increasing role in endangering these resources.

The biggest anthropogenic threats to mangrove ecosystems identified by MESCAL Vanuatu include overharvesting of timber as firewood and for building houses and boats, overfishing, encroachment of leased land for conversion into housing and agricultural areas (Baereleo, 2013).

Over 90% of all of Vanuatu's mangroves can be found on the island of Malekula, where Crab Bay-Amal is located, and the need for a mangrove management plan to sustainably manage these resources was highlighted in Vanuatu's latest National Forest Policy (2011). Land tenure issues have been the sources of disputes in Malekula for decades, especially in relation to harvesting of resources. At one point, resources such as crabs and mangrove timber were harvested on a commercial and unsustainable scale to meet demands in Port Vila. It was, therefore, considered a milestone for community-led management of mangroves and other coastal resources when the traditional community leaders in the Crab Bay-Amal area finally agreed to the collective establishment of a *tabu eria* to control resource exploitation (Hickey, 2006). This has allowed the resources to slowly recover and support the local communities' subsistence needs.

Efate, where Eratap is located, is the most urbanised and densely populated island in Vanuatu. With 28% of Vanuatu's population currently living on the island and an annual growth rate of 4.5% (twice the national rate of 2.3%), it is the country's fastest growing population centre (Vanuatu National Statistics Office, 2009). At this rate of growth, the demand for land and other resources will only continue to increase pressure on any undeveloped areas, especially in the coastal zones. The expansion of land leased for coastal development projects is rapidly expanding and approaching the Eratap area (Figure 7.1). If this trend continues, the impact of land reclamation combined with rising sea level will accelerate the loss of mangroves in this area. Local traditional practices such as gathering of material to make dance costumes and the use of plants as medicine in the area would also be at risk of being lost.

Mangrove areas and resources in Vanuatu are property of the customary landowners. There is currently no legal framework dedicated to the management of mangroves. A review of current legislations under the project will aim to facilitate the formulation of a framework which would guide policy makers to take the necessary measures to ensure the protection of these ecosystems.

While loss of mangrove ecosystems may be inevitable by the end of the century, it is vital that they are sustainably managed to prolong its role in providing for the local communities' in Vanuatu.

8 Fiji

MESCAL Fiji is implemented locally by the Department of Environment under the Ministry of Local Government, Urban Development, Housing and Environment.

8.1 Mangrove distribution and demonstration sites

Fiji has approximately 424.64 km² of mangrove forests – the third largest in the Pacific region (Spalding et al., 2010). Much of the mangroves can be found around the deltas of the major river systems on the two main islands of Viti Levu and Vanua Levu (Gray, 1993).

MESCAL Fiji's demonstration site encompasses the whole of the Rewa River Delta region, which is located on the southeast coast of Viti Levu. The Rewa River system is the largest in Fiji and its catchment covers almost one-third of Viti Levu. An estimated area of 51.3 km² of mangroves in the delta support a high diversity of marine, estuarine and freshwater flora and fauna in the mangroves forest itself and the associated coral reefs and seagrass beds (Watling, 1985). Lata and Nunn (2011) estimate the size of the Rewa River Delta to be about 86 km². Representing about 60% of the land area of the Rewa River Delta and 12% of Fiji's total mangrove forests, this system is valued as the most diverse mangrove ecosystem in Fiji and is frequented as a site for education and environmental research. Figure 8.1, below, shows the location and extent of mangroves in the demonstration site.

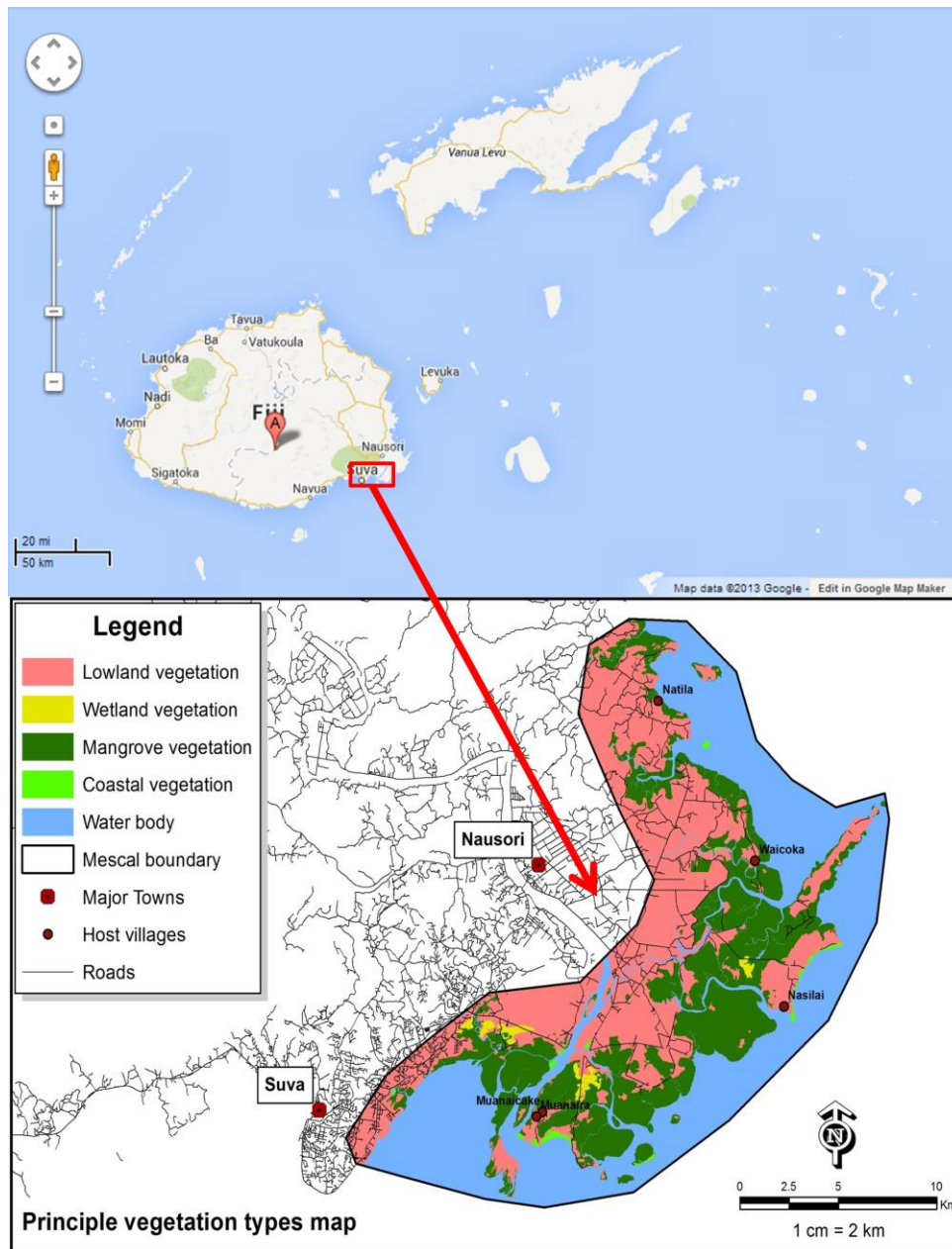


Figure 8.1: Map of Fiji's main islands and mangrove coverage in the Rewa River Delta (Google Maps, 2013, Nand, 2013).

8.2 PCCSP

For Fiji, surface air temperature, sea surface temperature and sea level have all been projected with moderate confidence to continue increasing over the 21st century (BOM and CSIRO, 2011a). These projections are presented in detail in Table 8.1, below.

Table 8.1: PCCSP climate projections for Fiji (BOM and CSIRO, 2011a).

	Emission scenario	Year			Confidence level
Variable		2030	2055	2090	
Annual surface air temperature (°C)	Low (B1)	+0.6 ± 0.4	+1.0 ± 0.5	+1.4 ± 0.7	Moderate
	Mid (A1B)	+0.7 ± 0.5	+1.4 ± 0.5	+2.1 ± 0.8	Moderate
	Hi (A2)	+0.7 ± 0.3	+1.4 ± 0.3	+2.6 ± 0.6	Moderate
Annual sea surface temperature (°C)	Low (B1)	+0.6 ± 0.4	+0.9 ± 0.4	+1.3 ± 0.4	Moderate
	Mid (A1B)	+0.6 ± 0.3	+1.2 ± 0.4	+1.9 ± 0.6	Moderate
	Hi (A2)	+0.7 ± 0.4	+1.3 ± 0.4	+2.4 ± 0.4	Moderate
Annual mean sea level (cm)	Low (B1)	+10 (5–16)	+18 (10–27)	+32 (16–47)	Moderate
	Mid (A1B)	+10 (5–15)	+20 (9–31)	+39 (20–59)	Moderate
	Hi (A2)	+10 (3–16)	+20 (8–31)	+41 (21–62)	Moderate

Surface air temperature for Fiji is projected to range from 1.4°C to 2.6°C (average of 2°C) higher than the 1990 baseline by 2090, while sea surface temperature is expected to be between 1.3°C and 2.4°C (average of 1.9°C) higher. Sea level rise is projected to range from 16 cm to 62 cm (average of 39 cm) compared to the 1990 baseline.

8.3 PSLM

Fiji's SEAFRAME station, which is located in Lautoka, on the western side of Viti Levu, was installed in 1992. This was one of the first stations in the PSLM network to be installed. A Continuous Global Positioning System (CGPS) was also installed in 2001 to measure the effect of vertical tectonic land movement (BOM, 2010a). Rewa River Delta is located on the opposite side of same island, about 130 km southeast of the station.

The annual mean sea level rise for Fiji, between 1992 and 2010, is calculated to be 4.8 mm per year (Table 3.1), after the effects of atmospheric pressure and tectonic movement have been removed. The linearly extrapolated sea level for Fiji for the year 2100 is 518.4 mm above mean sea level. Between the installation of the Lautoka SEAFRAME station in 1992 and the end of 2010, the station has recorded 18 years of data.

8.4 Threats to community livelihoods

Fiji's mean monthly temperature ranges from about 24°C in July/August, when it is the coolest, to about 27°C during January/February, when it is the warmest (BOM and CSIRO, 2011a). These temperatures border on the upper range of the mangrove's ideal temperatures. Even under the highest temperature rise projections for Fiji for the 21st century (Table 8.1), it would still be below the 35°C when mangroves start to experience thermal stress.

With the average projected sea level rise of 39 cm for Fiji (BOM and CSIRO, 2011a), it would seem that Fiji mangroves can still keep up with Ellison and Stoddart's 45 cm per 100 year sustainable rate of sediment replenishment (1991) for mangroves in deltaic setting. However, if the upper range of the projections (sea level rise of 62 cm according to PCCSP and the linearly extrapolated rise of 52 cm according to PSLM) were to eventuate, it would then mean that much of Fiji's mangroves would become severely diminished or totally lost by the end of this century.

Lata and Nunn (2012) reconstructed inundations scenarios for the Rewa River Delta using projections from recent studies (IPCC, 2007, Rahmstorf et al., 2007, Vermeer and Rahmstorf, 2009, Nicholls et al., 2011). The result suggested a possible 1.2 m rise in sea level by 2100, which is even greater than both of the previously discussed projections. If this were to eventuate, most of the Rewa River Delta's mangrove could be lost as early as 2060 (Figure 8.2).

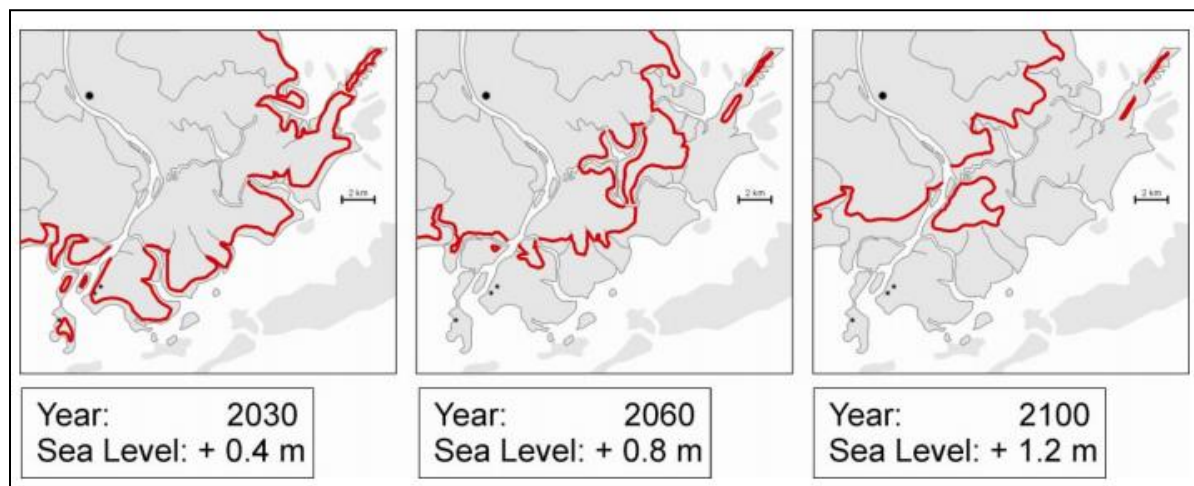


Figure 8.2: Rewa River Delta sea level rise inundation scenarios (Lata and Nunn, 2012).

Studies in the stratigraphy of mangrove areas in Fiji suggest that while they managed keep up with rising sea levels in the past, the recent slow rate of landward mangrove migration may indicate that it has become more difficult now for the mangroves to adapt (Ellison and Strickland, 2010).

Even if all other natural conditions permit landward migration of mangroves to occur, the infrastructure in these highly urbanised delta areas will ultimately form a physical barrier to prevent this process.

The main population centres in Fiji are concentrated around delta regions of the major river systems such as the Rewa, Nadi, Ba and Navua rivers. Currently, over 51% of Fiji's population live in urban centres, and this is expected to increase to 61% by 2030 (FIBS, 2007). The rapid rate of urbanisation in recent decades has seen many mangrove areas around the urban centres being converted to informal "squatter" settlements. The use of mangroves as a convenient site for improper waste disposal, as well as the harvest of mangrove timber as a cheap source of fuel and construction material all contribute to the rapid degradation of the ecosystems.

Reclamation of foreshore areas, which in Fiji is technically government land and which traditional landowners have also been granted customary access rights, for agriculture and commercial developments is also a major threat as constructions on these scales usually require large areas of land. It was estimated that about 86% of mangrove areas reclaimed up till 1990 had been done so for conversion to sugarcane and rice farms (Lal, 1990). With the shift in Fiji's economy away from agriculture and towards more service-based activities in the urban areas, current reclamations appear to be more commonly used for the latter purpose.

One of the major consequences of the concentrated urban growth in coastal and delta regions is the vulnerability of the large populations in those areas to sea level rise. Nunn (2013) highlighted that the natural rate of delta subsidence, combined with the increasing weight of infrastructure above it, increased flooding frequency and the accelerating rate of sea level rise would make most delta urban centres in the Pacific, such as Nadi Town, uninhabitable by 2030.

The needs of an increasing urban population and urban economic activities must not overshadow the importance of mangroves and associated coastal ecosystems. In fact, to compare in monetary terms, it is estimated that fisheries products from Fiji's mangrove ecosystems is worth a substantial FJ\$ 31 million annually (about US\$ 17 million in 2013 values) (Ellison, 2010). This is the amount that would be lost by the communities that would otherwise have harvested those fisheries products for sale in the domestic market.

The complex nature of land tenure in Fiji and the distribution of responsibilities for the different aspects of mangrove and coastal ecosystem and resource management among various government departments are institutional challenges hindering the effectively monitoring and managing these ecosystems (Nand, 2013). An updated National Mangrove Management Plan for Fiji, from the 1985 and 1986 versions, and an economic valuation of mangrove ecosystem services and resources are expected to be completed in 2013. These tools will become major milestones towards integrated management of mangrove resources in Fiji.

9 Tonga

MESCAL Tonga is implemented locally by the Ministry of Lands, Environment, Climate Change and Natural Resources.

9.1 Mangrove distribution and demonstration sites

There is approximately 3.36 km² of mangrove forests distributed throughout the islands of Tonga (Spalding et al., 2010). Mangrove occurrence in Tonga is known in the following islands:

- a) Tongatapu Island
 - **Nukuhetulu/Folaha**
 - Kolovai
 - Sopu
 - Popua
 - Patagata
- b) Vava'u Island
 - Toula
 - 'Utungake
 - Vaimalo
 - Okoa
 - Koloa
 - Holeva
 - Leimatu'a
- c) Ha'apai Island
- d) 'Eua Island
- e) Niuatoputapu Island
- f) Niuafo'ou Island

The Nukuhetulu/Folaha mangrove area is valued nationally as the largest mangrove stand in Tonga, which also has the highest biological diversity. Figure 9.1, below, shows the mangrove distribution in Tonga's main island groups and the mapped demonstration site.

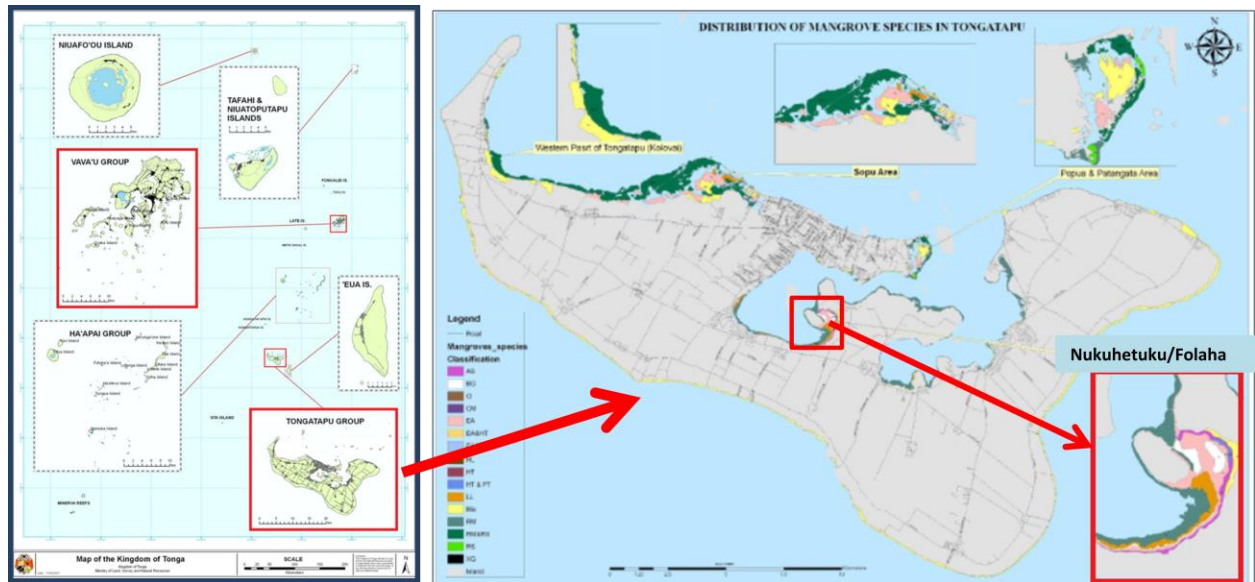


Figure 9.1: Tonga mangrove distribution (left) and the Nukuhetulu/Folaha demonstration site (Lepa, 2013).

9.2 PCCSP

For Tonga, surface air temperature, sea surface temperature and sea level have all been projected, with moderate confidence, to continue increasing over the 21st century (BOM and CSIRO, 2011d). These projections are presented in Table 9.1, below.

Table 9.1: PCCSP climate projections for Tonga (BOM and CSIRO, 2011d).

	Emission scenario	Year			Confidence level
Variable		2030	2055	2090	
Annual surface air temperature (°C)	Low (B1)	+0.6 ± 0.4	+1.0 ± 0.5	+1.4 ± 0.6	Moderate
	Mid (A1B)	+0.7 ± 0.5	+1.3 ± 0.6	+2.1 ± 0.8	Moderate
	Hi (A2)	+0.7 ± 0.4	+1.4 ± 0.4	+2.6 ± 0.7	Moderate
Annual sea surface temperature (°C)	Low (B1)	+0.6 ± 0.3	+0.9 ± 0.4	+1.3 ± 0.5	Moderate
	Mid (A1B)	+0.6 ± 0.3	+1.2 ± 0.4	+1.9 ± 0.6	Moderate
	Hi (A2)	+0.7 ± 0.4	+1.3 ± 0.4	+2.4 ± 0.6	Moderate
Annual mean sea level (cm)	Low (B1)	+10 (5–16)	+19 (10–27)	+32 (16–47)	Moderate
	Mid (A1B)	+10 (4–16)	+21 (10–31)	+39 (20–59)	Moderate
	Hi (A2)	+10 (3–17)	+20 (9–31)	+41 (21–62)	Moderate

Surface air temperature for Tonga is projected to range from 1.4°C to 2.6°C (average of 2.0°C) higher than the 1990 baseline by 2090, while sea surface temperature is expected to be between 1.3°C and 2.4°C (average of 1.9°C) higher. Sea level rise is projected to range from 16 cm to 62 cm (average of 39 cm) compared to the 1990 baseline.

9.3 PSLM

Tonga's SEAFRAME station, which is located in Nuku'alofa, on the island of Tongatapu, was installed in 1993. A Continuous Global Positioning System (CGPS) was also installed in 2002 to measure the effect of vertical tectonic land movement (BOM, 2010d). Nukuhetulu/Folaha is located on the same island, about 3.4 km south southwest of the station.

The annual mean sea level rise for Tonga, between 1993 and 2010, is calculated to be 7.8 mm per year, after the effects of atmospheric pressure and tectonic movement have been removed (Table 3.1). The linearly extrapolated sea level to the year 2100 for Tonga is 842.4 mm above mean sea level. This is the fastest sea level rise trend of the MESCAL countries and second out

of the whole PSLM network. Between the installation of Tonga's SEAFRAME station in 1993 and the end of 2010, the station has recorded 18 years of data.

9.4 Threats to community livelihoods

Tonga is located farther south from the equator than the other four MESCAL pilot countries and experiences slightly larger seasonal variation in atmospheric temperature. The variation is also more pronounced in the southern group of islands than it is in the north. Tonga's mean monthly temperature ranges from about 22°C in July, when it is the coolest, to about 28°C during February, when it is the warmest (BOM and CSIRO, 2011d). These temperatures border around the upper range of the mangrove's ideal temperatures. Even under the highest temperature rise projections for Tonga for the 21st century (Table 9.1), it would still be below the 35°C when mangroves start to experience thermal stress.

MESCAL Tonga's demonstration site is located within the Fanga'uta Lagoon in Tongatapu, in the southern part of Tonga. Given the slight variation in climate between the island groups, the mangrove community structure and composition would likely differ slightly to reflect the local conditions. Island-level climate projections are currently not available for Tonga but they would be most valuable in the assessment of coastal ecosystem responses to future temperature changes.

Tonga is likely to experience rise in sea levels from 16 cm to 62 cm (average of 39 cm) by the end of the 21st century, according to PCCSP projections (BOM and CSIRO, 2011d). Linear extrapolation of the current observed trends suggest that it could be as high as 84 cm (BOM, 2010d). Lagoonal mangroves depend on vegetative detritus for its sediment supply, and require sediment replenishment at a rate of at least 12 cm per 100 years (Ellison and Stoddart, 1991). This rate is already being exceeded under even the most conservative of these sea level rise scenarios. With this outlook, the mangroves at Nukuhetulu/Folaha could be completely lost well before the end of 2100 due to sea level rise.

Additional anthropogenic threats that could exacerbate the degradation of Tonga's mangrove ecosystems also include overfishing, overharvesting of mangroves for firewood, construction material and tapa dye and the expansion of coastal developments into mangrove areas (Lepa, 2013).

In Tonga, all land technically belongs to the King and the Government. There is no customary ownership, unlike in most other parts of the Pacific, and mangroves and other foreshore areas and resources are seen as common public property (Rohorua and Lim, 2006). The only current exception is in Tongatapu, where the Birds & Fish Preservation Act (1989) specifically makes provision for the protection of the whole lagoon, where the demonstration site is located, and its resources. Similar provisions are currently not, but should be, extended to the other mangrove

and coastal ecosystems of the other islands in Tonga. However, despite the protection status of mangroves in Tongatapu, the residential and commercial areas of nearby Nuku'alofa continue to expand, usually illegally, into the boundaries of the protected mangrove area (Government of the Kingdom of Tonga, 2010). A review of current legislations under the MESCAL project will aim to facilitate the formulation of a framework which would guide policy makers to take the necessary measures to ensure the protection of these ecosystems.

Mangrove and its resources form a significant part of the Tongan culture. From this ecosystem, local communities can obtain food, traditional medicine, wood material for constructing boats, houses and fish traps, tannin can be extracted and used for anti-fungal treatment of fishing nets and traps and a dye for tapa cloth is sourced from mangrove bark (Rohorua and Lim, 2006). The overharvesting and resulting shortage of the mangrove used for extracting tapa dye is already forcing the tapa makers to look for other alternatives. With the current rate of mangrove degradation, the loss of certain traditional knowledge and practices may be imminent.

10 Samoa

MESCAL Samoa is implemented locally by the Division of Environment and Conservation under the Ministry of Natural Resources and Environment.

10.1 Mangrove distribution and demonstration sites

There is approximately 3.7 km² of mangrove forests found in Samoa (Spalding et al., 2010). Its distribution is limited to the two main islands of Savai'i and Upolu.

MESCAL Samoa's demonstration site is Le Asaga Bay, located on the south coast of the island of Upolu. Le Asaga Bay is part of the larger Safata Marine Protected Area, which was established in 2004, as part of Samoa's commitment to the United Nations Convention on Biological Diversity (UNCBD).

Although the eastern tip and much of the south coast of Upolu were badly affected during the 8.0 magnitude earthquake and subsequent tsunami that struck Samoa in September 2009, Le Asaga Bay and the general Safata Bay area sustained relatively small damages. This was attributed to the Le Muta Peninsula and dense mangrove swamps shielding the Le Asaga coastal areas from much of the impact of the waves (World Bank et al., 2009) Figure 10.1, below, shows a map of Samoa and Le Asaga Bay.



Figure 10.1: Map of Samoa and demonstration site, Le Asaga Bay (Wikipedia, 2004, Google Earth, 2013).

10.2 PCCSP

Sea surface temperature has been projected with high confidence to continue increasing over the 21st century for Samoa, while surface air temperature and sea level have both been projected to respond the same way, with moderate confidence (BOM and CSIRO, 2011b). These projections are presented in detail in Table 10.1, below.

Table 10.1: PCCSP climate projections for Samoa (BOM and CSIRO, 2011b).

	Emission scenario	Year			Confidence level
Variable		2030	2055	2090	
Annual surface air temperature (°C)	Low (B1)	+0.6 ± 0.4	+1.0 ± 0.4	+1.4 ± 0.6	Moderate
	Mid (A1B)	+0.8 ± 0.4	+1.4 ± 0.5	+2.2 ± 0.7	Moderate
	Hi (A2)	+0.7 ± 0.3	+1.4 ± 0.4	+2.6 ± 0.7	Moderate
Annual sea surface temperature (°C)	Low (B1)	+0.6 ± 0.4	+0.9 ± 0.3	+1.3 ± 0.4	High
	Mid (A1B)	+0.7 ± 0.3	+1.2 ± 0.4	+2.0 ± 0.7	High
	Hi (A2)	+0.7 ± 0.4	+1.3 ± 0.5	+2.4 ± 0.8	High
Annual mean sea level (cm)	Low (B1)	+10 (5–15)	+18 (10–26)	+31 (17–45)	Moderate
	Mid (A1B)	+10 (6–14)	+21 (11–30)	+38 (20–57)	Moderate
	Hi (A2)	+10 (5–15)	+20 (10–29)	+40 (21–59)	Moderate

Surface air temperature for Samoa is projected to range from 1.4°C to 2.6°C (average of 2°C) higher than the 1990 baseline by 2090, while sea surface temperature is expected to be between 1.3°C and 2.4°C (average of 1.9°C) higher. Sea level rise is projected to range from 17 cm to 59 cm (average of 38 cm) compared to the 1990 baseline.

10.3 PSLM

Samoa's SEAFRAME station, which is located in Apia, on the island of Upolu, was installed in 1993. A Continuous Global Positioning System (CGPS) was also installed in 2001 to measure the effect of vertical tectonic land movement (BOM, 2010b). Le Asaga Bay is located about 20 km south southwest of the station, on the opposite site of the same island.

The annual mean sea level rise for Samoa, between 1993 and 2010, is calculated to be 4.3 mm per year (Table 3.1), after the effects of atmospheric pressure and tectonic movement have been removed. The linearly extrapolated sea level for the year 2100 is 464.4 mm above mean sea level. Between the installation of the Apia SEAFRAME station in 1993 and the end of 2010, the station has recorded 18 years of data.

10.4 Threats to community livelihoods

Samoa's mean monthly temperatures are fairly constant and range from about 26°C in July, when it is the coolest, to 27°C during March, when it is the warmest (BOM and CSIRO, 2011b). These temperatures are around the upper margin of the ideal temperature range for mangrove growth. Average projected temperature rise in both the sea and air is around 2°C but could be as high 2.6°C for the air and 2.4°C for the sea surface. Even under the highest temperature rise projections for the 21st century (Table 10.1), it would still be well below the 35°C when mangroves start to experience thermal stress.

Samoa is likely to experience rise in sea level from 17 cm to 59 cm (average of 38 cm) by the end of the 21st century, according to PCCSP projections (BOM and CSIRO, 2011b). Linear extrapolation of the current observed trends suggest that it could be as high as 46 cm (BOM, 2010d). Lagoonal mangroves depend on vegetative detritus for its sediment supply, and require sediment replenishment at a rate of at least 12 cm per 100 years (Ellison and Stoddart, 1991). This rate is already being exceeded under even the most conservative of these sea level rise scenarios. Coastal erosion and rising high tide levels are already being observed by the communities in Le Asaga Bay. With this outlook, the mangroves in this area could be completely lost well before the end of 2100 due to sea level rise.

The Le Asaga Bay communities rely on the mangrove and nearby coastal ecosystems to provide them with food and timber for construction of houses and boats. Unsustainable practices such as improper waste disposal in the mangrove areas, beach sand mining and overharvesting of resources also contribute to the vulnerability of the ecosystems to degradation. In other mangrove forests in Samoa, harvest of timber on a commercial scale and reclamation for conversion for agricultural and residential purposes, as well as coastal tourism developments are also major challenges hindering the protection of mangroves (Suluvale, 2001, FAO, 2007, Ministry of Natural Resources and Environment, 2009, Siamomua-Momoemausu, 2011).

Samoa's State of the Environment report (2010) highlighted that preservation of mangroves, especially those surrounding Apia, was previously compromised for the purpose of urban development. The resulting severely degraded ecosystems have become a reminder to the government and local communities that previous mistakes must not be repeated. Mangrove restoration projects have been implemented in some areas, including Vaiusu Bay and Matafaa, to ensure that communities in these areas can enjoy the goods and services provided by these ecosystems (Global Adaptation Atlas, 2013a, Global Adaptation Atlas, 2013b).

A review of current legislations and economic valuation of mangrove ecosystem services and resources under the MESCAL project will aim to facilitate the formulation of a framework which would guide policy makers to take the necessary measures to ensure the protection of mangrove and the associated coral reef and seagrass ecosystems.

11 Challenges

The Pacific region is just beginning to realise the value of mangrove and associated coastal areas not only for the livelihoods of communities but also for their ecosystem services and role in climate change mitigation and adaptation. Several major challenges need to be overcome to ensure effectiveness in the measures taken to preserve and sustainably manage these resources.

11.1 Projections

- Longer tide gauge records are needed to provide reliable long-term sea level trends. The PSLM network has only existed for just less than 20 years, which is useful but barely enough to establish clear trends to represent long-term climate change.
- Downscaled climate and island-level projections are needed, especially for countries that are geographically scattered across a large area and where local climatic conditions vary widely between the island groups.
- Climate records with large proportions of missing data is an issue which many Pacific islands face. Short duration of climate records and missing data will both limit the amount of analyses for reliable baseline climatology and projection of future trends.

11.2 National assessment and monitoring

- While mangrove forests in Fiji and Samoa are concentrated around the main islands, those in Solomon Islands, Vanuatu and Tonga are distributed on different islands across the country. While the project facilitated baseline biodiversity and spatial assessments to be undertaken for the selected demonstration sites, a complete national assessment remains a challenge. Several limiting factors include time, funds, skills and transportation between islands. Regular re-assessment and monitoring of the ecosystems would also be a challenge due to the same reasons.
- Different methods have been used to estimate mangrove area coverage and have produced widely differing results. For example, recent analyses of total mangrove coverage in Fiji have ranged from 387 km² (FAO, 2010) to 517 km² (Ellison, 2010). Estimates from other sources, including Spalding et al.'s 464 km² (2010) and Tokalauvere's 450 km² (2007), also fall within the range. FAO (2007) estimated as much as 13 km² of mangroves in Tonga, which is four-times the area suggested in Spalding et al (2010). In Fiji's example, an inconsistency of 130 km² is a significant area to have been either underestimated or overestimated, and this underscores the need for common assessment methods.

11.3 Legal framework

- While some countries may have provisions within certain legislations for the protection of mangroves and other coastal ecosystems, the countries face a lot of difficulty in enforcing them. Conflicts and confusion over the ownership and right of access to these resources is also a factor hindering the protection of mangrove ecosystems.
- On a regional level, the Regional Wetlands Action Plan for the Pacific Islands 2011 – 2013 aims to “address some of the fundamental issues, challenges and emerging threats to Pacific wetlands” (SPREP, 2011). One issue is the need for regional mangrove database. The Pacific Regional Mangrove Monitoring Database is currently being developed to address this. This database will become an online repository for mangrove-related data for countries in the region.

11.4 Public awareness

- Mangroves and other coastal ecosystems are highly valued by the communities that live close to them. Unfortunately, this is not always true for the most of general public who do not directly interact with and thus do not appreciate their functions. Many people even see mangrove areas as dirty, smelly wasteland that can be exploited as a convenient rubbish dump (Gilman et al., 2006, SPREP, 2009). The public still need to be educated on the basic roles and functions of these ecosystems so that they can be more supportive of the measures being implemented.
- Public perception of the roles and benefits of coastal wetlands in the Pacific has not been properly assessed. Understanding the public’s perception will allow these ecosystems to be effectively managed. For example, if it is found that majority of the public is ignorant towards mangrove conservation, then measures need to be taken to increase their awareness, prior to the implementation of any mangrove protection projects. This could also improve the visibility and support of subsequent projects. However, if they are found to already have a positive understanding and appreciation of mangroves, then money and efforts can be saved in avoiding redundant outreach campaigns.

12 Conclusion

Mangrove and associated ecosystems are threatened by both natural events and anthropogenic processes. Climate change and the resulting sea level rise are long-term natural threats that are difficult to mitigate and the anthropogenic threats already described are also exacerbating the rate of ecosystem degradation. While climate change mitigation is largely out of the hands of minor carbon emitters like the small island in the Pacific, it is still possible to locally manage the anthropogenic threats.

Coastal communities depend on the nearby ecosystems to sustain their livelihoods. However, the pressure of rapidly increasing population is driving these very communities, as well as local governments, to exploit mangrove areas and its resources at an unsustainably high rate. Sustainability is the key factor in allowing communities to enjoy the resources and services of the mangrove and associated ecosystems for as long as they are viable.

Alongi (2002) argues that deforestation could most likely be the biggest threat to mangrove survival while Giri et al. (2011) reckons that sea level rise would pose an even greater threat in the future. The difference in views is likely due to the relatively modest projections from a decade ago compared to the improved confidence and accuracy in current projections. While non-climatic factors such as population pressures, urbanisation and ecosystem exploitation all contribute to increasing the rate of loss and ecosystem degradation, there is little doubt that climate change is indeed the major long-term challenge that needs to be addressed.

It is inevitable that the effects of the changing climate and rising sea level will severely reduce mangrove coverage in the Pacific region by the end of this current century. Depending on the physical settings they are found in, for some mangroves, this will happen well before 2100. There is still some degree of uncertainty associated with the rate of climate change and sea level rise in the Pacific. As data availability and climate models continue to improve, so will projections of the future climate and the confidence in the projections.

For now, the impacts already felt by the coastal communities provide undeniable evidence that precautionary adaptation measures must be taken to ensure that mangroves and associated coastal ecosystems continue to support the livelihoods of these communities for as long as possible.

Key impacts of loss of mangroves and coastal ecosystems

Solomon Islands

- Coastal inundation and shoreline retreat
- Loss of coastal and nearshore food supply
- Loss of income for coastal communities
- Loss of material and skills in traditional house and boat construction

Vanuatu

- Coastal inundation and shoreline retreat
- Loss of coastal and nearshore food supply
- Loss of income for coastal communities
- Loss of material and skills in traditional house and boat construction and medicinal supplies

Fiji

- Coastal inundation and shoreline retreat, especially in major deltaic urban centres
- Loss of coastal and nearshore food supply
- Loss of income for coastal communities

Tonga

- Coastal inundation and shoreline retreat
- Loss of coastal and nearshore food supply
- Loss of traditional practices including tapa-making, use of traditional medicines and construction of houses, boats and fishing traps using traditional material.

Samoa

- Coastal inundation and shoreline retreat
- Loss of coastal and nearshore food supply
- Loss of material and skills in traditional house and boat construction

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