PACIFIC ADAPTATION STRATEGY ASSISTANCE PROGRAM

SOLOMON ISLANDS

International CLIMATE CHANGE ADAPTATION Initiative

Building social and ecological resilience to climate change in Roviana, Solomon Islands

Component 2 Final Report

Australian AID

Australian Government Department of Climate Change and Energy Efficiency

The University of Queensland Australia

WorldFish Center

Roviana Conservation Foundation

WWF

Kastom Gaden Association Solomon Islands

Activity Title: Building social and ecological resilience to climate change in Roviana, Solomon Islands

Component 2 Final Report

Activity date: December 23 2010-March 30 2012

Recipient: The University of Queensland

Sub-contractors: WWF, The WorldFish Center

Reference: Albert S, Grinham A, Bythell J, Olds A, Schwarz A, Abernethy K, Aranani K, Sirikolo M, Watoto C, Duke N, McKenzie J, Roelfsema C, Liggins L, Brokovich E, Pantos O, Oeta J, Gibbes B,. 2010. Building social and ecological resilience to climate change in Roviana, Solomon Islands. The University of Queensland, Brisbane.

See specific chapters for chapter authors.

EXECUTIVE SUMMARY

Roviana and Vonavona Lagoons comprise a diverse social-ecological system that has supported human populations for 15,000 years. The area has a highly dynamic history socially, environmentally and geologically with influences including; epicentre of tribal warfare, religious diversity, major battleground for World War II, high rainfall, tectonic uplift/subsidence and tsunamis. This dynamic social-ecological history has built an inherent resilience into the communities and ecosystems present. We anticipate this resilience will, to some extent, buffer Roviana and Vonavona to future climate change pressures.

However, the integrated assessment conducted indicated a number of factors that are reducing this resilience and making the Roviana socio-ecological system more vulnerable to climate change.

Marine- Lack of adequate management of passages and offshore reefs, lack of connectivity between seagrass, mangrove and reef in some marine protected area, limited genetic connectivity between Roviana and elsewhere in some fish species, high loads of sediments and nutrients from unsustainable logging in Roviana catchment.

Coastal-Significant human disturbance of mangroves, tectonic subsidence causing mangrove die-back, lack of awareness of importance of mangroves for coastal protection, some communities will have village area halved from 50cm sea level rise.

Gardens-Traditional knowledge surrounding gardens and bushfoods not being passed on, increase in pests and diseases of food crops, lack of skills to improve soil fertility, increasing reliance on processed foods, fertile garden land being used for commercial agroforestry.

Social- Erosion of traditional value systems, high levels of youth unemployment, erosion of customary governance.

Whilst some of these factors are externally driven, many can be addressed at the local level through community based adaptation. Through a consultative participatory process with Roviana people we have identified several local actions that will re-enforce existing community resilience. Marine ecosystems can be strengthened by improving management of mangrove ecosystems, increasing connectivity between seagrass, mangroves and reef habitats, enforcing existing catchment management regulations. Coastal ecosystems can be protected through limiting removal of mangroves adjacent to villages and coconut plantations. Gardening practices could be improved through better land use planning to limit agroforestry encroachment onto garden lands, training in soil fertility improvement methods, distribution of species/cultivars more resistant to climate extremes. Valuable traditional knowledge of garden practices and bushfoods should be documented for future generations.

Roviana people have a strong history of adapting in the face of dramatic social-ecological changes, with a blend of new ideas presented in this report and the existing rich body of traditional ecological knowledge we anticipate the Roviana communities will sustain and flourish under the influences of global climate change in the coming centuries.

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CHAPTER 1

APPROACH

Simon Albert

INTRODUCTION

This report provides an overview of investigations by the University of Queensland, WWF, Kastom Gaden Association and The WorldFish Center towards the Solomon Islands PASAP program- Building social and ecological resilience to climate change in Roviana, Solomon Islands. Specifically focussing on project Objective 3 (Assess the vulnerability of the area to climate change impacts in the context of other threats posed to the coastal terrestrial and marine habitats and ecosystems, based on the customary resource owners' assessment and on scientific evidence). Other objectives of this project are led by the University of California-Santa Barbara for which a separate progress report will be developed.

STUDY SITE

The Roviana region covers an area of 700 km^2 in the Western province of Solomon Islands. It is a remote area with 17,000 people spread across 20 villages (50-300 people each) and numerous smaller hamlets. The majority of people live a subsistence lifestyle from the rich marine and terrestrial resources. 15% of the population live in the small urban settlements of Munda and Noro. Land tenure systems across the area are customary, which has historically has contributed to strong stewardship of marine and terrestrial resources. More recently this traditional stewardship of resources has been re-vitalised with the formation of the Roviana Conservation Foundation which has established a network of 23 marine reserves across the Roviana area. Whilst the region is referred to as Roviana, it is actually comprised of two lagoon systems; Roviana Lagoon and Vonavona Lagoon Figure 1. This study focussed on these two lagoon systems, herein often using the term Roviana or Roviana Lagoon to refer to both lagoons.

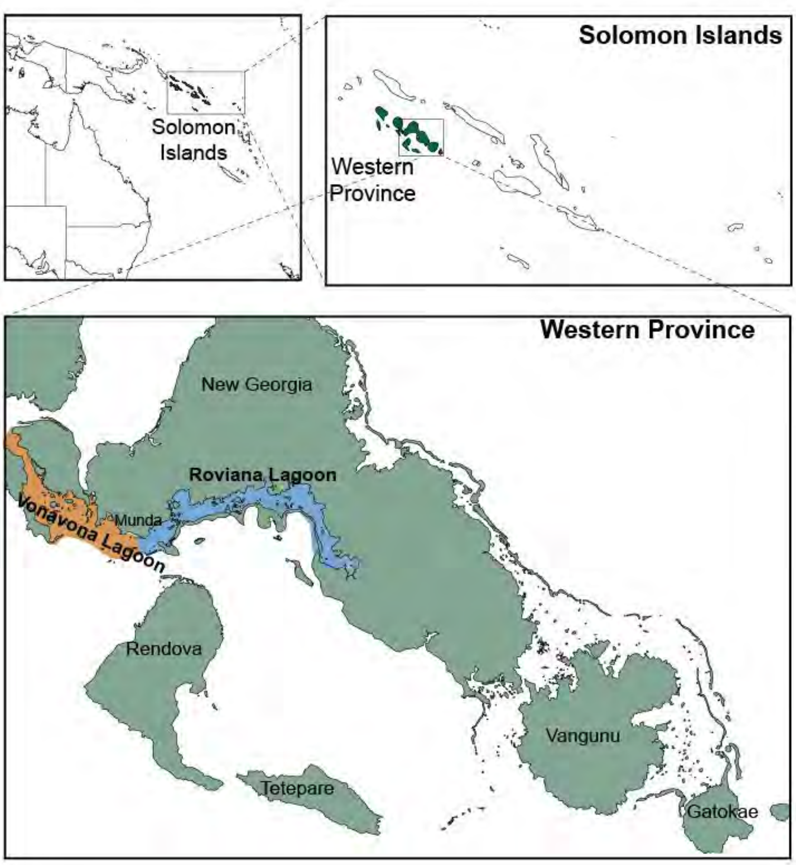

Figure 1 Roviana and Vonavona Lagoons

THE APPROACH

Understanding projected impacts of climate change on marine and terrestrial ecosystems of Roviana Lagoon is a complex challenge. The assessments conducted as part of this program were not intended to cover all possible impacts across all habitats and resources of the area. Instead we were guided by key concerns of the local communities and specifically targeted resources that they rely on for subsistence needs. Hence the biophysical research aspects of this project focussed on marine ecosystems and terrestrial food crops. There is an increasing body of work addressing projected climate impacts on these ecosystems that provides general guidance to Roviana communities of how climate change may impact Roviana. The large gap in our knowledge of Roviana (and Melanesia in general) is quantitative baseline data in which to frame projected impacts and provide reference for future data sets. In all aspects of this project we aimed to build this baseline understanding of ecosystem condition and threats.

CAPACITY BUILDING

The research activities carried out under this project were conducted in a participatory manner, involving Roviana people in design, implementation and analysis. The Roviana Conservation Foundation acted as an intermediate between research staff and the broader Roviana community, ensuring that communities were engaged with in a respectful and productive manner that maximised outcomes for Roviana people. RCF staff, traditional leaders and the broader community were actively involved alongside researchers during the assessments (Figure 2). This participation yielded a rich exchange of information in both directions and in many ways the core objective of helping Roviana people understand and respond to climate change was achieved during these sessions.

Figure 2 Surveying fish communities inside marine protected area in Roviana

COMMUNICATION OF RESULTS

In addition to the transfer of knowledge during the active data collection phase of the project, a series of meetings and workshops were also held to specifically present results of analysis back to the Roviana community. The most successful means of communication of often complex data sets was through spatially representing data through a GIS platform and overlaying this data on satellite images. The resulting maps were then printed in large format (1x4 m) onto a durable waterproof medium. These maps were then presented at meetings, workshops and village awareness sessions (Figure 3). Community members could use the satellite image to spatially reference the data and rapidly compare their village with surrounding areas.

Figure 3 Discussing habitat mapping results with Roviana Conservation Foundation Executive members

ACKNOWLEDGEMENTS

Firstly we would like to thank the Roviana people for their support in implementing this project. The outcomes are a testament to the rich body of traditional knowledge and stewardship of resources that guided our work throughout. We would also like to extend gratitude to the Pacific Adaptation Strategy Assistance Program (PASAP) within the Department of Climate Change and Energy Efficiency in the Australian Government for funding this program. Specifically the PASAP manager south- Liz Dovey provided a critical link between the broader Australian Government initiatives, SPREP, project partners and the Roviana people. This project would not have been possible without our colleague Shankar Aswani who conducted the pioneering work over the past 20 years that led to this project. Thank you to the Solomon Islands Government Ministry of Environment, Climate Change and Disaster Management, in particular Frank Wickham, Douglas Yee, David Hiba and Hudson Kauhiona. The Roviana Conservation Foundation executive and chairman Roddy Maebule provided guidance for this project. A special thanks to Nixon Tooler and his team of three coordinators who provided leadership and ensured community engagement throughout the project, this work would not have succeeded without you.

Coral bleaching surveys would not have been possible without field assistance from Dominic Villa and Osborne Sunga. Marie Badjeck and Edward Allison provided assistance with V&A method development, and Regon Warren and Andrew Bana (Western Province Government Fisheries Officer) assisted with field work during expert elicitations. Habitat mapping support by M.Lyons for image pre-processing, and with OBIA image analysis support provided by M. Lyons, Dr's K. Johansen and L. Arroyo and Definiens. Thank you to Gavin for analysing over 10,000 benthic photos! During the fieldwork, Captain Morgan Jimuru performed feats of navigation and seamanship unlike anything we have seen in nearly 30 years of marine field research, all without using any electronics or, in fact, any navigation aids other than his eyes, ears and accumulated knowledge. He is a legend already.

A special appreciation to the community members of Roviana/Vonavona lagoon who provided valuable information during the research process; we appreciate your genuineness and openness. To families who have been supportive and have allowed the research team to observe and visit reefs, mangroves, communities and gardens; your support is appreciated.

CHAPTER 2

CLIMATE CHANGE IN ROVIANA

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KEY MESSAGES

- Increase in air temp 0.5-1.5 degrees by 2030
- Increase in sea surface temperature of 1 degree by 2050
- Ocean acidification below threshold for healthy coral by 2045
- Sea level rise since 1996 has increased 8mm per year. Global predictions of 0.5-1.4m by 2100
- Rainfall – small increase with more intense floods
- Fewer cyclones, but stronger ones
- Low cost manual survey methods can yield accurate sea level rise inundation information
- Participatory approach to sea level rise mapping helped transfer knowledge
- Some communities in Roviana are highly vulnerable to sea level rise with over 50% of village land inundated under 50 cm sea level rise scenarios

CLIMATE CHANGE PROJECTIONS

INTRODUCTION

As part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program (PASAP) aims to enhance the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans, mainstream adaptation into decision-making, and inform robust long-term national planning and decision-making in partner countries. The Department of Climate Change and Energy Efficiency contracted University of Queensland (UQ) and University of California, Santa Barbara (UCSB) to lead the project: "Building social and ecological resilience to climate change in Roviana, Solomon Islands" (2010-2012). Under this project The WorldFish Center was subcontracted to undertake outputs 5 and 6 of Objective three: (5) Review of climate change evidence and projections for the study area and (6) Vulnerability and adaptation assessment for the study area. This report addresses the first of these and comprises a desktop review of climate change evidence and projections for the study area.

Published historical trends in climate data as well as projected climate data for the region of Solomon Islands are reviewed and some of the possible climate related changes that might be expected to occur in (primarily) marine ecosystems in the future are summarised. The brief review has been completed with the assistance of the Solomon Islands Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM). It includes projections from the Pacific Climate Change Science Program report "Climate change in the Pacific; Scientific Assessments and New Research" (PCCSP 2011a), which carried out modelling under specific emission scenarios (IPCC 2007b). Specifically Volume 2, Solomon Islands Country Report was drawn upon.

This purpose of this review was to serve as a quick reference document for Roviana project partners at an early stage of the study. It was completed prior to the release of the final results from the PCCSP in late 2011. Following the PCCSP (2011a) report release the projections were updated to incorporate this new information.

CLIMATE CHANGE

"In the future no country will be immune from the impact of human-induced climate change". The Intergovernmental Panel on Climate Change (IPCC) is unequivocal in its pronouncement that global warming will cause significant climate changes throughout the world, including increases in air, sea surface and ocean temperatures and changed patterns of precipitation, wind flow and ocean salinity (IPCC 2007a). The world is expected to experience increased climate variability as well as extreme weather events, such as prolonged drought, heavy rains and heat waves, and an increased frequency and intensity of tropical cyclones. Sea level rise is also predicted. The effects of such changes will be significant for all the Pacific Island Countries and Territories (PICTS), although "the nature and degree of the socioeconomic impact of climate change cannot be predicted with any certainty at this point in time" (Lal et al. 2009b).

Rising atmospheric greenhouse gas concentrations have increased global average temperatures by ~0.2°C per decade over the past 30 years, with most of this added energy being absorbed by the world's oceans. As a result, the heat content of the upper 700 m of the global ocean has increased by 14 × 1022 J since 1975, with the average temperature of the upper layers of the ocean having increased by 0.6°C over the past 100 years. These changes are ongoing; global ocean surface temperatures in January 2010 were the second warmest on record for the month of January, and in the period June to August 2009 reached 0.58°C above the average global temperature recorded for the 20th century, 16.4°C (Hoegh-Guldberg and Bruno 2010).

In addition to acting as the planet's heat sink, the oceans have absorbed approximately one-third of the carbon dioxide produced by human activities. The absorption of anthropogenic CO_2 has acidified the surface layers of the ocean, with a steady decrease of 0.02 pH units per decade over the past 30 years and an overall decrease since the pre-industrial period of 0.1 pH units. Although these increases appear small in terms of pH, they are associated with a substantial decline in the concentration of carbonate ions and represent a major departure from the geochemical conditions that have prevailed in the global ocean for hundreds of thousands if not millions of years (Hoegh-Guldberg and Bruno 2010).

Increases in the heat content of the ocean have driven other changes. These include; increased ocean volume (as a result of thermal expansion of the oceans as well as increased meltwater from terrestrial glaciers and ice sheets), more intense storm systems, greater stratification of the water column and reducing mixing in some parts of the ocean; consequently affecting nutrient availability and primary production and also affecting the behaviour of ocean currents (Hoegh-Guldberg and Bruno 2010).

These physical effects of climate change are expected to result in significant effects on ecological systems such as coral reefs and on human populations, their livelihoods and well-being (Figure 4, Tompkins et al. (2005)).

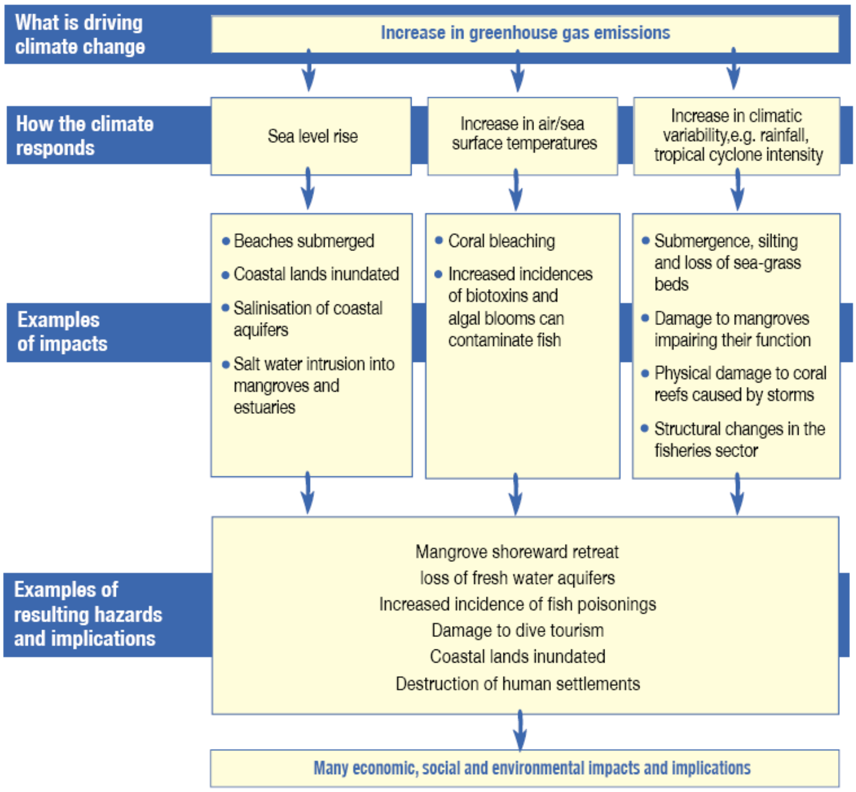


Figure 4 The potential impacts of climate change on coastal zones (Tompkins et al., 2005)

CLIMATE CHANGE IN THE SOLOMON ISLANDS

Solomon Islands are a group of over 990 islands grouped into 9 provinces (Figure 5).

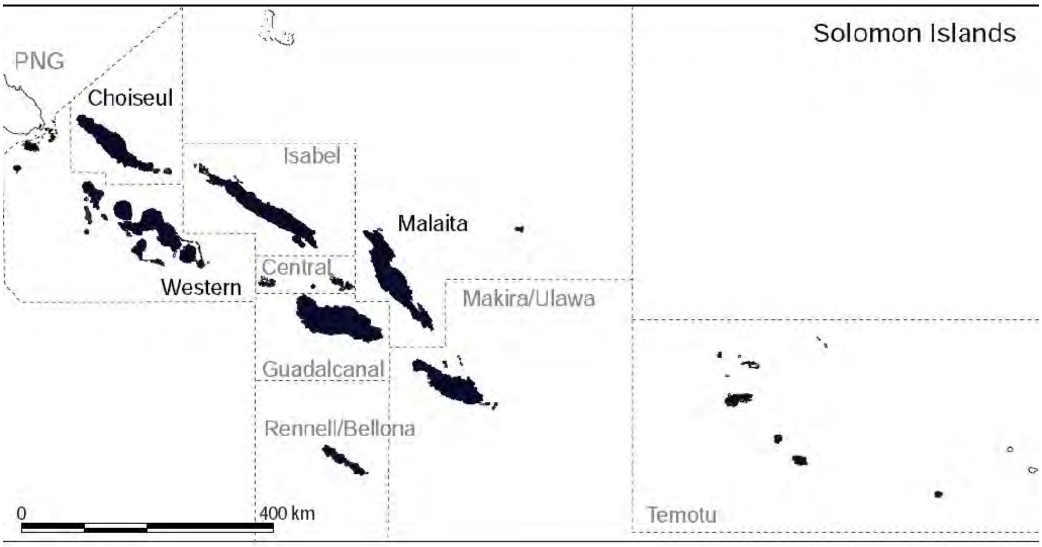


Figure 5 Map of Solomon Islands with provinces delineated by dotted lines

The largest province in terms of area is Western Province and the most populated is Malaita. However, Central Islands Province has the highest population density, closely followed by Malaita (Table 1).

Table 1 Geographic and demographic data for Solomon Islands provinces (MECM/MFMR, 2010). HH – household.

Province	Capital	land Area (km²)	# HH	Population	HH Size	Population density (km^{-2})
Central	Tulagi	615	4209	24412	5.8	39.7
Choiseul	Taro Island	3837	5056	31347	6.2	8.2
Guadalcanal	Honiara	5336	14611	84743	5.8	15.9
Isabel	Buala	4136	4614	23531	5.1	5.7
Makira-Ulawa	Kirakira	3188	7524	50410	6.7	15.8
Malaita	Auki	4225	22115	141536	6.4	33.5
Rennell - Bellona	Tigoa	671	672	4435	6.6	6.6
Temotu	Lata	895	4300	23650	5.5	26.4
Western	Gizo	5475	13650	81900	6	15.0
[Honiara]			9984	[68889]	6.9	

SLOW ONSET CHANGES IN CLIMATE

Slow onset changes are changes which happen gradually, over many years (such as sea level rise), as opposed to extreme sudden events such as storms.

AIR TEMPERATURE

Increases in surface air temperatures have been greater in the Pacific than global rates of warming. For example, since 1920, temperature has risen by 0.6-0.7°C in Noumea (New Caledonia) and Rarotonga (Cook Islands), which is greater than the mean global increase of 0.6°C (Tompkins et al. 2005) and in general, the central equatorial region has showed stronger warming effects than other areas from the equator (Lal et al. 2009b). In the period 1981-1990 the southern Pacific experienced, compared to the past (1911-1920), a significantly drier and warmer climate (by 15 % and 0.8°C, respectively). The central equatorial Pacific experienced a similarly hotter climate over the same time period (0.6°C) (Hay et al. 2003).

In Solomon Islands an increase of maximum (Figure 6) and minimum temperatures with time has been recorded by MECDM (Griffiths et al. 2005) and this was found to be one of the highest rates of increase in the region. The same study also reported a positive correlation between the maximum temperature and the frequency of hot days.

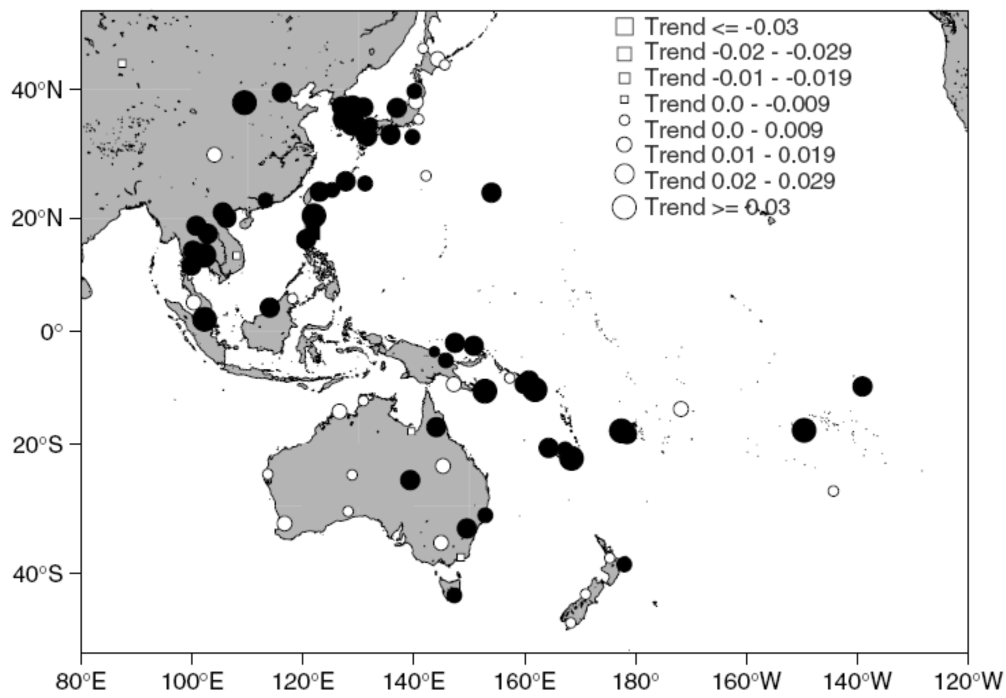


Figure 6 Trends in maximum temperature 1961–2003 in oC per year. Trends ranged between −0.04 �C per year and +0.05 oC per year and the significance of the trends is indicated by the size of the black (p ≤ 0.05) and white (p > 0.05) symbols (Griffiths et al., 2005).

Solomon Islands air temperature data records (held by MECDM) are available for six provinces and date back to the 1960's in some instances. Trends in the raw data suggest that Malaita, Guadalcanal, Makira and Choiseul have experienced an increase in average daily temperatures of ca. 2 °C the last 40-50 years, while for Western and Temotu provinces, there appears to have been no, or little increase in over the recording period. Griffiths (2005) cautions that these data sets from Solomon Islands are not complete for all stations but were able to identify that Lata, in Temotu Province has in fact showed a showed significant decrease in hot days.

FUTURE PROJECTIONS FOR AIR TEMPERATURE

Air temperatures in the region of Solomon Islands are projected to increase further. Based on IPCC climate projections (IPCC 2001), Tompkins et al. (2005) (and see references within), summarised that the average warming in regions where small Pacific islands are located is likely to be between 2.0 and 2.8°C by 2050 (compared with 1990 temperatures). Leisz (2009) reviewed the projected climate data from a spatial viewpoint for Melanesia and examined the projected changes in land surface temperature, sea-surface temperature, precipitation, cloud cover, and changes in the Degree Heat Weeks (DHW)[1] by geographically registering climate projections to a map base and spatially overlaying them. Warming projections were based on outputs from the MIROC-HIRES1 model (Hasumi and Emori 2004). It was projected that in the next 70 years Solomon Islands will be close to the high end of potential thermal stress in the region. By the end of 2040 land areas of Solomon Islands were projected to have a rise in overall average surface temperatures of between 0.5° and 1 ° C from present (Figure 7).

More recently the Pacific Climate Change Science Program (PCCSP) refined projections through the use of a range of models. Under the IPCC A2 scenario, a slight increase (<1°C) in annual and seasonal mean temperature by 2030 was predicted by the majority of models, however almost all models simulated temperature increases of greater than 2.5°C by 2090 under the A2 (high) emissions scenario (PCCSP 2011a).

Possible local effects of higher air temperatures (i.e. at a smaller scale than shown by the predictive plots in Figure 7) will be higher sea surface temperatures , especially in shallow water areas and lagoons, effects on agriculture and consequently effects on the general well-being of people.

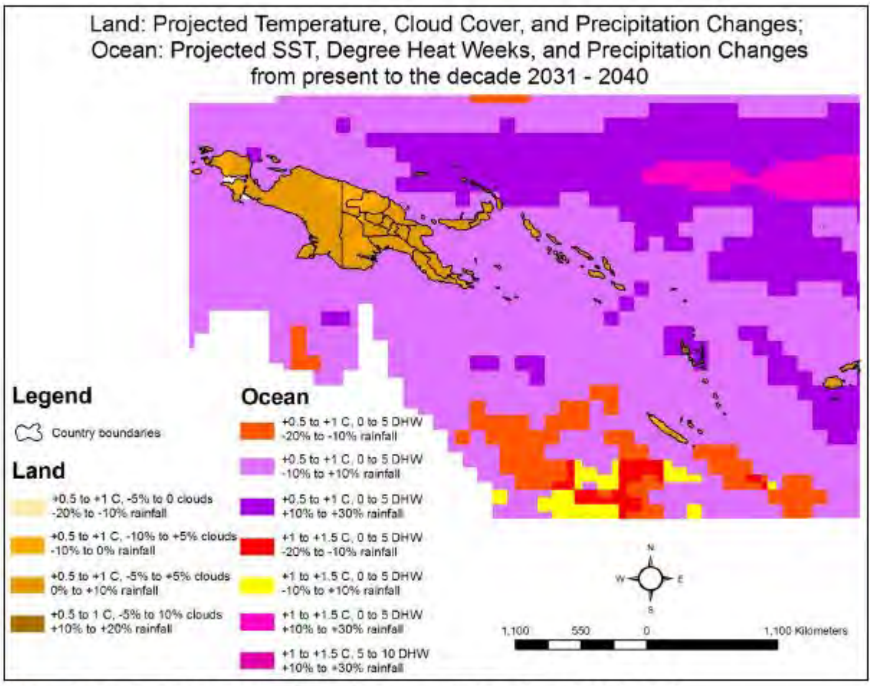


Figure 7 Projected changes from the present decade to 2031-2040 (Leisz, 2009).

[1] The Degree Heat Weeks (DHW) is the number of weeks in which the sea surface temperature of an area exceeds its average thermal maximum by 1-2 °C.

SEA SURFACE TEMPERATURE

Sea-surface temperatures (SST) in north and south Pacific areas have increased by about 0.4°C (1981-1990 compared with 1911-1920) (Hay et al. 2003). In Solomon Islands, recent models show an increase of about 0.2°C in the last 30-60 years (Hoegh-Guldberg & Bruno 2010, Figure 8).

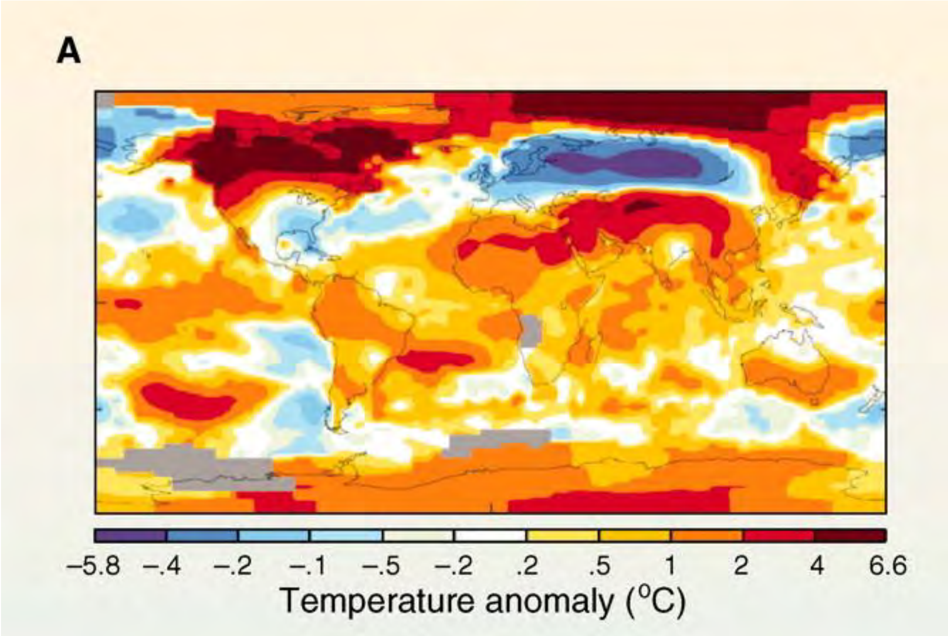


Figure 8 Recent changes in ocean temperature - Surface temperature anomaly for January 2010 relative to the mean for 1951–1980. From (Hoegh-Guldberg and Bruno, 2010).

FUTURE PROJECTIONS FOR SST

Areal projections made by Leisz (2009) projected that by 2040 the ocean areas around Solomon Islands will also experience an increase in the average sea-surface temperatures of between 0.5° and 1° C (Figure 7). The PCCSP (2011) study states the surface air temperature and sea-surface temperatures are closely connected and so a similar or slightly weaker level of warming is predicted for the surface ocean as for air temperature (that is <1°C by 2030 and >2.5°C by 2090). There is high confidence in this link between the two because over the past 50 years in the locality of the Solomon Islands there is close agreement in general between modelled and observed temperature trends, even though observational records are limited.

Rises in SST are likely to exacerbate existing problems of coral bleaching and diseases. Mangroves, sea grass beds, other coastal ecosystems are also likely to be adversely affected by rising temperatures and accelerated sea-level rise. For Pacific islands that rely on marine tourism and fisheries the consequences for society are significant. Without healthy reefs the diving industry is likely to suffer and the productivity of local fisheries is likely to be severely affected (Tompkins et al. 2005).

The most comprehensive assessment on bleaching and coral diseases for Solomon Islands now dates back to 2004. A geographically wide survey undertaken by the Nature Conservancy (TNC) in 2004 (Green et al. 2006) reported relatively healthy reefs with some places showing high crown of thorns densities (Turak 2006). Overall reef health in Solomon Islands was assessed as “good” in that most reefs visited were not impacted by human activities, which are usually of concern in other areas of the region. The main cause of reef damage was from crown of thorns starfish infestations. The coral eating snail *Drupella*, which when in full outbreak can cause serious damage to reefs, was seen at most locations. However, numbers were always very low and damage very limited. In addition, some evidence of damage following bleaching events in 2000-2001 was observed, as well as some minor current (at the time of the survey) bleaching damage. The TNC survey confirmed that damage from the 2000-2001 bleaching was overall limited and patchy and less extensive in comparison to places like Fiji.

Evidence of coral disease was occasionally seen though without widespread effect (Turak 2006). However at one site (Uepi, Western province), which is one of the popular tourist dive sites, significant mortality was seen with some diseased corals. Anecdotal information from locals indicated that a gradual spread of mortality was noted in the area over the two years preceding the survey (2002-2003), which was identified as possibly being the result of a coral pathogen.

OCEAN ACIDIFICATION

Data collected in the Pacific region as a part of the Joint Global Ocean Flux Study/World Ocean Circulation Experiment CO_2 survey allow estimates to be made of the aragonite saturation states of seawater in the pre-industrial era and in the 1990s (PCCSP, 2011), although data coverage is poor for the region of Solomon Islands. In pre-industrial times, the saturation state values were above 4 throughout most of the sub-tropical and tropical

By the mid 1990s, the uptake of anthropogenic CO2 had resulted in a widespread decline in the aragonite saturation state, with values slightly above 4 only found in the region of the South Equatorial Current and in the western Pacific. Values of aragonite and other carbonate saturation states have continued to decline since the 1990s and only the surface waters of the South Equatorial Current now have aragonite saturation states that remain at or slightly above values of 4 (PCCSP, 2011).

Recent global models estimate the change in pH for the south west Pacific between pre-industrial times and present as -0.06 (Hoegh-Guldberg and Bruno 2010), Figure 9).

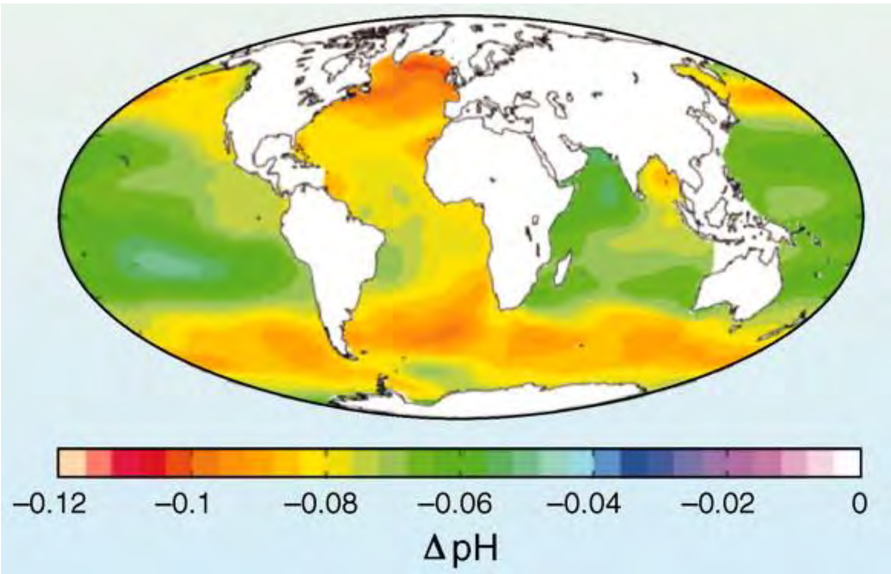


Figure 9 Changes in acidity - Estimated change in annual mean sea surface pH between the pre-industrial period (1700s) and the present day (1990s). From (Hoegh-Guldberg and Bruno, 2010).

FUTURE ACIDIFICATION PROJECTIONS

Leisz's (2009) projections showed that by 2040 ocean acidification will begin to impact the areas around Solomon Islands. One of the main parameters used to describe the change in carbonate ion concentration that results from ocean acidification, is aragonite saturation (Ωar). There is strong evidence to suggest that when Ωar of ocean waters drops below 3 (Langdon and Atkinson 2005) reef organisms cannot precipitate the calcium carbonate that they need to build their skeletons or shells, although note that Guinotte et al (2003) suggest that Ωar of above 4 is optimal for coral growth and the development of healthy reefs. To the south of Solomon Islands in Leisz's (2009) projections, Ωar was projected to fall to just below 3, a level at which corals may have trouble producing the calcium carbonate they need to build their skeletons. To the north of the country aragonite saturation levels were projected to remain at or slightly above 3 (Leisz 2009) (Figure 10).

The PCCSP (2011) report stresses that during the 21st century, acidification of the ocean will continue to increase. There is a very high confidence in this because the rate of ocean acidification is driven mainly by the increasing oceanic uptake of carbon dioxide as concentrations continue to increase in the atmosphere. Climate model results suggested that by 2045 the annual maximum aragonite saturation state for the Solomon Islands will reach values below 3.5 and continue to decline thereafter (PCCSP, 2011).

Despite the remaining uncertainty in critical thresholds, all these projections suggest that coral reefs will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of the reef structures to have growth rates that exceed natural bioerosion rates. Increasing acidity and decreasing levels of aragonite saturation are also expected to have negative impacts on ocean life apart from corals; including calcifying invertebrates, non-calcifying invertebrates and fish. High levels of CO_2 in the water are expected to negatively impact on the lifecycles of fish and large invertebrates through impacts on reproduction, settlement, sensory systems and respiratory effectiveness (Raven et al. 2005, Kurihara 2008, Munday et al. 2009a, Munday et al. 2009b). Consequently, the abundance of reef fish, those who earn their livelihoods from reef fisheries and those who rely on the fisheries as a significant food source are likely to be affected (Tompkins et al. 2005). The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure (PCCSP, 2011)

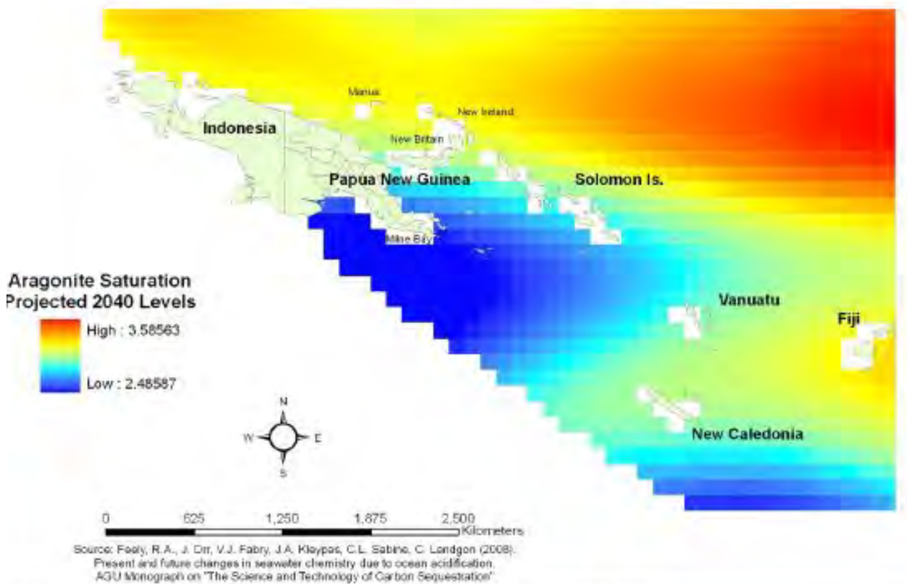


Figure 10 Projected aragonite saturation levels for 2040 (Leisz, 2009). Projections drawn from Feely et al. (2008).

SEA-LEVEL RISE

Satellite altimeter data reveal that the average global sea level changed at a rate of 3.3 ± 0.4 mm/year (over the period 1993–2006)(Cazenave and Llovel 2010). This is consistent with tidal gauge data. Further estimates of future sea level rise by 2100 range from 0.5 to 1.4m, tracking and exceeding the highest projections of the fourth assessment report of the IPCC (Rahmstorf 2007, Cazenave and Llovel 2010). This scenario does not take into account the melting of the ice sheets. Changes in ice sheet volume have important implications for sea level rise, with an expected overall contribution of up to 12 m to mean sea levels if both Greenland and the West Antarctic Ice Sheet were to melt completely (Hoegh-Guldberg and Bruno 2010).

Projected sea-level response to global warming is not spatially uniform with some regions experiencing higher or lower sea-level changes than the global average. Satellite altimetry shows that Solomon Islands has been experiencing the high end of the range of global sea-level rise (Figure 11) at a rate of 8-10 mm per year (Hoegh-Guldberg and Bruno 2010).

Sea level in the Solomon Islands is projected to rise by a range of 5 – 15 cm by 2030 (PCCSP, 2011). Under higher emissions scenarios (A2 and A1B) increases of 20 – 60 cm are indicated by 2090. Sea level rise varies according to regions. Factors influencing this regional variability include wind and waves associated with weather phenomena, ocean and mass changes and local tectonic motions.

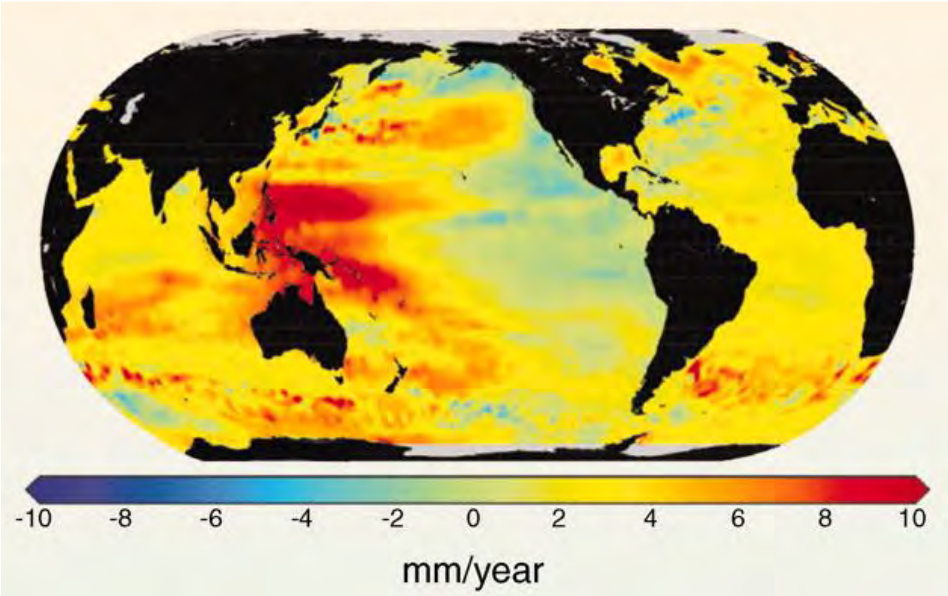


Figure 11 Average rate of global sea level rise (1993–2010) from TOPEX/Poseidon and Jason satellite altimetry data, shown as a map (Hoegh-Guldberg and Bruno, 2010).

As part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring Project (SPSLCMP; "Pacific Project") for the South Pacific Forum region (the Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu), in response to concerns raised by its member countries over the potential impacts of an enhanced greenhouse effect on climate and sea levels in the South Pacific region, a **SEAFRAME** (**Sea** **L**evel **F**ine **R**esolution **A**coustic **M**easuring **E**quipment) gauge was installed in Honiara, Solomon Islands in July 1994. According to the Pacific country report on sea level and climate for Solomon Islands in 2009 (http://www.bom.gov.au/pacificsealevel/picreports.shtml), the gauge had been returning high resolution, good scientific quality data since installation and the trend in sea-level rise near Honiara was calculated at 7.7 mm per year (Figure 12).

The most striking oceanic and climatic fluctuations in the equatorial region are interannual changes associated with the El Niño Southern Oscillation (ENSO). These affect virtually every aspect of the system, including sea level, winds, precipitation, and air and water temperature. An illustration of this shown in Figure 13 where the lowest sea level anomalies (i.e. sea levels were much lower than average) over a 15 year period occurred during the 1997/1998 El Niño.

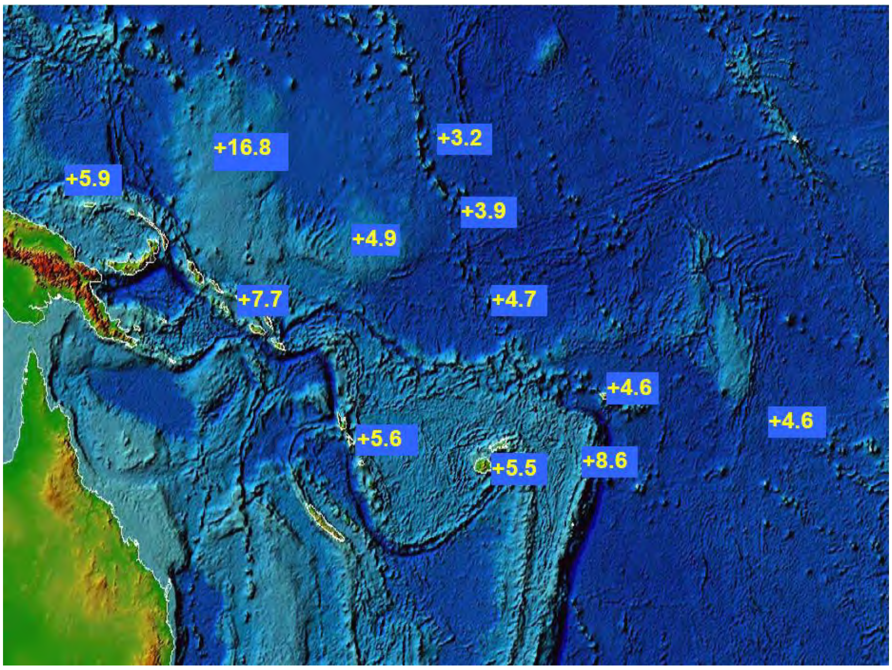


Figure 12 Current trends in sea-level rise around the Solomon Islands (Pacific country report on sea level & climate: their present state, Solomon Islands, 2009; http://www.bom.gov.au/pacificsealevel/picreports.shtml).

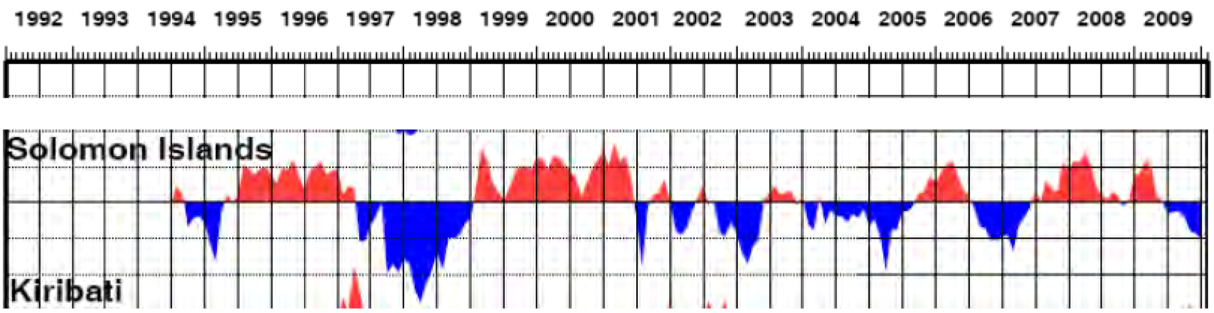


Figure 13 Sea-level anomalies for Honiara (Pacific country report on sea level and climate: their present state, Solomon Islands, 2009; http://www.bom.gov.au/pacificsealevel/picreports.shtml). A sea-level anomaly is the difference between the total sea-level and the average sea-level for this time of year, in this case after tides, seasonal cycles and trends have been removed.

As highlighted in the Solomon Islands NAPA (MECDM 2008) sea level rise may potentially create severe problems for low lying coastal areas, atolls such as Ontong Java and artificial islands dwellers. With sea-level rise increased salt water intrusion into coastal areas is expected and people living in low laying atolls such as Ontong Java have already complained about the effects of king tides and salt water intrusion to their gardens (Hilly et al. 2010).

The projected sea-level rise of 5-15cm by 2030 is likely to increase rates of coastal erosion and loss of land. For communities living in the coastal zone there is a potential for loss of infrastructure and property, potential dislocation of people, increased risk from storm surges and possible saltwater intrusion into freshwater resources. The danger of soil salinisation, coupled with the existing limited area of arable land, makes agriculture, both for domestic food production and cash crop exports, highly vulnerable to climate change (Tompkins et al. 2005).

Accurately assessing the effect of sea level rise on land inundation in Solomon Islands will require precise map-based predictions of water level rise vs. actual land elevation. In Solomon Islands such estimates have been made for Choiseul Province by TNC (Richard Hamilton pers comm.) and in specific sites in Roviana and Vonavona Lagoons as part of this study.

EXAMPLES OF SUDDEN, EXTREME EVENTS

TROPICAL CYCLONES AND OTHER STORMS

Solomon Islands are considered to have a relatively low cyclone risk with an average of 0.1 cyclones per year (Figure 14). However, the frequency of cyclones grows exponentially with latitude with the southernmost provinces the most cyclone-prone (Table 2; Figure 15).

Table 2 Number of tropical cyclones in vicinity of the Solomon Islands' provinces between 1969-2007 (Bureau of Meteorology Australia and Australian government, 2010b). Data is relative to a point in the middle of each province.

Province	Latitude (°S)	Longitude (°E)	Number of cyclones within 50 km	100 km	200 km
Choiseul	7	156.9	1	1	5
Isabel	8	159	3	3	6
Western	8.33	157.27	0	1	8
Central	9.1	160.15	2	5	9
Malaita	9.05	161	1	4	9
Temotu	10.7	165.8	0	3	10
Guadalcanal	9.6	160.15	2	6	13
Makira-Ulawa	10.6	161.8	2	10	19
Rennell - Bellona	11.65	160.3	5	12	25

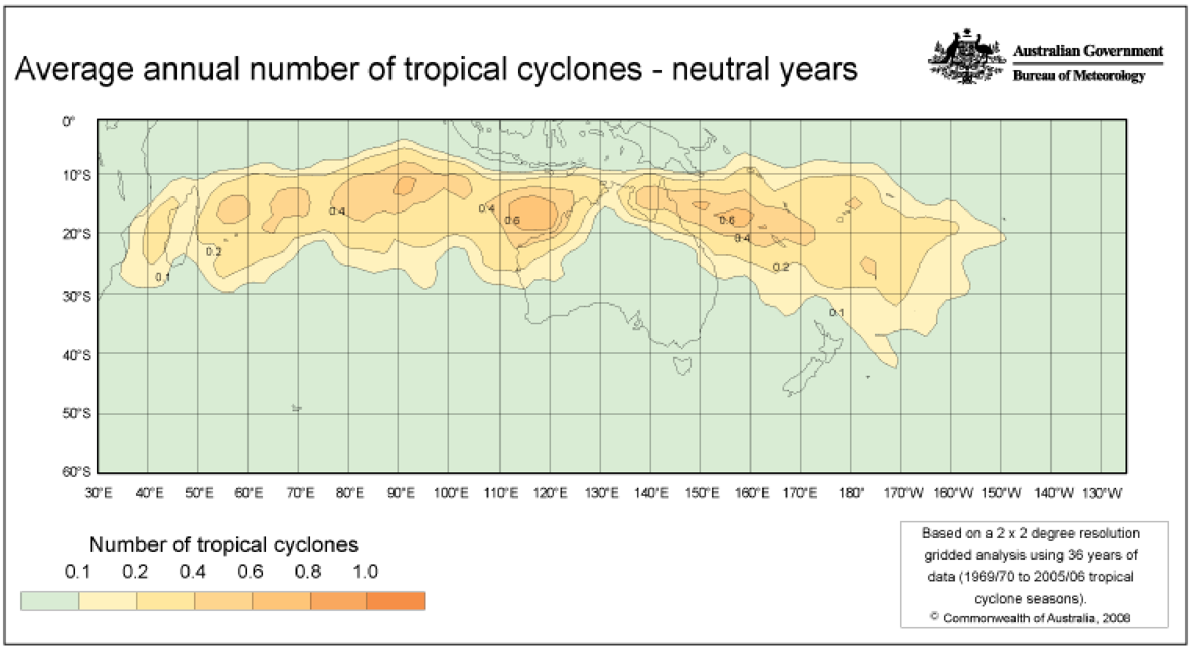


Figure 14 Average tropical cyclone frequency for the southwest Pacific during neutral years, i.e. excluding El Niño and La Niña events (Bureau of Meteorology Australia and Australian government, 2010a).

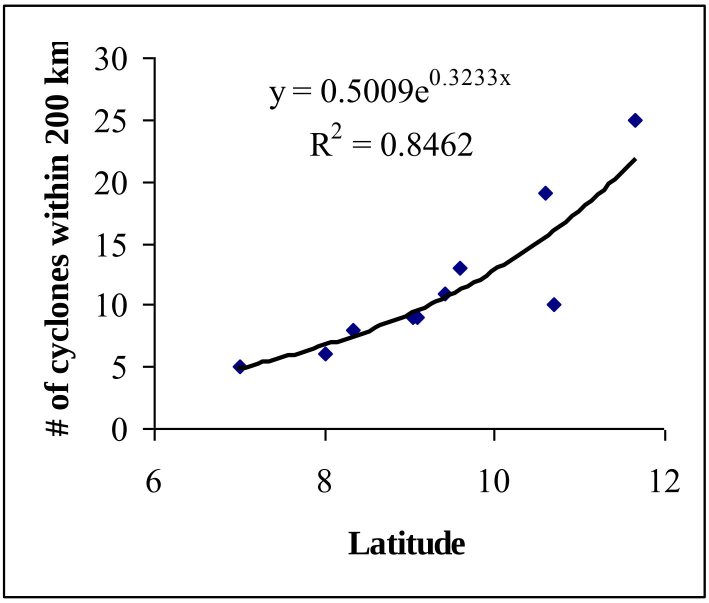


Figure 15 Correlation between the numbers of tropical cyclones within 200 km (1969-2007) to the latitude of Solomon Islands' provinces.

The impact of tropical cyclones on the physical environment of Pacific Islands depends on their frequency, intensity, speed of movement, longevity, size and proximity to the island groups and how the physical features of the affected islands influence their response to the geomorphic and hydrological processes triggered by the cyclone. Emanuel (2005) has shown that the dissipation force of a cyclone is correlated to SST and will probably increase with increasing sea surface temperature (Figure 16), moreover, the number of high intensity cyclones (categories 4 and 5) in the Western, North Pacific has increased in the last 30 years (Figure 17, (Webster et al. 2005)) and (Oouchi et al. 2006, Knutson et al. 2010) state that this trend is predicted to continue to increase regardless of a general decrease in cyclone frequency. However, it is worth noting that Kuleshov et al. (2010) showed that for the South Pacific region there is no significant trend in cyclone frequency nor intensity.

The most recent projections available for the region (PCCSP, 2011) are consistent with (Oouchi et al. 2006, Knutson et al. 2010) in projecting with moderate confidence that the numbers of tropical cyclones in the south-west Pacific Ocean basin (0- 40°S, 130°E- 170°E) will decline over the 21st century and that there is an indication in an increase in the number of the most severe cyclones.

Low-lying coral islands, such as those on atolls, are the most vulnerable to cyclone related impacts. These islands consist of unconsolidated heaps of coralline sands and gravel on top of reef foundations and are prone to overtopping by storm surge and wave action generated by cyclones. On mountainous volcanic islands, characterized by rugged topography and weathered clay soils, heavy cyclonic rainfall can result in landslides on hills and deposition of sediment in valley bottoms. Tropical cyclones usually have less impact on limestone islands, because these have no significant relief on which slope failures can occur and no surface drainage channels that can be flooded.

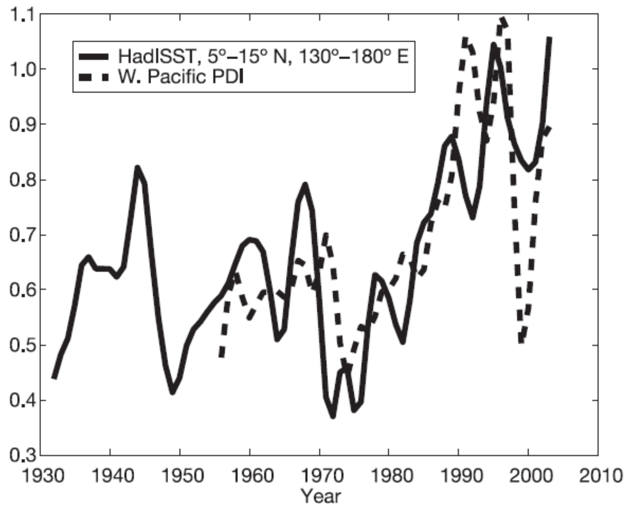


Figure 16 Annually accumulated Power Dissipation Index for the western North Pacific (dashed line), compared to July–November average SST (solid line) (Emanuel 2005).

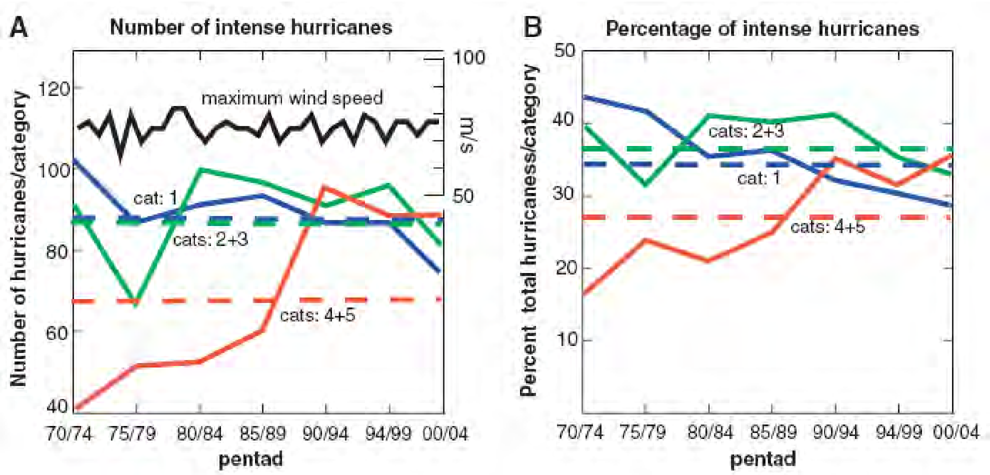


Figure 17 Intensity of hurricanes according to the Saffir-Simpson scale (categories 1 to 5). (A) The total number of category 1 storms (blue curve), the sum of categories 2 and 3 (green), and the sum of categories 4 and 5 (red) in 5-year periods. The bold curve is the maximum hurricane wind speed observed globally (measured in metres per second). The horizontal dashed lines show the 1970-2004 average numbers in each category. (B) Same as (A), except for the percent of the total number of hurricanes in each category calss. Dashed lines show average percentages in each category over the 1970-2004 period (Webster et al. 2005).

During the 1950-2004 period cyclones alone accounted for 76 % of the reported disaster events in the Pacific, accounting for almost 90 % of total direct costs and 79 % of fatalities (World Bank 2005). The majority of other natural disasters are accounted for by floods, droughts and storm surges (Lal et al. 2009b). Tropical cyclones already have damaging impacts on agriculture, infrastructural development and wider commerce. Tourism, which is an important source of income and foreign exchange for many islands, inevitably faces severe disruption after major cyclones. Human health is also affected by cyclone activity through human exposure to diseases and stress, both during the event and throughout the recovery period which can take years. Cyclones may also damage infrastructure, boats and the reef itself (Tompkins et al. 2005).

RAINFALL PATTERNS

Because convection and thunderstorms preferentially occur over warmer waters, the pattern of sea surface temperatures influences the distribution of rainfall (and tropical cyclones) in the tropics and the associated warming of the atmosphere through the release of latent heat when changing the water phase from vapour to liquid (Hay et al. 2003). The heating drives the large-scale monsoonal type circulations in the tropics, and consequently influences the wind patterns. As climate change is projected to lead to global changes in SST it may also lead to periods of very intense rainfall, leading to flash floods and landslides.

PCCSP (2011) presented a “most likely” future as well as a “largest change” future based on selected models. Under the IPCC A2 and A1B scenarios the “largest change” projected future change for rainfall in Solomon Islands was for a wetter climate; with an increase in annual rainfall by >5%. However the “most likely” climate future for Solomon Islands was for little change in annual and seasonal rainfall (-5% to 5%) by 2030 (PCCSP, 2011).

In Solomon Islands between 1961 and 1998 the number of rain days has decreased at all meteorological stations , with Honiara, Kira Kira and Munda showing significant decreases (Manton et al. 2001). However at Honiara, the proportion of annual rainfall from extreme rainfall has increased significantly (Manton et al. 2001). If this trend continues longer drought periods in the dry season and more severe flood events in the rainy season may be expected. However in general the incidence of drought is expected to decrease over the 21st century (PCCSP, 2011). The inconsistency between the projected increase in annual rainfall (“largest change”) and the recent declining trend observed from Honiara may be related to local factors not captured by the models, or the fact that the projections presented by PCCSP (2011) represent an average over a very large geographic region, and so are not necessarily universally applicable to specific sites.

Changes in rainfall patterns and extreme events, such as floods and drought will affect subsistence and commercial agriculture and food security as well as physical infrastructure important to the market chain. Floods also affect the incidence of water- and vector-borne diseases and human health. Rainfall in general, plays an important role in spreading or reducing malaria cases. While cases of malaria increase during the rainy season, higher rainfall in La Niña years and lower rainfall in El Niño years increases and reduces malaria transmission respectively. Climate change may increase malaria incidence (Hay et al. 2003, Abawi et al. 2009), however, seasonal variability due to ENSO has been recommended as the focus of control programs in the Solomon Islands (Abawi et al. 2009).

Islands with very limited water supplies are already vulnerable to periods of droughts. They are likely to become increasingly vulnerable to the impacts of climate change on water supplies. Moreover, fresh water flooding will affect sea water quality as well as sea-grass and coral health and survival (Tompkins et al. 2005). Across the Pacific region, atoll dwellers speak of having to move their houses away from the ocean because of coastal erosion; of having to change cropping patterns because of saltwater intrusion; of changes in wind, rainfall, and ocean currents (Tompkins et al. 2005).

El Niño southern oscillation (ENSO)

El Niño weather patterns have become more frequent since 1977, bringing an increase in rainfall in the Northeast Pacific and a decrease in rainfall in the Southwest. Each El Niño event in the past has resulted in water shortages and drought in some parts of the Pacific (e.g., Papua New Guinea, the Republic of the Marshall Islands, Samoa, Fiji, Tonga and Kiribati), and increased precipitation and flooding in others (e.g. Fiji, Solomon Islands). In El Niño years ocean conditions also change and the western Pacific warm pool expands generally eastwards in the tropical waters. In northern equatorial waters on the other hand, warm pools contract slightly westwards. In La Niña years the warm pool is largely constrained to the western tropical Pacific, while expanding slightly to the east in northern equatorial waters. These oceanic patterns influence primary and secondary productivity in the Pacific and define core habitats of the marine flora and fauna species, including tuna.

Interannual rainfall over Solomon Islands is strongly influenced by ENSO in the current climate. There have been predictions that with global warming, El Niño events are expected to become more frequent (Lal et al. 2009b); accordingly the variations expected to be brought about by climate change (including changes in rainfall and more extreme weather conditions). However caution is urged in interpreting such predictions as more recently, climate projections from PCCSP (2011) recommended assuming no change in climate variability associated with ENSO due to a lack of consensus in ENSO projections.

The frequency of extreme temperatures (e.g. heatwaves)

Globally, extreme temperatures have been shown to be increasing since suitable records have been available in the 1960's. Since 1960 the number of hot days (frequency of days when temperature is above the 1961-1990 mean 99th percentile) has increased throughout the southeast Asia region (Figure 18,Figure 19 (Manton et al. 2001, Griffiths et al. 2005)). 'Degree Heat Weeks' (DHW) has become a key operational metric for reef monitoring and management. In Solomon islands DHW is projected to be between 0-5 until 2040 (Figure 7, Leisz 2009).

The intensity and frequency of days of extreme heat are also reported as the "1-in-20 year hot day". According to the PCCSP (2011) study, the majority of models simulate an increase of about 1°C in the temperature of the 1-in-20 year hot day under IPCC B1 emissions scenario by 2055; and an increase of over 2.5°C by 2090 under IPCC A2 emissions scenario. The increase in intensity of extreme heat is consistent with the physical effects of rising greenhouse gas concentrations (PSSCP, 2011).

Increased temperatures and increased humidity due to increased rainfall can raise the incidence of heat strokes, asthma and other respired illnesses, affecting human productivity.

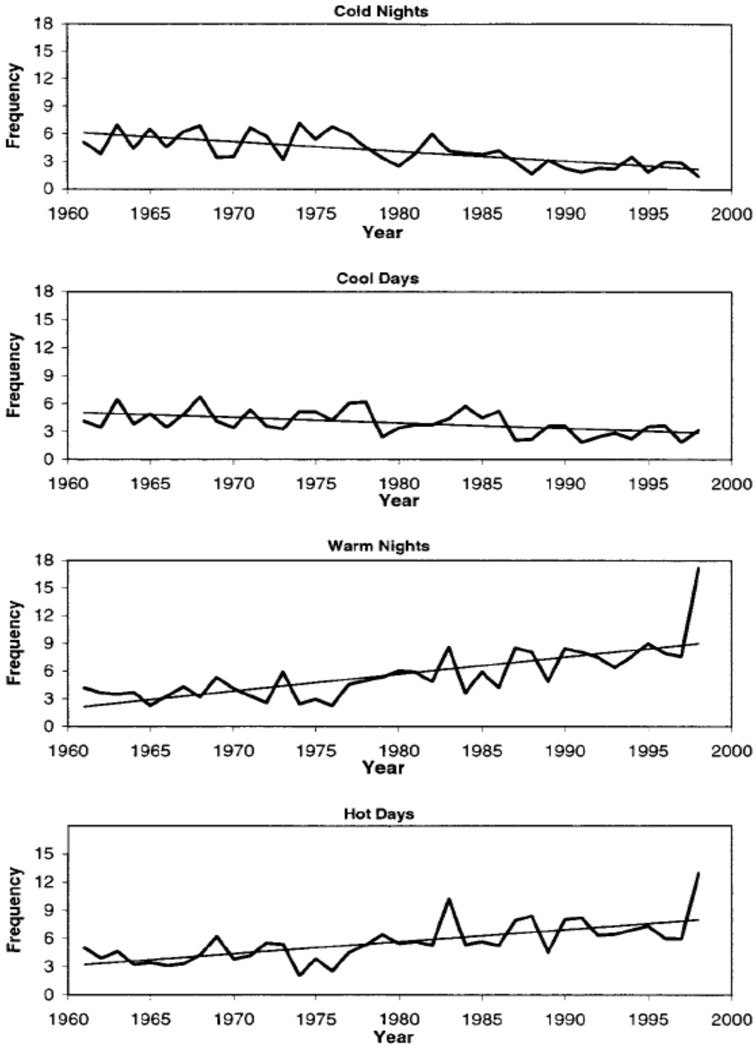


Figure 18 Time-series of the south east asia regional averages of the frequency of hot and cold days and nights. The thin line is a trend-line computed by linear regression (Manton et al., 2001).

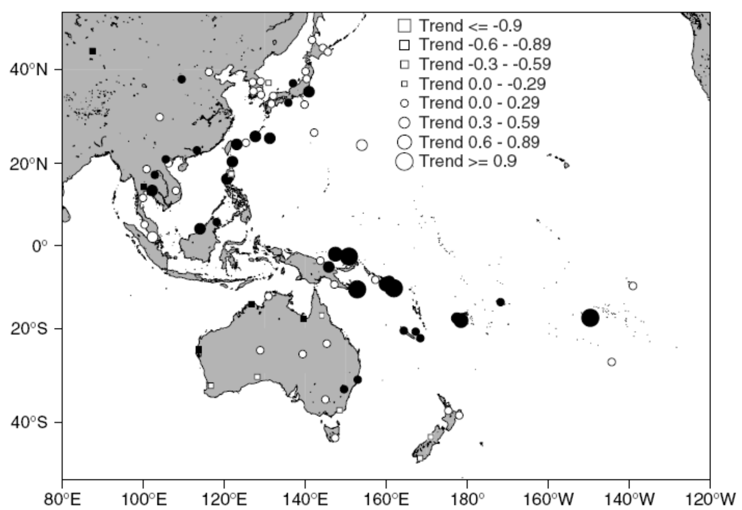


Figure 19 Trends in hot days 1961–2003. Trends as indicated in the scale (days per year). Trends ranged between −0.2 days per year and +2.2 days per year and the significance of the trends is indicated by the size of the black (p ≤ 0.05) and white (p > 0.05) symbols (Griffiths et al., 2005).

COMBINED EFFECTS – CORAL REEFS STRESS AS AN EXAMPLE

The different stresses manifested and predicted by climate change may interact and cause greater stresses on ecosystems than if operating independently. As an example, Guinotte et al. (2003) combined projected SST with aragonite saturation levels to produce a map depicting the predicted stress on coral reefs. Solomon Islands are projected to be in the high stress zone for this combination (Figure 17).

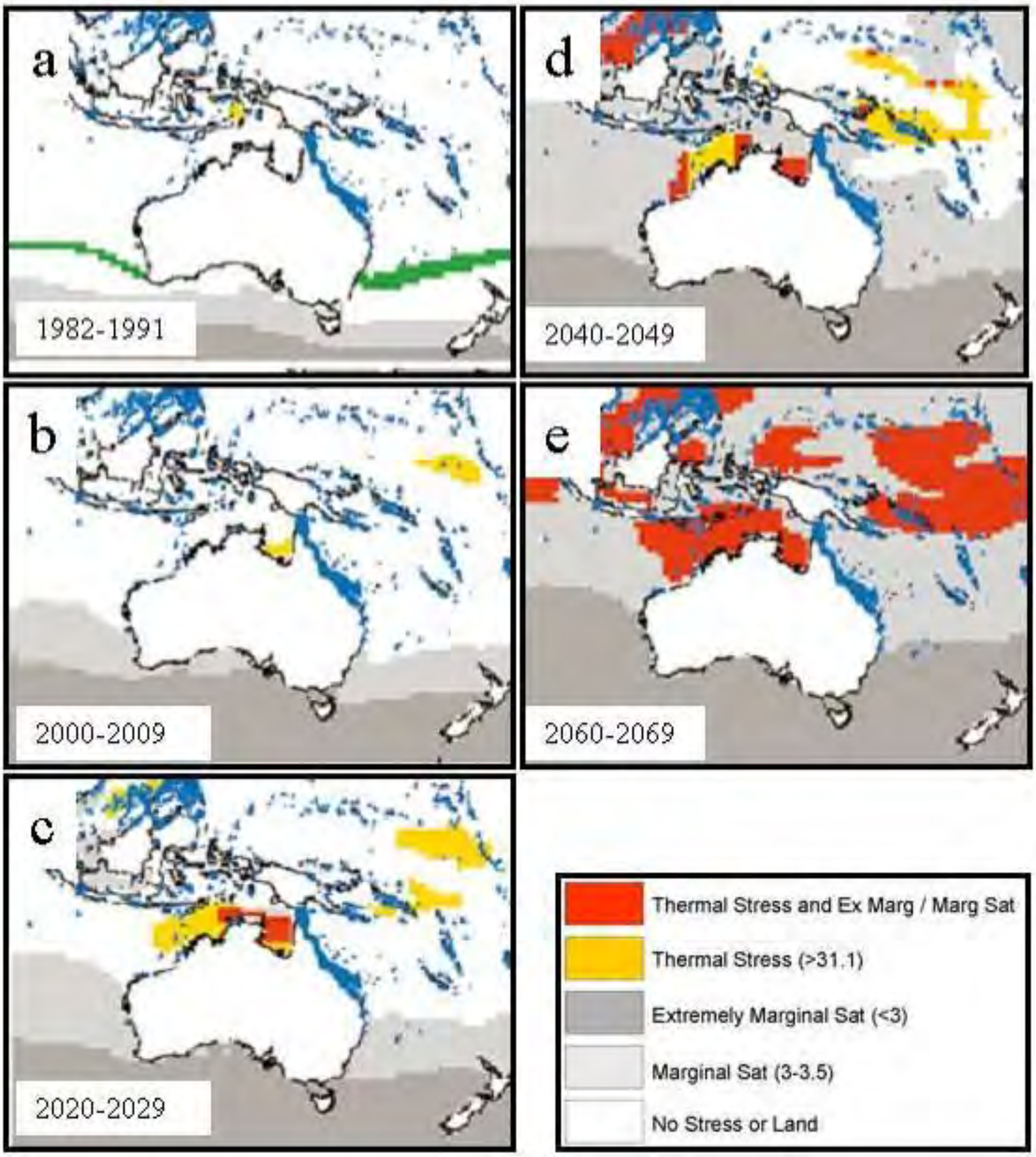


Figure 20 Projections of thermal stress, CaCO3 saturation state, and combined effects of both by decade through 2069 (Guinotte et al., 2003). In regards to thermal stress, it should be noted that these projections have the underlying assumption that upper thermal threshold for coral bleaching are fixed values; this is not the case however, since temperatures that induce coral bleaching range up to nearly 10° C depending on region.

ROVIANA AND VONAVONA LAGOONS

The Roviana and Vonavona lagoons are located adjacent to the island of New Georgia in the Western province of Solomon Islands (Figure 21). At the time of writing, pertinent climate-change related data such as SST, sea levels and pH for the region are at this stage were only able to be based on broad scale predictions for the region as described above. It was possible however to focus in on the region for some parameters using measured climate related data from the Munda weather station in Roviana lagoon.

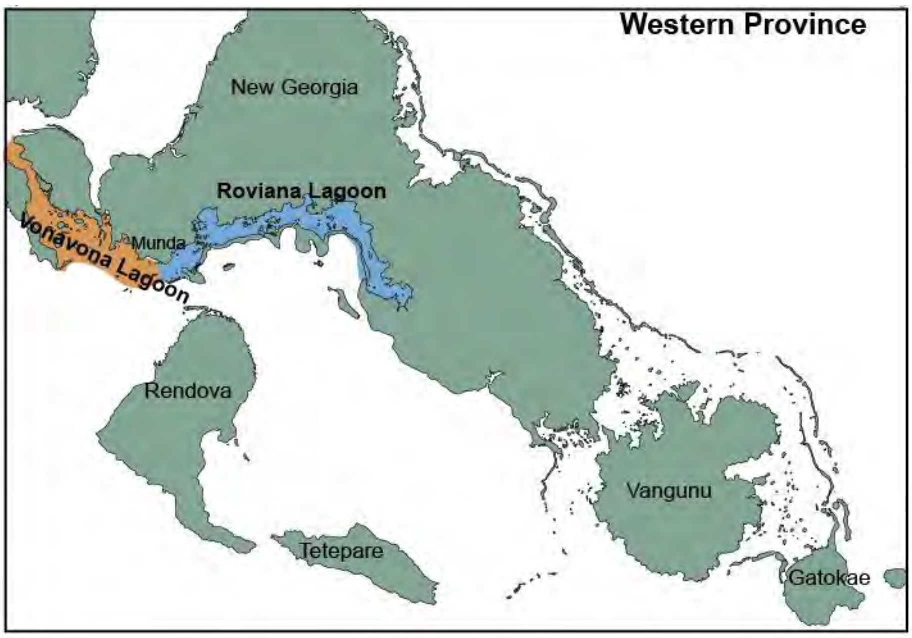


Figure 21 Map showing the location of the Roviana and Vonavona lagoons and the location of the weather station in the town of Munda.

The Munda weather station has been operating since 1962 and records temperature, precipitation and wind speed and direction. When daily minimum and maximum temperatures supplied by MECDM are plotted there is a trend for both to be increasing over time (data not shown). The data suggests that maximum air temperatures have increased over the last 50 years by about 0.4 ^{o}C on average and the minimum temperature by about 0.7 ^{o}C on average. Precipitation levels (mm rain) at Munda show no trend to increase or decrease and fluctuate around a mean of 3565 mm (MECDM data). Note however that between 1961 and 1998 the number of actual rain days has decreased at all stations in the Solomon Islands, with Honiara, Kira Kira and Munda having significant decreases (Manton et al. 2001).

Past cyclone activity for the region has been generated for two locations using (Bureau of Meteorology Australia and Australian government 2010) (Table 3) and is consistent with the Western province in general (Table 2 above).

Table 3 Cyclone tracks frequency in the vicinity of the project sites (1969-2006).

	Latitude	Longitude	Number of cyclones within			
site	(°S)	(°E)	50 km	100 km	200 km	400 km
Vonavona lagoon	8.30	157.31	0	1	8	25
Roviana lagoon	8.33	157.17	0	1	8	25

SUMMARY

The best projections available for the Roviana and Vonavona region at the time of writing were those that can be extrapolated from regional models described above and the most recent are those published by PCCSP in 2011. Specific site models have not been utilized for the Roviana and Vonavona region, although they would be able to be generated through SolCLIM (a customized version of the climate change impact and adaptation assessment software tool SimCLIM) or a similar tool. SolCLIM software has previously been purchased and used by MECDM but the software is currently out of date. SolCLIM has the potential to generate digital elevation models for each province, a full suite of IPCC Fourth Assessment Report Global Circulation Models, plus SimCLIM impact models including extreme event analysis, sea level rise scenario generator and site and spatial precipitation and temperature scenarios. However, the models will only be as good as the scale of data that is available. Table 4 summarises the available data presented in this report and identifies missing data. Most current trends and projected changes are available only on a global or regional scale. These usually consider oceanic conditions and are not very accurate for coastal and lagoonal areas. There is very limited data available at a provincial level or smaller scale.

Table 4 Data available for exposure characters in three geographic scales, global, Solomon Islands area and within provinces in 2010. C – current trends; P – projections; na – non available; Superscript numbers depict sources as follows: 1 - Griffiths et al. 2005; 2 - Hoegh-Guldberg & Bruno 2010; 3 - Leisz 2009; 4 – SIG MECDM weather stations data; 5 - Coles 2008; 6 - Leisz et al. 2009; 7 - Bureau of Meteorology Australia & Australian government 2010; 8 - Emanuel 2005; 9 - Lal et al. 2009; 10 - Manton et al. 2001; 11- Pacific country report on sea level & climate: their present state, Solomon Islands, 2009; http://www.bom.gov.au/pacificsealevel/picreports.shtml; 12- PCCSP, 2011.

Character	Global or pacific data	SI area data	Munda and surrounding area
Air temp	C[1,9,10], P[6,9]	C[4], P[3], P[12]	MECDM
Sea surface temp	C[2], P[5,6]	C[3], P[3]	na
Acidity	C[2], P[3,5,6]	P[3], P[12]	na
Sea level rise	C[2,6,], P[6]	C[11]	na
Cyclone frequency	C[7]	C[7]	C[7]
Cyclone intensity	C[8]	Na	na
Storms frequency	na	Na	na
Precipitation	C[10], P[9]	C[3], P[3], P[12]	MECDM

SEA-LEVEL INUNDATION ASSESSMENT

INTRODUCTION

The risk of coastal inundation from climate change associated sea level rise is one of the more pressing concerns for coastal communities in the Pacific. Although low lying atolls are most vulnerable to sea level inundation, communities surrounding high volcanic islands are also likely to be impacted. In Roviana lagoon all communities are situated along the coastline, often in low lying areas or small lagoon islands with limited potential for movement in-land. Whilst individual families typically have ownership of higher elevation lands on the mainland relocation to these areas would not be possible at the whole community scale and hence would cause hamletisation or fracturing of the cohesive community unit that underpins life in the rural Solomon Islands.

In Roviana, the impacts of sea level rise are already being felt by some particularly vulnerable communities with houses already being inundated during spring high tides. This has led to a sense of uncertainty and in some cases fear for future sea level rise under climate change scenarios. Hence we identified an urgent requirement to provide some accurate advice to these communities on how or if they are likely to be impacted by sea level rise. Vulnerability to sea level rise is primarily determined by fine scale coastal topography.

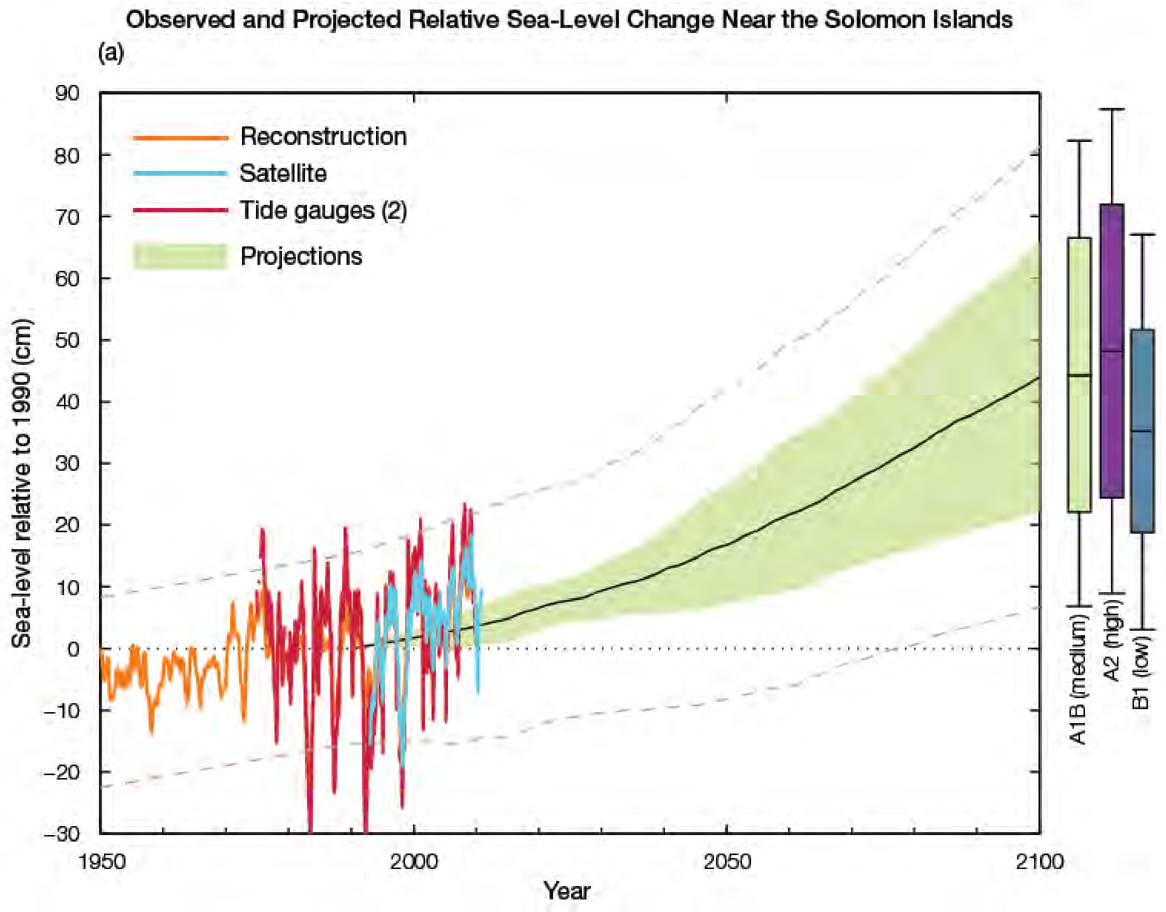


Figure 22 Sea level rise projections for Solomon Islands (PCCSP 2011)

Options for modelling sea level rise impacts on coastal communities

Shuttle Radar Topography Mission

There is freely available near-global coverage of elevation based on radar data collected by the Shuttle Radar Topography Mission (SRTM) in 2000. This data forms the basis for freely available Digital Elevation Model (DEM) and those in the Google Earth platform. There are a number of online tools that model coastal inundation from sea level rise based on SRTM topographic data e.g. http://flood.firetree.net/

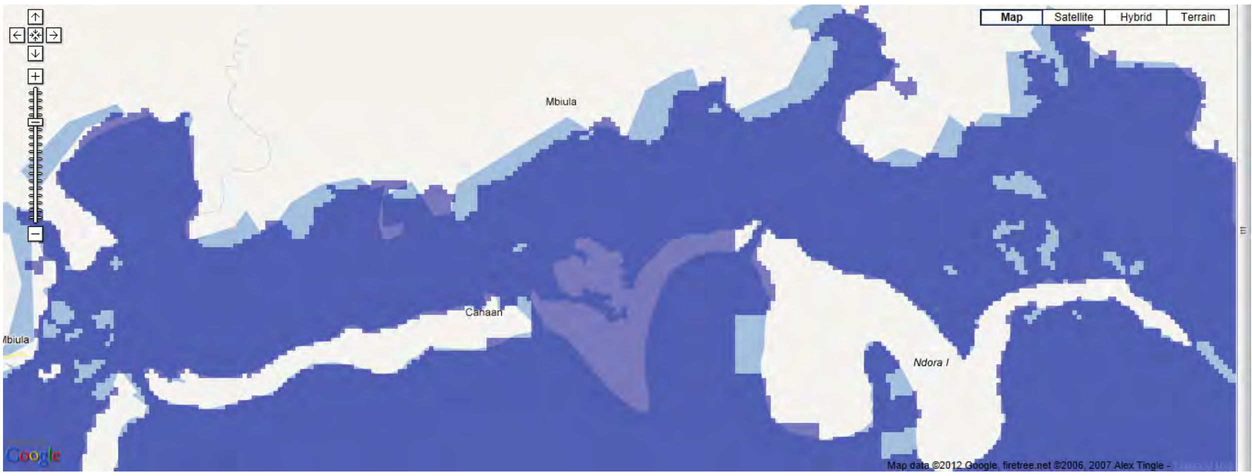


Figure 23 Example of modelled 1 m sea level rise in Roviana Lagoon from SRTM based inundation tool.

The major limitation of SRTM data based methods is its accuracy level. Vertical accuracy of the data is between 5 and 10m (Rodríguez et al. 2006) rendering it unsuitable for making assessments of sea level in the range of 20-100 cm. The grid size of SRTM data available globally is 90 x 90 m, effectively provide an overage elevation over this area. In some areas of extensive flat homogenous topography SRTM data has been successfully used to accurately map topography, however in areas of highly variable topography in the coastal environment (nearshore limestone cliffs up to 40m high) the averaging of elevation data over a 90x90 m grid renders the data useless for fine scale topographic assessments. Hence the online tools and software packages providing sea level inundation assessments based on SRTM data should be used with caution. As indicated in Figure 23 above, large areas of Roviana are predicted to be inundated by a 1 m rise using SRTM data including the large barrier island between Nusa Hope and Baraulu, which in fact has an elevation of 15-25 m.

LiDAR

LiDAR or Light Detection And Ranging is an airborne laser system that is able to accurately determine high resolution topography. Typically mounted on customised light aircraft, LiDAR has become the preferred method to gain the topographic information required to accurately map coastal topography and hence model sea level rise inundation. Spatial resolution of LiDAR data is very high with typically 50-100 data points per square metre. Although spatially there can be approximately 5 cm of error in the X and Y positioning of this data due to inherent GPS errors. Vertical resolution of LiDAR data is also very high with error ranges of 5-10 cm often reported. The negative feature of LiDAR derived sea level inundation models in the Pacific Island context is the expense of acquiring data for areas and the need for experienced GIS specialists to process and map the data. To collect LiDAR data for a typical rural community or small island in the pacific (~10 km2) costs $0.5-1 M AUD. The processing and mapping of the data can often take several months. Final products visualising predicated sea level inundation are both highly accurate and can cover a large area. Figure 24 shows an example inundation map developed by this project at a trial site on

North Stradbroke Island, Australia with yellow and brown shading indicating inundation under 0.5 m and 1.0 m sea level rise scenarios respectively.

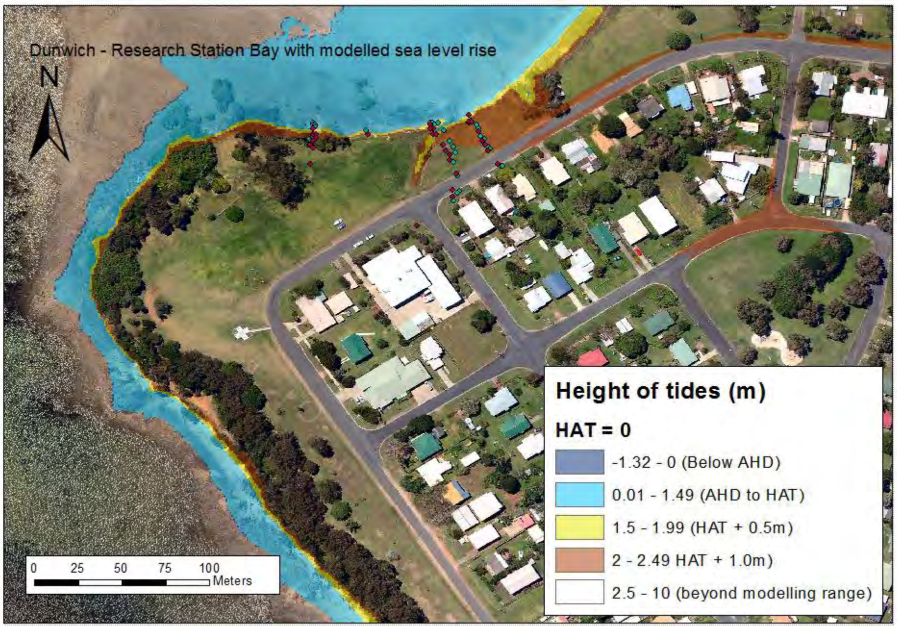


Figure 24 Inundation map of Dunwich, North Stradbroke island, Australia-based on LiDAR data

Manual Survey methods

Total Station

Digital Total Stations incorporate a laser range finder and electronic theodolite to accurately determine the distance and angle to a specific point. By taking a series of measurements, trigonometry can be used in computer post-processing (or on-board computers) to accurately determine elevation of a range of points. Both the field use and post processing of data requires a moderate level of training and experience.

Optical Level

Optical levels or transits provide a simple accurate means of surveying elevation across a range of points. The observer looks through the magnified view finder at an assistant holding a calibrated staff. By measuring the distance between the observer and the assistant and repeating the process across other survey points, an accurate profile can be obtained.

Laser Level

Laser levels are typically used in the construction industry for setting levels across the building site or slope/grade of an incline. A rotating laser is mounted on a tripod, providing a 360° level beam. A small laser detector mounted on a staff is used to detect the signal and indicate the point is level with other survey points. By moving the laser detector vertically on the staff the laser level can be utilised in a similar fashion to an optical level to determine elevation differences between a range of points.

Method comparison

A coastal profile from high tide to 1.25 m elevation at Dunwich, North Stradbroke Island was used to compare five methods of determining coastal elevation. LiDAR and SRTM data were acquired and processed using ARC GIS 10.0. A Topcon GTS 212 total station was used to determine elevation at ten survey points (See Figure 25) along this coastal profile. At each of these ten survey points a Leica Rugby 100LR laser and Leica optical level were also used to assess elevation.

Figure 25 Ten survey points along a coastal profile at Dunwich, North Stradbroke Island, Australia.

Table 5 Comparison of elevations from LiDAR, Total station, laser and optical levels for nine survey points on Nth Stradbroke Island. ***Note the 30 m transect was all within one 90x90 m SRTM grid and hence elevation data is constant.***

Survey Point	Elevation (m)				
	SRTM	LiDAR	Total Station	Laser Level	Optical level
0	2	0.31	0	0.01	0.04
1	2	0.68	0.66	0.69	0.7
2	2	0.76	0.72	0.73	0.73
3	2	0.76	0.78	0.78	0.77
4	2	0.79	0.79	0.8	0.8
5	2	0.85	0.85	0.86	0.86
6	2	1.02	1.08	1.09	1.09
7	2	0.91	0.91	0.92	0.92
8	2	1.17	1.12	1.12	1.12
9	2	1.23	1.22	1.25	1.25

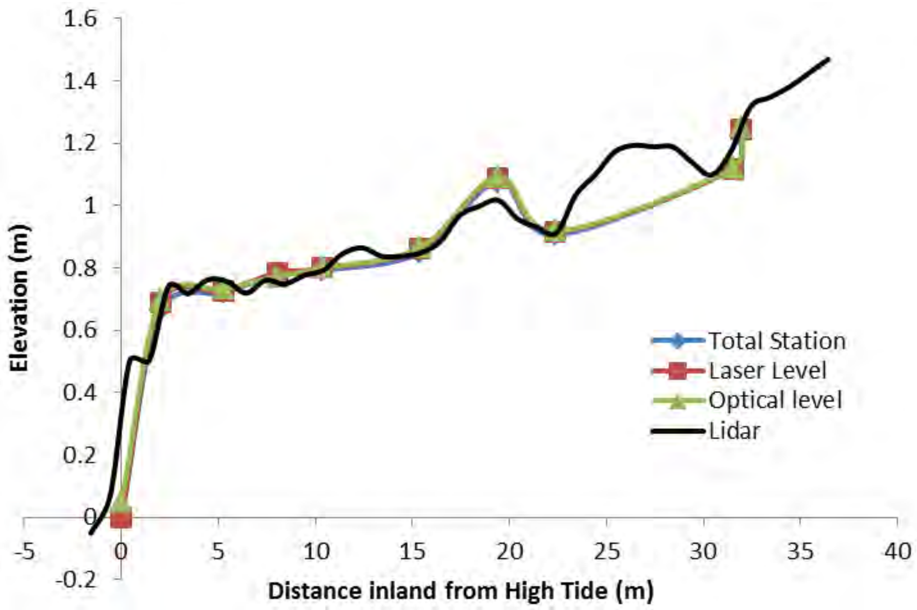


Figure 26 Comparison of elevation data from High tide to 1.2 m inland using LiDAR, Total Station, Laser and Optical level

SUMMARY OF METHODS FOR SEA LEVEL INUNDATION MODELLING

Table 6 Summary of pros/cons of various methods for sea level inundation surveys

	Instrumental vertical accuracy	**Cost**	**Technical skills**	**Time to acquire data**	**Applicability to rural pacific islands**
SRTM	5-10 m	Free	Very Low	Very Low	Low
LiDAR	5-10 cm	Very high	Very high	Low	Low
Total Station	<5 cm	Moderate	High	Moderate	Low
Laser Level	<5 cm	Low	Low	High	High
Optical Level	<5 cm	Very Low	Low	Very High	High

Based on these comparisons the combination of low cost, simplicity and accuracy of the optical and laser level surveys make them applicable to the rural pacific context.

MAPPING SEA LEVEL RISE INUNDATION IN ROVIANA

METHODS

A Leica Rugby 100LR rotating laser level was attached to an elevating tripod was used to survey coastal topography in Roviana lagoon. Through consultation with the Roviana Conservation Foundation and trial of various approaches, a standardised method was developed. This method focussed on mapping three contour lines of relevance to sea level rise rather than trying to determine the full coastal profile of an area. These three contour lines are:

- 0 m (estimated Highest Astronomical Tide (HAT))
- 0.5 m anticipated sea level rise over the next 50-100 years
- m possible sea level rise over the next 100+ years

Whilst there is a large amount of uncertainty surrounding projections of Sea level Rise, the general consensus when discussing this uncertainty with the Roviana community was people needed to plan for a realistic worse-case scenario. Hence the 0.5 m and 1.0 m contours were chosen.

Estimating HAT

The referencing of coastal topography surveys to a known datum or reference point is important to ensure accuracy and repeatability of surveys. Ideally these surveys would be referenced to highest astronomical tide (HAT) determined from surveying from known reference points or through tide gauge information. Unfortunately neither of these options are available in Roviana (and most rural areas of the Pacific). Hence traditional local knowledge was relied on to estimate HAT and to reference each survey to. At each survey site several local residents were consulted for the location of estimated HAT. This information was combined with observation of coastal profile features (such as location of sediment/rubble berm or terrestrial grasses. Once this estimated HAT mark was determined a white survey peg was driven into the ground to provide a reference point for the start of surveys.

Figure 27 Establishing estimated HAT and marking with survey peg

Setting up tripod and Laser level

The laser level and tripod were positioned approximately half-way between the HAT mark and expected 1m contour. The tripod was positioned within line of sight of the first HAT reference point and as much of the survey area as possible. The laser level height was typically 1.5 m - 2 m.

Figure 28 Tripod and laser level set up ready to survey

LASER DETECTOR

Three Leica digital Rod Eye Plus laser detectors were attached to either a 4m survey staff or a locally created staff with 1 cm increments ruled onto a 4m length of 25x 50 mm hardwood. Each of these laser detectors and staffs were allocated to a contour-either 0 m, 0.5 m or 1 m.

Figure 29 Laser detector attached to 4 m staff (left) and locally created staff (right)

Recording contours

Each of the three staffs were position on top of the first HAT survey peg and laser detectors moved vertically until level with the laser beam (as indicated by high pitched beep). The GPS position (using a Garmin 72H handheld GPS) of this first point would be recorded. The 0m contour staff and assistant would then proceed 5 m along the shoreline and position staff on the ground, moving it until the laser detector was in line with laser beam, the 0m contour team would then record the GPS position of this second 0 m point. The 0m team would then continue along the shoreline every 5-10m (depending on variability of the coastline) recording the 0 m contour, approximately every tenth survey point (or every 50-100m) would be marked with a survey peg.

The 0.5m team would lower their laser detector exactly 50 cm on the staff (after referencing it level with laser at first 0m survey mark) and move inland, moving the staff position until the laser detector indicated it was level with the laser beam. The 0.5m team would then record the GPS position of this point (the first 0.5m contour) and mark it with a survey peg. The 0.5m team would then move 5-10 m along the coastline and move the staff until the detector indicated it was level with laser beam, again marking with this second 0.5m point with the GPS. This process would continue marking the 0.5m contour every 5-10m along the coast, approximately every tenth survey point (or every 50-100m) would be marked with a survey peg.

The 1 m team would lower their laser detector exactly 100 cm on the staff (after referencing it level with laser at first 0m survey mark) and move inland, moving the staff position until the laser detector indicated it was level with the laser beam. The 1m team would then record the GPS position of this point (the first 1m contour) and mark it with a survey peg. The 1m team would then move 5-10 m along the coastline and move the staff until the detector indicated it was level with laser beam, again marking with this second 1m point with the GPS. This process would continue marking the 1m contour every 5-10m along the coast, approximately every tenth survey point (or every 50-100m) would be marked with a survey peg.

Figure 30 Marking contours with survey peg (left) and GPS (right)

Moving laser level within a site

Once the three teams marking contours can no longer mark any more points due to interference between trees, terrain or buildings and the laser level, the laser level must be moved down the coastline. The point chosen to move the laser level to must be within line of sight (laser range) of at least one of the existing survey points (preferably at 0 m) and provide line of sight to the new section of the coastline to be surveyed. Prior to moving the laser a reference point must be chosen (preferably at 0m) and marked by the staff of the relevant (0, 0.5 or 1m) survey team. The laser level is then re-located to the new site within view of this reference point. Assuming the reference point is at the 0 m contour then all three teams must adjust the vertical height of their laser detectors until level with the new location of the laser level. Then repeat process as described above (0.5 m team lower their detector 50 cm, 1 m team lower their detector 100 cm) to continue survey the new section of coastline.

Mapping

After the complete coastline has been surveyed and GPS positions recorded for 0, 0.5 and 1 m contours every 5-10m across the survey area, a map can be developed. Firstly 0 m contour marks are imported into the Google Earth platform. A polygon is then drawn around these points. The area of this polygon can be calculated using Google Earth Pro or the freely available GEPath software. 0.5m contour points are then imported and a polygon drawn and area calculated. Lastly the 1 m contour points are imported and a polygon drawn and area calculated. The differences between the areas of these polygons indicates area of inundation under the 05m or 1m sea level rise scenario. It should be noted that whilst the elevations measured using this method are accurate to 10-20mm, due to inherent 3-5 m error in handheld GPS units the maps produced have a potential 3-5m positional inaccuracy. Hence the actual ground based surveys and positioning of the survey pegs are what should be relied upon by communities in making sea level rise adaptation decisions.

Survey results

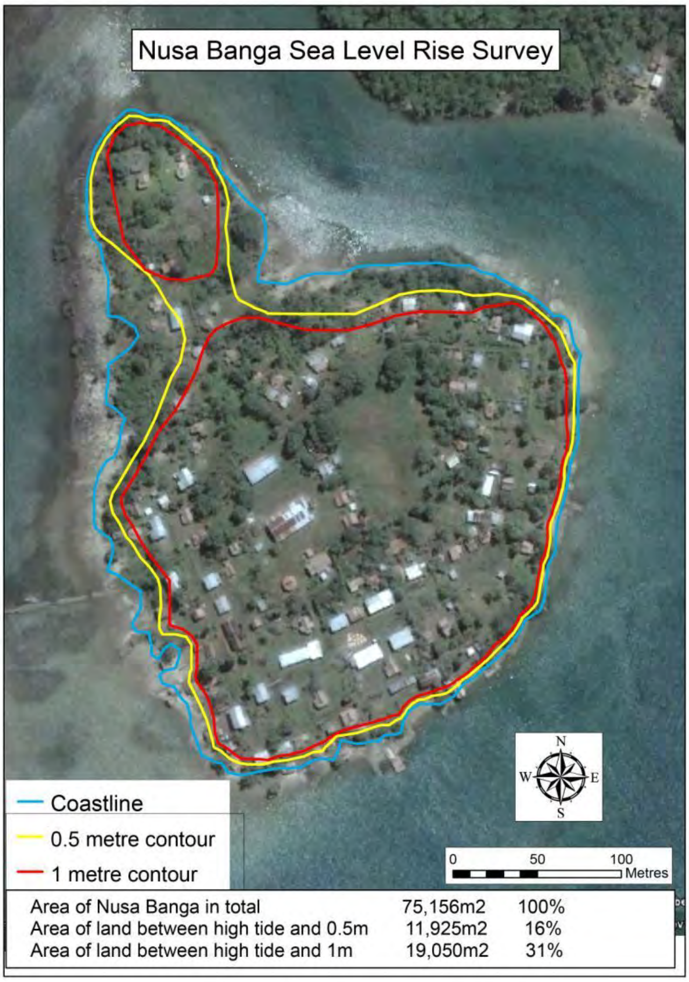
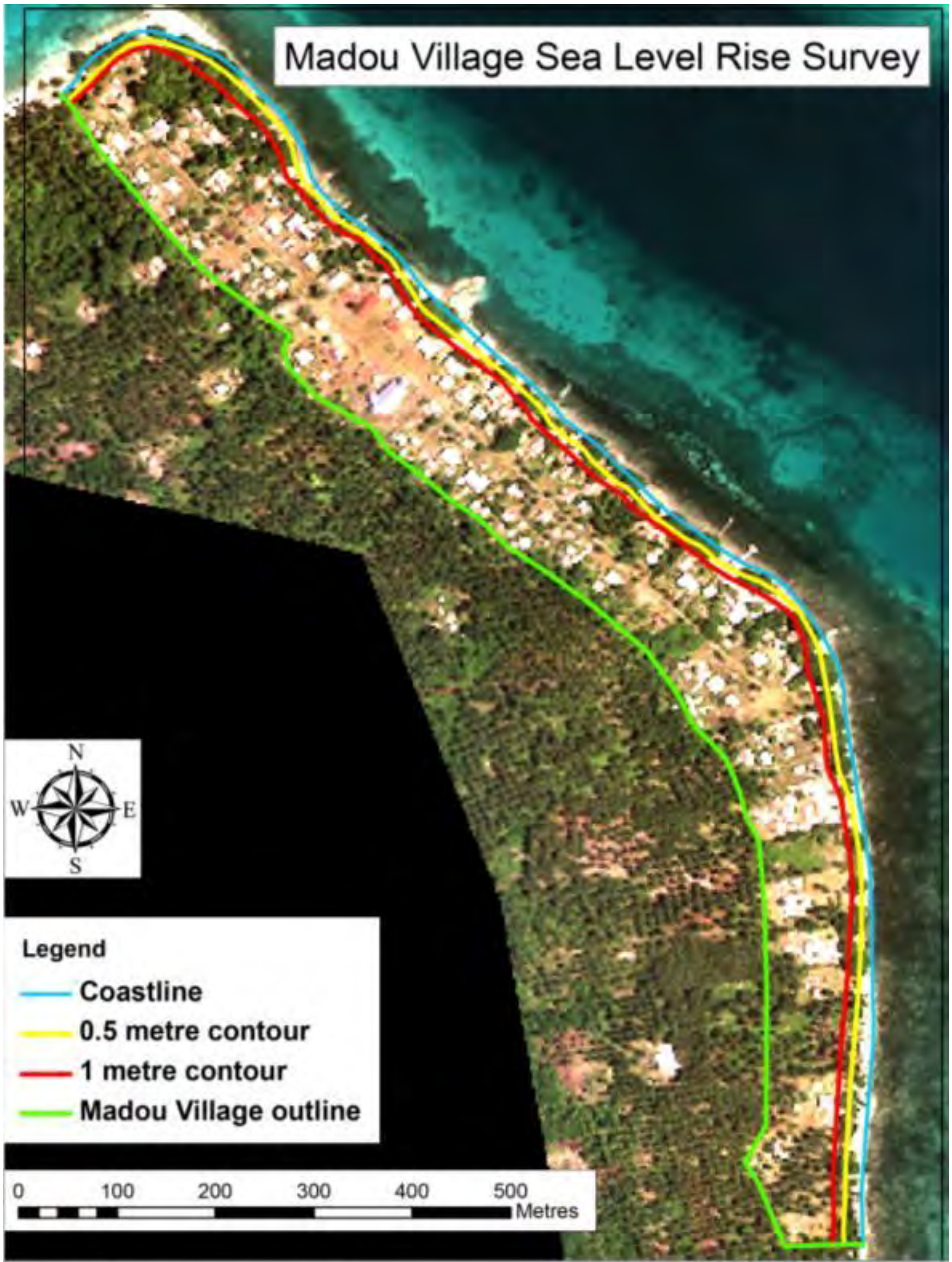


Figure 31 Sea level rise inundation map for Nusa Banga



Area of Madou village in total	148,396 m2	100%
Area of land between high tide and 0.5m contour	15,033 m2	10%
Area of land between high tide and 1.0m contour	27595 m2	19%

Figure 32 Sea level rise inundation map for Madou

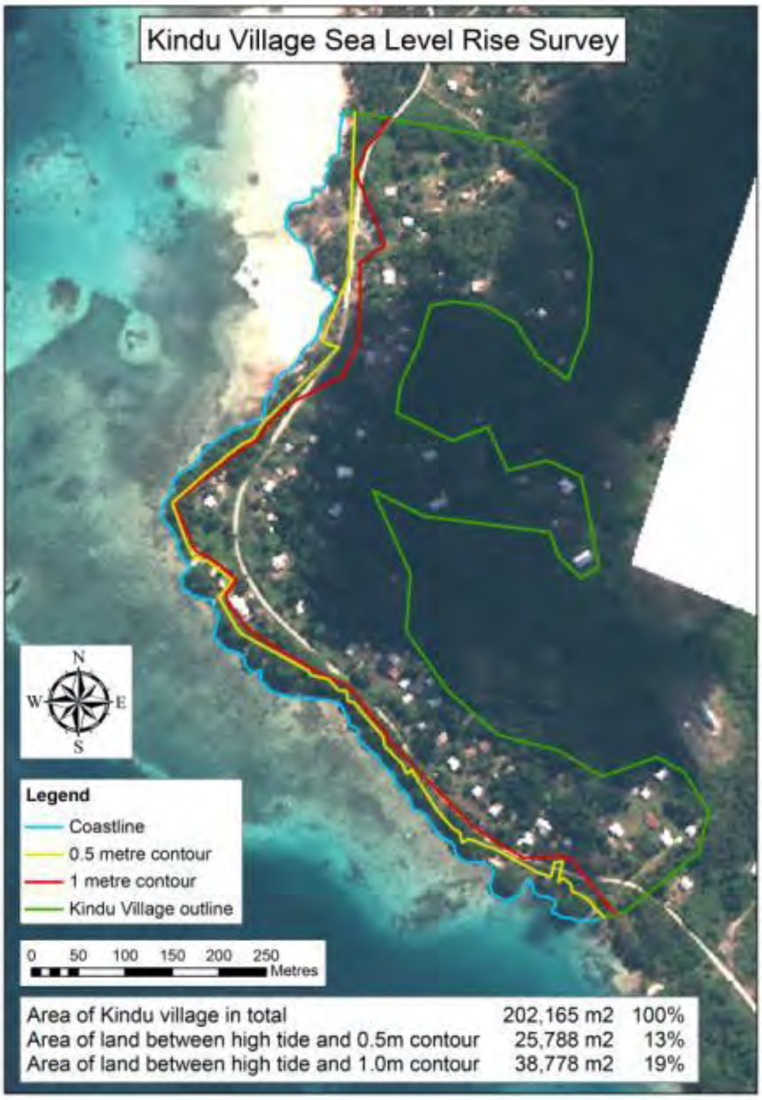


Figure 33 Sea level rise inundation map for Kindu

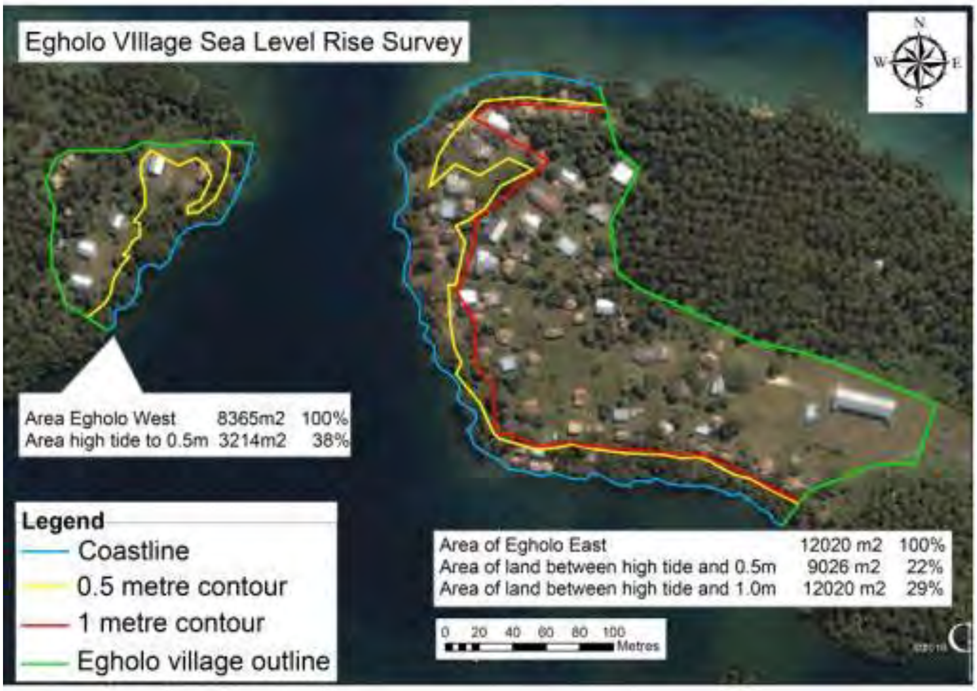


Figure 34 Sea level rise inundation map for Egholo

Figure 35 Sea level rise inundation map for Nusa Hope

These results can be used as an indicator of Sea level rise vulnerability of each village. Of the villages surveyed Nusa Hope is most vulnerable to sea level rise with a projected 52% loss of village area under a 0.5m scenario and 61% loss under 1 m scenario. Madou is the least vulnerable community to sea level rise with 10% and 19% loss under 0.5 m and 1 m sea level rise scenarios.

TRAINING CONDUCTED

The Roviana Conservation Foundation project manager and three zone co-ordinators were trained in the use of a laser level for coastal inundation mapping. Following this training the method was incorporated into village awareness sessions, whereby general climate change awareness and information was discussed with the community in the evening and the following day interested community members would participate in surveying 0, 0.5 and 1m contours using the laser level. Using these methods RCF staff mapped five villages independently using skills learnt during the training sessions.

Figure 36 Training RCF zone co-ordinators in the use of laser level survey equipment

CHAPTER 3

MARINE HABITAT VULNERABILITY

Simon Albert

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KEY MESSAGES

- The majority of marine protected areas are not reducing coral bleaching and disease impacts
- Nusa Hope MPA, the most well enforced reserve, has significantly lower prevalence of coral bleaching and disease than surrounding reefs
- Higher prevalence of coral disease on offshore reefs
- Lower prevalence of disease in lagoonal areas due to more resilient species present
- Mild coral bleaching event occurring in Roviana during 2011
- Higher prevalence of coral bleaching on offshore reefs
- Lower prevalence of bleaching in lagoonal areas due to resilience to temperature fluctuations (exposure to high natural variability)
- High diversity of marine habitats in Roviana quantified by high resolution remote sensing
- 920 ha of coral reefs
- 1495 ha of seagrass
- More than 5000 ha of sparse seagrass and corals amongst sediment, rubble, rocks and algae
- Further management of herbivore populations required to maintain coral reef health and hence resilience
- New marine reserves incorporating seagrass and mangrove ecosystems should be encouraged
- Lagoon passages are particularly important habitats to manage well due to inherent resilience to temperature fluctuations, importance as spawning ground, high connectivity and productivity.

HABITAT MAPPING

OVERVIEW

As part of the PASAP project: Building social and ecological resilience to climate change in Roviana, Solomon Islands; Reef Area, Reef Type, Geomorphic, and Benthic Community coral reef maps were created for Vonavona and Roviana Lagoon, Western Province, Solomon Island. This section will explain how the coral reef maps at the four hierarchical spatial scales were created using object based satellite image analysis.

To create the habitat maps six high spatial resolution Quickbird satellite imagery were acquired for the period 2006-2010. To calibrate and validate the imagery, field knowledge and benthic data was gathered in 2011. The acquired satellite imagery was radiometric, atmospheric, sun glint corrected and integrated into a mosaic. Benthic community categories were assigned to individual georeferenced benthic photos that were collected along a series of transects distributed through the study area. Hierarchical mapping at reef type, geomorphic and benthic community scale maps, was completed using object based image segmentation and semi-automated labelling through membership rules using gained field experience and benthic photo data for calibration and validation.

The resulting maps are composed of a variety of categories for each scale: Reef Area: Land, Deep Water, Lagoon Water and Shallow Reef; Reef Type – Lagoon, Barrier and Fringing Reef; Geomorphic: Slope, Crest, Pass, Flat, and Lagoon; Benthic Community, 23 categories that are combination of cover types: Algae, Seagrass, Coral, Rock, Rubble and Sand. The majority of field data was used to for the validation process, which resulted in 82% Overall accuracy for the geomorphic zone and 65% overall accuracy for the benthic community map.

The classified area of the image mosaic covering the study area extended 605 km^2, this included: land (170 km^2), deep water (39 km^2), lagoon water (170 km^2), cloud (19 km^2), and shallow reef (173 km^2). Within the shallow reef there were 19 benthic community categories that were predominantly: sediment (108 km^2), rubble (29 km^2), rock (10 km^2), seagrass (15 km^2), coral (9 km^2), and algae (2 km^2).

INTRODUCTION

For monitoring, modelling and management of complex environments, habitat maps at geomorphic and benthic community spatial scales and large spatial extent are needed (Green et al. 2000, Mumby et al. 2004b, Andréfouët 2008). High spatial resolution satellite imagery, with pixels < 5 m, integrated with field survey data can provide these maps through pixel (Andréfouët et al. 2003) or object-based image analysis (Benfield et al. 2007, Roelfsema et al. 2010, Phinn et al. 2012).

As coral reef systems can extend beyond the scene of a high spatial resolution image, they often require a mosaic of various images. The mosaics are generally not seamless as each image was acquired under unique atmospheric and environmental (e.g. tidal range, water clarity) conditions. This is especially challenging for pixel based approaches as these mainly rely on the reflectance values of the individual pixel.

Object based analysis mapping approaches on the other hand, incorporates in addition to the pixel reflectance values, the texture, location and biophysical characteristics of groups of pixels (objects)(Blaschke 2010). This object rather than pixel based approach provides more options to differentiate mapping categories and to create habitat maps of large and complex coral reef systems (including seagrass and sediment), therefore these techniques were utilised in this project.

This report will explain the techniques applied and present the results from the application of object based analysis for coral reef habitat mapping at geomorphic and benthic community spatial scales for Roviana and Vonovona Lagoon, Western Province in Solomon Islands.

METHODS

OVERVIEW AND STUDY SITE

The object based image analysis approach that was applied was based on previously developed and published approaches for single reefs: Heron Reef on the Great Barrier Reef in Australia, Navakavu Reef in Fiji and Ngdarack Reef in Palau [6], and for larger reefs in, Bikini Atoll, Marshall Islands, Kadavu and Kubulau in Fiji (Knudby et al. 2010, Roelfsema et al. 2010, Phinn et al. 2012). The lessons learned from these studies were implemented for the reefs covered in this study site (Figure 37).

The methods will first describe the collection and analysis of the field data acquired in January 2011 to result in information on the benthic community composition. This will be followed with descriptions of image acquisitioning and pre-processing of the cloud free and least sun glinted satellite imagery selected from an existing image archive for period 2006-2010. After the field and image data processing steps, the classification steps are explained with the development of the hierarchical classification structure. The classification structure, field data and knowledge, and image data are then used to develop the object based image classification to create four levels of classification: 1) Reef, 2) Reef Type, 3) Geomorphic and 4) Benthic Community. After the classification process the final step is the validation that focuses on geomorphic and benthic community classes.

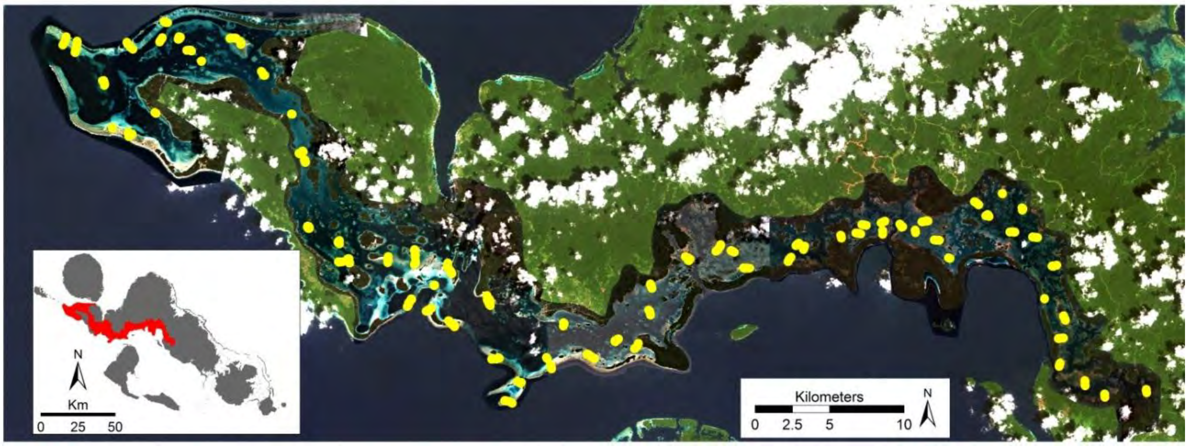


Figure 37: Mosaic of Quickbird Satellite imagery projected on a Landsat Imagery with field sites projected in yellow for Roviana and Vonavona, Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands

Field Data Collection and Analysis

Benthic cover data was acquired using a georeferenced photo transect method (Roelfsema and Phinn 2010) for 74 transects throughout the study area (Figure 37).

Towing a surface float GPS that logged its position every five seconds and using a standard digital camera in an underwater housing, a snorkeler/diver swam over the bottom taking photos of the benthos every 2 - 4 m, approximating the size of one pixel in the high-resolution satellite data (Figure 38). At a constant height of 0.5 m above the benthos, the camera provided a footprint of approximately 1 m x 1 m. The snorkeler/diver would occasionally take overview photos to aid in subsequent interpretation.

Figure 37 presents the location of the photo transects. In order to ensure representative coverage over the major habitat types, photo transect locations, direction and length had been selected prior to surveys by visual assessment of the spatial pattern of benthic structures evident in each satellite image covering the study area, following an approach applied in previous studies (Andréfouët and Guzman 2005, Roelfsema and Phinn 2010).

Figure 38: Conceptual diagram of georeferenced photo transects, where a snorkeler is taking photos of benthos at regular intervals while a GPS is tracking its position at the surface.

A Solomon islander was trained in computer based photo analysis software to process each of the field images collected. Each of the 9378 photos were manually assigned with a benthic community cover category using Coral Point Count Excel® software (Kohler and Gill 2006). Using a hierarchical benthic cover scheme containing 4 first-level categories (Coral, Algae, Seagrass, Non-living) and 30 second-level categories (Table 7) that was derived from (Knudby et al. 2010).

The categories in Knudby et al 2010, are similar to those used in previous image-based coral reef mapping (English et al. 1997, Mumby and Harborne 1999, Hill and Wilkinson 2004, Roelfsema and Phinn 2010). Each photo was linked to its geographic coordinates through time synchronization of the GPS and camera using the GPS-Photo Link software. This allowed the photos, the corresponding benthic composition data and benthic mapping category to be viewed at their position in the study area through a GIS interface.

Table 7 Hierarchical scheme used for benthic classification of the photo transect data.

First Level	Description	Second Level	Description
Coral (C)	>10% coral cover	Hard coral dominant	>70% Coral
		Hard coral and Macroalgae	>10% Macroalgae
		Hard coral and seagrass	>10% Seagrass
		Hard coral and sand	>10% Sand
		Hard coral and rubble	>10% Rubble
		Hard coral and reef matrix	>10% Reef Matrix
		Hard coral and less soft coral	>10% Soft Coral
		Hard coral live and dead	>10% Dead Coral
Soft Coral (SC)	>10% soft coral cover	Soft coral dominant	>70% Soft Coral
		Soft coral and macroalgae	>10% Macroalgae
		Soft coral and seagrass	>10% Seagrass
		Soft coral and sand	>10% Sand
		Soft coral and rubble	>10% Rubble
		Soft coral and reef matrix	>10% Reef Matrix
		Soft coral and less hard coral	>10% Hard Coral
Macro algae (MA)	<10% live coral cover, macroalgal cover >10% and dominant over seagrass	Macroalgae dominant	>70% Macroalgae
		Macroalgae and Seagrass	>10% Seagrass
		Macroalgae and Sand	>10% Sand
		Macroalgae and Rubble	>10% Rubble
		Macroalgae and Reef Matrix	>10% Reef Matrix
		Macroalgae and dead coral	>10% dead Coral
Seagrass (SG)	<10% live coral cover, seagrass cover >10% and dominant over macroalgae	Seagrass dominant	>70% Seagrass
		Seagrass and sand	>10% Sand
		Seagrass and rubble	>10% Rubble
Non-Living Substratum (BS)	<10% live coral cover, <10% algal cover, <10% seagrass cover, >70% bare substratum	Sand dominant	>70% Sand
		Rubble dominant	>70% Rubble
		Reef matrix dominant	>70% Reef Matrix
		Mud/silt dominant	>70% Mud/Silt
		Sand/rubble dominant	>70% Sand/Rubble
		Dead coral dominant	>70% Dead Coral

Image Acquisitioning and Pre-Processing

Six archived high spatial resolution Quickbird (2.4 m pixels) were acquired, dates were: 17 March 2005, 31 May 2006, 16 Sept 2006, 15 June 2008, 27th October 2008 and 19th February 2010. As the satellite imagery was captured at various dates over the period of 2006-2010, each image had specific environmental parameters (e.g. tides, wind, clouds and water clarity). The satellite image data sets were corrected for radiometric and atmospheric distortions to at-surface reflectance as in (Phinn et al. 2012). Geometric corrections were not conducted due to limited overlap between satellite imagery and lack of adequate ground control points. Mosaics of the corrected satellite imagery were created for the whole study site. The

17 March 2005, 16 Sept 2006 and 15 June 2008 images were corrected for sun-glint using existing approaches (Hedley et al. 2005).

Hierarchical Classification Structure

The mapping was based on a four level hierarchical classification structure which is similar to those used in other studies (Knudby et al. 2010, Roelfsema et al. 2010). These four hierarchical spatial map scales in order of increasing detail were: 1) reef; 2) reef type; 3), geomorphic zone, and 4) benthic community. Figure 39 shows an example for hierarchical scheme for the Barrier Reef only, the other reef types, Fringing and Lagoon Reef, would follow similar scheme with a variation in some of the underlying categories.

All scales contained the category, deep water, land, cloud/shade, Deep or turbid lagoon water, the reef scale map also contained the category reef. The reef type scale contained: fringing, barrier and lagoon reef; and the geomorphic scale map contained the categories: slope, crest, pass, flat and lagoon reef.

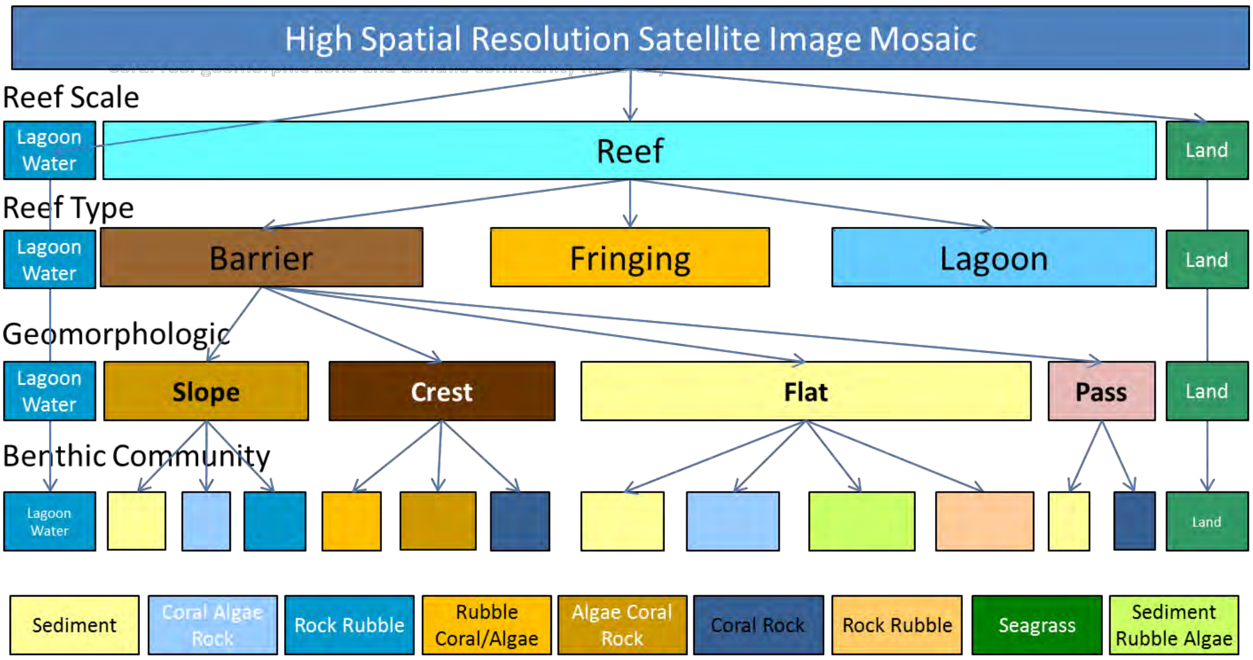


Figure 39: Example of schematic representation of the hierarchical class structure used with object based image analysis presented for the Barrier Reef Type.

Benthic community scale provided the finest detail resulting in more mapping categories compared to the geomorphic scale. The benthic community categories, were a combination of the major bottom types: coral, algae, seagrass, sediment, rubble and rock. The most dominant bottom type was placed first in the description of a specific benthic community category. For instance "sediment rubble coral" would represent pre-dominantly "sediment" followed by "rubble" and then "coral". It is however not possible to provide an exact quantification of each bottom type to the total due to the mapping approach followed.

Object Based Image Classification

The four hierarchical spatial scales of habitat maps were subsequently created based on object based image analysis using Definiens Developer 7.0 and the required field knowledge and experience with past projects that followed the same approach (Knudby et al. 2010, Roelfsema et al. 2010, Phinn et al. 2012). The object based analysis consisted of two steps: image segmentation and segment classification

(Roelfsema et al. 2010, Phinn et al. 2012). The first step determined the segments for a required spatial scale depending on the colour and shape of groups of pixels, and the spatial resolution of features to be mapped. The segmentation step was applied initially on the whole image or image mosaic but then sub-segmentation was applied on the mapping categories of higher level map scale (Figure 39). The second step assigned automatically or manually mapping categories to the segments of the first step based on membership rules, which incorporate the segment: colour, shape, texture, position or biophysical properties. This process was repeated for each of the mapping scales.

The membership rules for the study site were based on previously developed rules (Knudby et al. 2010, Roelfsema et al. 2010, Phinn et al. 2012) for similar: reef type, geomorphic zone or benthic community mapping category and generally required adjustments of thresholds. In some cases new membership rules were created to account for different mapping categories present in Roviana compared to previous studied locations. These membership rules could for example be determined by: Normalised Difference Vegetation Index value; brightness of the blue band; ratio of blue and red bands; standard deviation of the blue band, location of one mapping category to another, and distance to land.

The segmentation scales and the membership rule sets for the first three mapping scales (Reef, Reef Type and Geomorphic) were mostly driven by image interpretation and expert knowledge, whereas for the benthic community scale it was driven by: field assessment and on image interpretation experience based on previous studies in coral reef environments.

After completion of the object based image analysis, contextual editing was applied. Here parts of the image were randomly assessed and based on field knowledge and experience segments were relabelled or existing segment boundaries were edited. With the help of Landsat Thematic Mapper 5 imagery some of the areas covered by clouds were re-digitised and assigned a mapping category.

Accuracy Assessment

To assess the accuracy of the habitat maps at the geomorphic scale (6 classes) and benthic community scale (21 classes), we developed error matrices and calculated overall accuracies and individual category accuracies based on reference data for the individual map scales (Congalton and Green 1999). The individual category accuracy is described by the user's and producer's accuracies. The producer's accuracy is the probability of a reference data point being classified correctly, whereas the user's accuracy is the probability of a classified pixel being correct.

The accuracy assessment procedure varied for geomorphic and benthic community scale (Roelfsema et al. 2010, Phinn et al. 2012) as we developed the reference data sets for the geomorphic zone and the benthic community scales using different approaches. For the geomorphic zones, we generated 20 randomly distributed points within each class, for a total of 120 points, and manually assigned them to a reference geomorphic zone class. For the benthic community classes, we selected all the 2445 segments that contained at least one benthic photo. These segments were then manually assigned a benthic community class by assessing the photo, its benthic community label, and the underlying satellite image.

Results

Habitat Maps At Four Hierarchical Scales

Habitat maps were created at four hierarchical scales: 1) Reef (Figure 40), 2) Reef Type (Figure 41), 3) Geomorphic (Figure 42) and 4) Benthic Community (Figure 43). The fourth scale was used to merge categories resulting in a dominant benthic cover type or substrate map (Figure 45).

The object based approach showed that the membership rule sets that were not solely based on pixel values for one band proved to work cross study sites and scenes (e.g. band ratios, standard deviation, distance to other category) whereas rule sets based on the pixel value only (e.g. blue band value) could correctly assign a map category to segments in one scene in comparison to segments in adjacent scene (e.g. the image covering the area of Munda was for instance badly sun glinted and required some other rule sets).

Reef Land Water Map

Figure 40 shows the location of the shallow reefs throughout Roviana and Vonavona Lagoon covering 172.6 km^2 (Table 8) out of a total of 605 km^2 area being classified which include the deep water areas left out of the figure below.

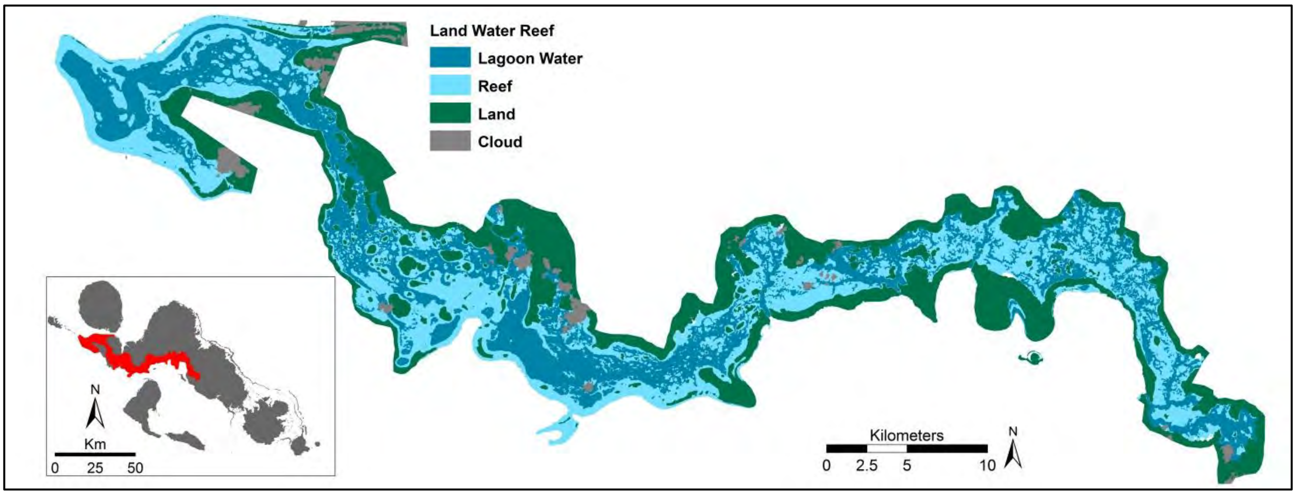


Figure 40: Reef Land Water Map, Roviana and Vonavona Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands

Table 8: Surface area for each reef, Roviana and Vonavona Lagoon, Western Province, Solomon Island.

	Surface area (km^2)	**Surface area (%)**	**Description**
Reef	172.6	33	Areas where bottom is visible through the water column or areas that are exposed but not considered land.
Land	172.8	33	Anything exposed and not part of the reef
Lagoon Water (Deep/Turbid)	170.6	33	Water within the lagoon where bottom is not visible due to depth or turbidity
Cloud	16.1		Cloud

REEF TYPE MAP

Four major reef types were identified in the studya area: Barrier Reef, Deep Reef, Fringing Reef and Lagoon Reef (Figure 41). Fringing reefs covered an area of 110 km^2, 63% of the shallow reef area (

Table 9).

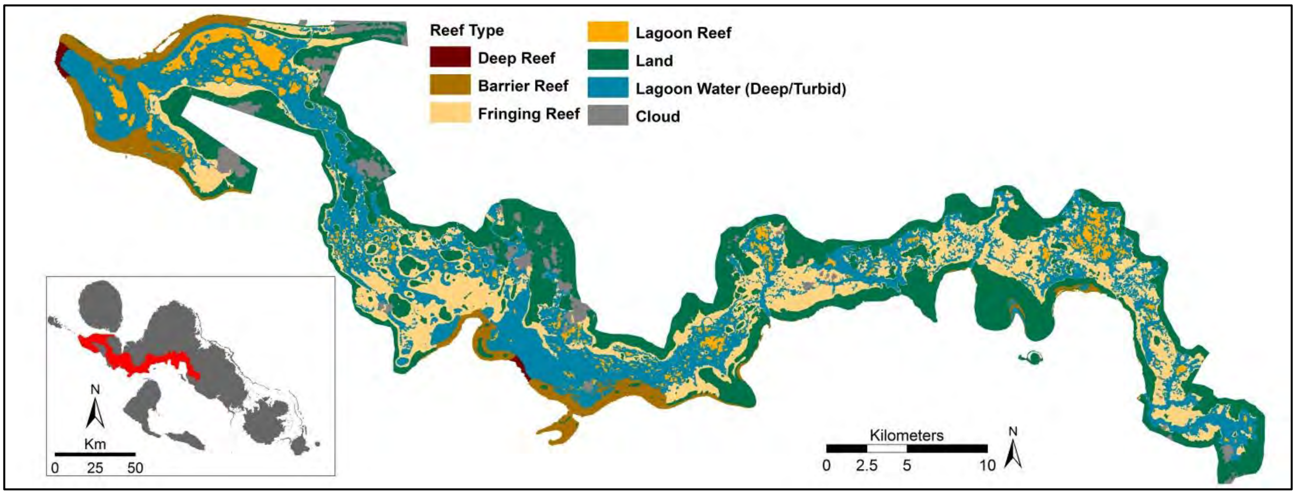


Figure 41: Reef Type Map, Roviana and Vonavona Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands

Table 9: Surface area for each reef type, Roviana and Vonavona Lagoon, Western Province, Solomon Island.

Reef Type	Surface area (km^2)	Surface area (%)	Description
Barrier	34.8	20	Reefs that are connected with open ocean and form a barrier for the lagoon and land behind it
Deep	1.5	1	Reefs that form a deep pass between barrier reef
Fringing	110.1	63	Reefs that are directly connected to land
Lagoon	27.1	16	Reefs that are within the lagoon and not connected to land

Geomorphic Map

The geomorphic map showed four major geomorphic categories: Reef Pass, Reef Slope, Reef Crest and Reef Flat (Figure 42). Of the shallow reef, 79 km^2 was reef flat and 85 km^2 was reef slope (Table 10). Reef slope included all the small lagoon reefs.

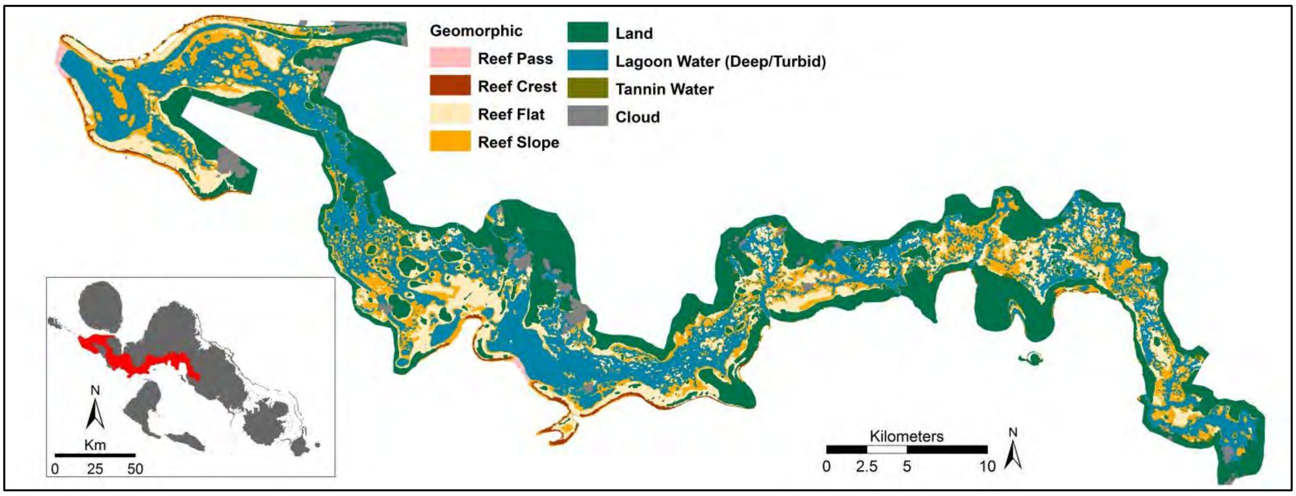


Figure 42: Geomorphic Map, Roviana and Vonavona Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands

Table 10: Surface area for each of the Geomorphic zones, Roviana and Vonavona Lagoon, Western Province, Solomon Island.

Geomorphic Zone	**Surface area (km^2)**	**Surface area (%)**	**Description**
Reef Crest	6.7	4	Area on the reef where water breaks as its shallow and provides a barrier for incoming ocean waves
Reef Flat	78.9	45	Shallow areas of the reef which could be directly behind the reef crest and/or connected with land.
Reef Pass	1.5	1	Deep areas between reefs
Reef Slope	85.5	50	Areas changing in depth over a short distance

BENTHIC COMMUNITY MAP

For the benthic community map (Figure 43) the benthic community categories were determined based on field data and field knowledge. The first cover type in each benthic community category represents the dominant category, followed by the second dominant category. A "forward slash" or "/" present in the name of a benthic community category between two cover types, indicates that neither cover type was more dominant then the other and/or that these cover type cannot be differentiated.

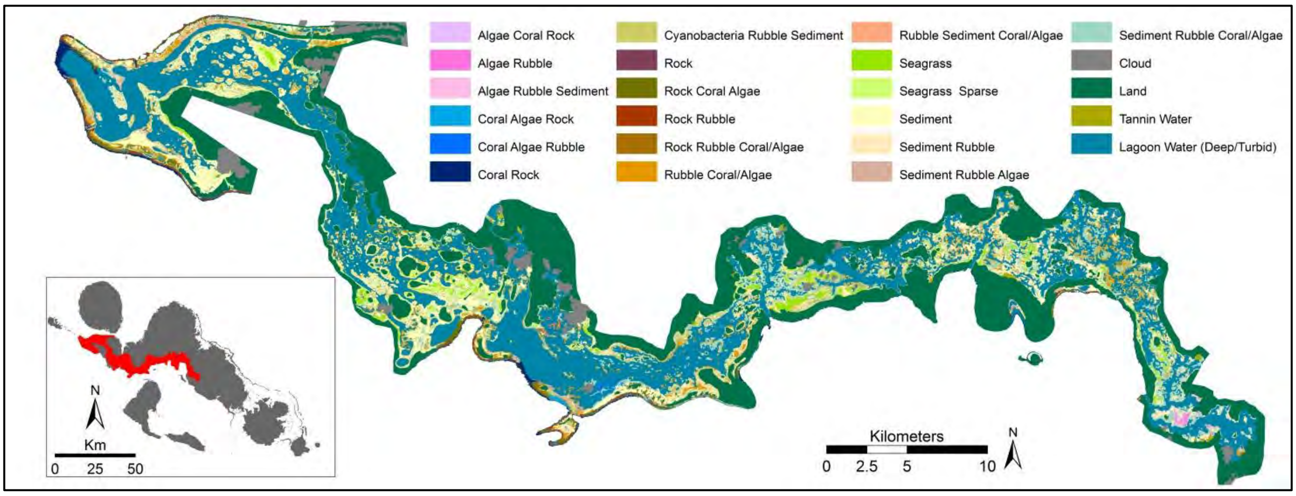


Figure 43: Benthic Community Map, Roviana and Vonavona Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands.

For each benthic community category of the benthic community map (Figure 43) the total surface area was calculated (Table 11) in the study area. The sediment category covers most of the area in relation to the other categories. The surface area for the benthic community categories present within the individual marine protected areas (MPA) of the study area (Figure 44) were also calculated (Table 11).

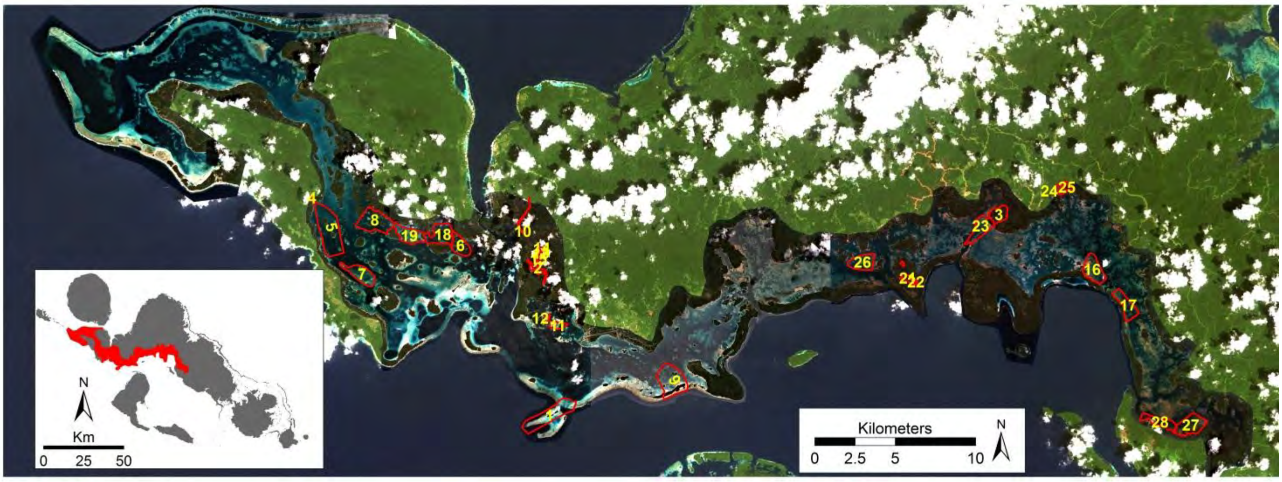


Figure 44: Location of Marine protected areas in Roviana and Vonavona Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands. The numbers represent the name of the MPA which are described in Table 11.

Table 11: Surface area for each of the benthic community categories, for MPA in Roviana and Vonavona Lagoon, Western Province, Solomon Island.

MPA Number Figure 8			5	26	7	1	17	6	19	24,25	11	12	8	2	3	23	9	16	28	18	27
Benthic	**All (km2)**	**All (ha)**	**Barasipo (ha)**	**Buni (ha)**	**Baraulu/ Bule Lavata (ha)**	**Dunde (ha)**	**Ha'apai (ha)**	**Kida (ha)**	**Kinamara (ha)**	**Kozou Zone (ha)**	**MPA1-EANA - Kindu (ha)**	**MPA2-REKOSO-Kindu (ha)**	**Nazareti (ha)**	**Ngangasa-Kidu (ha)**	**Nusa Hope (ha)**	**Nusa Hope/Heloro**	**Nusa Roviana (ha)**	**Olive (ha)**	**Opele (ha)**	**Saika (ha)**	**Tobo (ha)**
Algae Coral Rock	**0.33**	33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Algae Rubble	**0.62**	62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	8.7
Algae Rubble Sediment	**0.31**	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
Coral Algae Rock	**3.15**	315	0.5	0.8	0.3	8.6	0.0	0.4	1.6	0.0	1.6	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Coral Algae Rubble	**0.82**	82	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coral Rock	**5.22**	522	0.0	0.0	0.0	22.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyanobacteria Rubble Sediment	**1.1**	110	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rock	**1.85**	185	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rock Coral Algae	**5.3**	530	0.0	0.0	0.0	22.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rock Rubble	**1.97**	197	0.0	0.0	0.0	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rock Rubble Coral/Algae	**0.54**	54	0.0	0.0	14.5	0.2	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0
Rubble Coral/Algae	**28.45**	2845	33.1	18.9	0.0	21.4	20.9	12.9	22.7	0.3	1.1	0.0	35.6	0.5	0.0	0.0	0.0	37.3	0.1	16.0	0.2
Rubble Sediment Coral/Algae	**1.16**	116	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seagrass	**9.14**	914	1.3	0.4	4.4	0.0	7.6	0.2	4.2	0.0	0.0	0.0	7.6	0.0	0.3	6.6	0.0	13.5	0.0	3.2	0.0
Seagrass Sparse	**5.81**	581	3.2	4.3	0.0	0.0	0.0	2.9	18.8	0.0	0.8	0.0	8.4	0.1	0.0	0.0	0.0	0.0	0.0	11.3	0.0
Sediment	**35.82**	3582	34.6	83.0	0.9	33.3	1.7	3.8	25.2	1.0	4.3	0.0	24.9	0.0	0.1	8.3	0.0	16.3	0.1	9.6	4.1
Sediment Rubble	**26.66**	2666	4.9	4.9	16.0	7.6	27.7	4.3	5.8	0.7	0.4	0.0	8.3	3.3	0.9	31.9	0.0	13.2	9.6	1.0	29.8
Sediment Rubble Algae	**1.98**	198	0.0	0.0	0.0	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sediment Rubble Coral/Algae	**42.35**	4235	13.1	31.3	34.1	5.2	28.3	13.2	28.9	0.2	11.7	0.0	10.9	0.0	0.8	23.1	0.0	46.8	6.2	28.6	41.3
Tannin Water	**0.85**	85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.7	0.0	17.2
Lagoon Water (Deep/Turbid)	**170.53**	17053	292.9	29.1	82.6	3.5	69.8	94.9	36.4	28.3	18.8	0.0	134.7	31.5	0.0	69.8	0.0	47.2	83.4	103.7	73.6

To determine the abundance and distribution of the dominant benthic cover and/or substrate types, a map (Figure 45) was created by combining those benthic community categories that occurred in the benthic community map (Figure 43) that had the same dominant cover type. This resulted in the following benthic cover and substrate types: Algae, Coral, Seagrass, Rock, Rubble and Sediment. Cyanobacterial categories were joined in the sediment group.

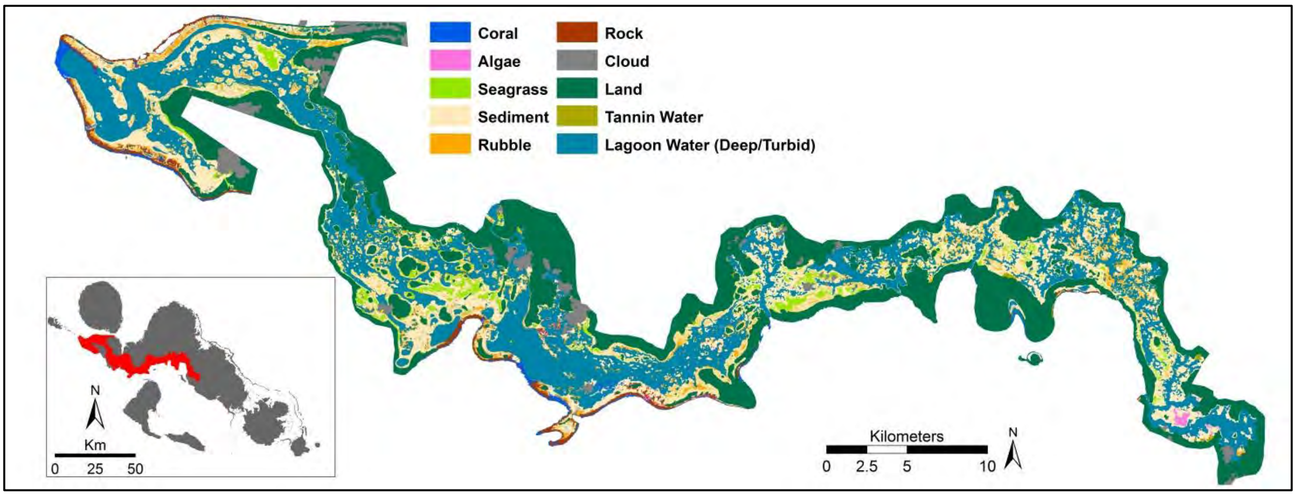


Figure 45: Dominant benthic cover or substrate type Map, Roviana and Vonavona Lagoon. Inset map shows location of study area in red in the Western Province, Solomon Islands

Table 12: Surface area for each of the Dominate benthic and substrate cover type categories, for MPA in Roviana and Vonavona Lagoon, Western Province, Solomon Island.

	All (km2)	All (ha)	Baraulu/Bule Lavata (ha)	Dunde (ha)	Ha'apai (ha)	Kinamara (ha)	Kozou Zone (ha)	MPA1-EANA-Kindu (ha)	MPA2-REKOSO-Kindu (ha)	Nazareti (ha)	Ngangasa-Kidu (ha)	Nusa Hope (ha)	Nusa Hope/Heloro (ha)	Nusa Roviana (ha)	Olive (ha)	Saika (ha)	Barasipo (ha)	Buni (ha)	Tobo (ha)	Opele (ha)	Kida (ha)
Algae	1.3	126.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4	0.3	0.0
Coral	9.2	919.0	0.3	31.2	0.2	1.6	0.0	1.6	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.7	0.5	0.8	0.0	0.0	0.4
Seagrass	15.0	1495.0	4.4	0.0	7.6	23.0	0.0	0.8	0.0	16.0	0.1	0.3	6.6	0.0	13.5	14.4	4.6	4.7	0.0	0.0	3.1
Rock	9.7	966.0	14.5	47.2	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rubble	29.6	2961.0	0.0	28.9	20.9	22.7	0.3	1.1	0.0	35.6	0.5	0.0	0.0	0.0	37.3	16.0	33.1	18.9	0.2	0.1	12.9
Sediment	107.9	10791.0	51.0	68.6	57.7	59.9	1.9	16.4	0.0	44.1	3.3	1.8	63.4	0.0	76.3	39.2	52.6	119.2	75.1	16.0	21.3

Accuracy Assessment Results

When interpreting the resulting habitat maps and the distribution of the different categories within the study area it is important to keep in mind what the accuracies are of these maps and of the mapping categories. The object based image analysis applied on the Vonavona and Roviana Lagoon resulted in an overall accuracy of 86.7 %(Table 13) for the Geomorphic zone map (Figure 42) and 65.1 % (Table 15) for the benthic community map (Figure 43) these accuracies were respectively 65.1 %. These results are in the same range as previous habitat mapping studies in coral reefs using object based image analysis (Phinn et al. 2012).

For the geomorphic map the users and producers accuracies (Table 13) for each of the mapping categories were similar and varied between 72 % and 100 %, suggesting that not only the overall accuracy of the map is high but also the individual categories.

Table 13 Error Matrix, Overall Accuracy, User and Producer Accuracy of Geomorphic Map

Geomorphic (sample units are polygone/segments)									
	Reference								
Image Classification	Lagoon Water (Deep/Turbid)	Reef Crest	Reef Flat	Reef Slope	Reef Pass	Tannin Water	Total User	User %
Lagoon Water (Deep/Turbid)	17	0	0	2	0	1	20	**85.0**
Reef Crest	0	15	5	0	0	0	20	**75.0**
Reef Flat	0	0	19	1	0	0	20	**95.0**
Reef Slope	2	0	0	18	0	0	20	**90.0**
Reef Pass	0	0	0	2	18	0	20	**90.0**
Tannin Water	0	0	1	2	0	17	20	**85.0**
Total Producer	19	15	25	25	18	18		
Producer (%)	**89.5**	**100.0**	**76.0**	**72.0**	**100.0**	**94.4**	Sum	120
						Total User*Producer		2400
						Total Diagonal		104
						Overall Accuracy		**86.7**
						Adjusted Overall Accuracy		**84.0**

When assessing the individual mapping category accuracies (Table 14) for the benthic community level, some categories showed a n.a. accuracy which is due to absence of reference data for these categories. In comparison to the geomorphic map category accuracies there was more variation present for user's and producer's accuracy, respectively 33%- 100% and 12% - 100% with an average of 75.6 % and 69% respectively. The error matrix showed more confusion between mapping categories such as "sediment rubble" and "sediment"; or "rock rubble" and "rock" resulting in lower accuracies then the other categories. This is potentially due to its location and characteristics making them hard to differentiate from each other compared to the other categories.

As the dominant groups resulted from merging the individual benthic community groups the number of categories reduced. Compared to the benthic community categories, the final dominant group categories had higher individual accuracies, ranging from 68.7%-100% for user accuracies and 55.7% - 100% for producers accuracies. Although this level of map will show less detail as there only six bottom type categories the accuracies are higher.

To assess the accuracy of the mapping when focussing on the dominate benthic and substrate cover types, the benthic community groups in Table 14 were merged for Algae, Coral, Seagrass, Rock, Rubble and Sediment (Table 15). Cyanobacterial categories were joined with the sediment group. The overall accuracy of the dominate cover type map was 78.7%.

Table 14 Error Matrix, Overall Accuracy, User and Producer Accuracy of Benthic Community Map

All Benthic Community Categories (sample units are polygone/segments)

Image Classification	Reference: Algae Rubble	Algae Rubble Sediment	Algae Rubble	Coral Algae Rock	Coral Algae Rubble	Coral Rock	Cyanobacteria Rubble Sediment	Rock	Rock Coral Algae	Rock Rubble	Rock Rubble Coral/Algae	Rubble Coral/Algae	Rubble Sediment Coral/Algae	Seagrass	Seagrass Sparse	Sediment	Sediment Rubble	Sediment Rubble Algae	Sediment Rubble Coral/Algae	Lagoon Water (Deep/Turbid)	Open Ocean Water	Tannin Water	Land	Total User	User %
Algae Rubble	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	15	**86.7**
Algae Rubble Sediment	3	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	12	**58.3**
Algae Rubble	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**n.a.**
Coral Algae Rock	0	0	0	92	2	2	0	0	10	0	0	2	0	5	9	1	0	0	1	0	0	0	0	124	**74.2**
Coral Algae Rubble	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	**100.0**
Coral Rock	0	0	0	0	0	41	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	**74.5**
Cyanobacteria Rubble Sediment	0	0	0	5	0	0	0	0	1	0	0	0	2	0	0	0	0	0	4	0	0	0	0	12	**n.a.**
Rock	0	0	0	0	0	7	0	18	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	34	**52.9**
Rock Coral Algae	0	0	0	3	0	9	0	0	196	3	8	10	2	0	2	0	1	0	3	0	0	0	0	237	**82.7**
Rock Rubble	0	0	0	1	3	9	0	2	13	22	13	2	0	0	0	0	0	0	1	0	0	0	0	66	**33.3**
Rock Rubble Coral/Algae	0	0	0	0	0	0	0	0	0	0	30	0	1	0	0	0	0	0	0	0	0	0	0	31	**96.8**
Rubble Coral/Algae	0	0	0	19	4	0	0	0	7	0	3	206	4	6	17	12	15	4	28	0	0	0	0	325	**63.4**
Rubble Sediment Coral/Algae	0	0	0	0	0	0	0	0	0	0	1	0	45	0	0	0	0	0	0	0	0	0	0	46	**97.8**
Seagrass	0	3	0	5	0	0	0	0	0	0	0	1	0	166	22	1	5	0	7	0	0	0	0	210	**79.0**
Seagrass Sparse	0	5	0	9	10	0	0	0	0	0	0	11	2	11	123	0	1	5	11	0	0	0	0	188	**65.4**
Sediment	0	1	0	6	12	1	3	0	1	0	2	10	13	2	18	201	24	19	40	0	0	0	0	353	**56.9**
Sediment Rubble	1	1	0	4	4	0	0	0	1	0	0	18	1	4	30	13	183	7	39	0	0	0	0	306	**59.8**
Sediment Rubble Algae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**n.a.**
Sediment Rubble Coral/Algae	1	2	0	6	0	0	0	0	2	0	0	25	4	16	37	20	56	12	217	0	0	0	0	398	**54.5**
Lagoon Water (Deep/Turbid)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	18	**100.0**
Open Ocean Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	**100.0**
Tannin Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	**n.a.**
Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	**100.0**
Total Producer	18	19	0	150	41	69	3	20	252	27	57	285	74	210	258	249	285	51	351	18	2	0	6		
Producer (%)	**72.2**	**36.8**	**n.a.**	**61.3**	**12.2**	**59.4**	**n.a.**	**90**	**77.8**	**81.5**	**52.6**	**72.3**	**60.8**	**79**	**47.7**	**80.7**	**64.2**	**n.a.**	**61.8**	**100**	**100**	**n.a.**	**100**		**2445**
	Total User*Producer				590940			Total Diagonal				1591												**Overall Accuracy**	**65.1**
																								Adjusted Overall Accuracy	**61.2**

Table 15: Error Matrix, Overall Accuracy, User and Producer Accuracy of Dominate benthic and substrate cover type Map.

Dominant Cover Type (sample units are polygone/segments)

Image Classification	Reference: **Sediment**	**Rubble**	**Rock**	**Coral**	**Algae**	**Seagrass**	**Land**	**Open**	**Lagoon**	**Tannin**	Total User	**User %**
Sediment	831	71	6	34	6	107	0	0	0	0	1055	**78.8**
Rubble	59	255	11	23	0	23	0	0	0	0	371	**68.7**
Rock	5	15	313	32	0	2	0	0	0	0	367	**85.3**
Coral	2	2	24	142	0	14	0	0	0	0	184	**77.2**
Algae	4	0	0	0	23	0	0	0	0	0	27	**85.2**
Seagrass	29	14	0	24	8	322	0	0	0	0	397	**81.1**
Land	0	0	0	0	0	0	6	0	0	0	6	**100.0**
Open	0	0	0	0	0	0	0	2	0	0	2	**100.0**
Lagoon	0	0	0	0	0	0	0	0	18	0	18	**100.0**
Tannin	1	0	0	0	0	0	0	0	0	0	1	**n.a.**
Total Producer	931	357	354	255	37	468	6	2	18	0		
Producer (%)	**89.3**	**71.4**	**88.4**	**55.7**	**62.2**	**68.8**	**100**	**100**	**100**	**n.a.**	Sum	2428
	Total User*Producer				1478649						**Overall Accuracy**	**78.7**
	Total Diagonal				1912						**Adjusted Overall Accuracy**	**71.6**

CONCLUSIONS

This study resulted in a classification of the Roviana and Vonavona Lagoon, Western Province, Solomon's in to four hierarchical mapping scales: 1) Reef, 2) Reef Type, 3) Geomorphic and 4) Benthic Community. By merging benthic communities that contain the same dominant benthic cover or substrate type, a dominance map was created for Coral, Algae, Seagrass, Sediment, Rubble and Rock. The maps were created through an object based image analysis system using high spatial resolution imagery, georeferenced photo transects, field knowledge, as developed by previous studies (Knudby et al. 2010, Roelfsema et al. 2010, Phinn et al. 2012).

Overall accuracies for the geomorphic and benthic community maps were 82% and 65% Respectively. Individual mapping category accuracies varied between the different mapping categories. The overall and individual mapping category accuracy levels were relatively high compared to similar studies covering such a large extent of complex habitats. When conducting future analysis, using the map products created in this study the corresponding accuracy levels should be taken into account to account for possible mapping errors.

The segmentation and membership rule set created for this study has not been tested to another image mosaic of the same area. It is expected that the bases of these rule sets can be used in future research for the same area with fine tuning of thresholds and adding rules for additional categories to account for variation in environmental factors (e.g. tides, wind, clouds) or image characteristics (e.g. date of acquisitioning, image type, pixel size).

The classified area in this project extended 605 km^2, this included: land (170 km^2), deep water (39 km^2), lagoon water (170 km^2), cloud (19 km^2), and shallow reef (173 km^2). Within the shallow reef there were 19 benthic community categories that were predominantly the following bottom types were: sediment (108 km^2), rubble (29 km^2), rock (10 km^2), seagrass (15 km^2), coral (9 km^2), and algae (2 km^2).

This study demonstrates the Roviana and Vonavona lagoos systems are comprised of 19 benthic communiites that form mosaics of complex marine habitats. The diversity of these habitats is influenced by the biological and physical processes within the lagoon and the diverse geology providing shallow and deep areas within the lagoon, deep passages and steep drop-offs into open ocean. The reefs in the clear waters of western Vonavona (Raramana) and central lagoon (offshore from Munda) are highly complex with extensive hard coral areas. While the eastern portion of the Roviana Lagoon is more turbid, with reefs interspersed with seagrass and algae. This east-west gradient in coral, algal and seagrass cover is primarily determined by lower oceanic flushing and high sediment inputs in the eastern lagoon.

The spatial information of the five different levels of detail: 1) Reef, 2) Reef Type, 3) Geomorphic, 4) Benthic Community, and 5) Benthic and substrate cover type can be used to assess climate change impacts on specific marine habitats, marine protected area planning and provide an important baseline at which future changes can be assessed

CORAL BLEACHING AND DISEASE ASSESSMENT

BACKGROUND

Tropical marine systems have been experiencing regional scale mortalities for almost 30 years, with mass coral bleaching events having increased in frequency since they were first reported in the early 1980s(Hoegh-Guldberg 2011). These impacts, along with local and regional human impacts, threaten the fundamental ecological functions of coral reefs worldwide(Wild et al. 2011), as well as the coastal protection, tourism, biodiversity, fisheries production and other ecosystem services that they provide(Costanza et al. 1997).

Many reef coral diseases have also emerged in the last 30-40 years, several of which have caused significant regional-scale ecological impacts(Hayes and Goreau 1998, Rosenberg et al. 2007a, Rosenberg et al. 2007b, Rogers 2009, Rosenberg and Kushmaro 2011). For example, Acropora species were formerly the dominant ‘bioengineer’ species on shallow and mid-depth zones of most Caribbean reefs. Shallow (0-6 m depth) reefs were typically dominated by A. palmata, while A. cervicornis was commonly a dominant species at 6-9 m depth. These species are now relatively rare, and the physiographic reef zones they constructed have been eliminated from all but a handful of reefs in the region(Lirman et al. 2010) due to the emergence of white band disease (WBD) in the mid-1970s(Bythell and Sheppard 1993, Bythell et al. 1993, Bythell et al. 2000, Aronson and Precht 2001, 2006). The coincidence of the emergence of wildlife diseases with global climate change(Daszak et al. 2001) has prompted several authors to hypothesise a causal link due to the effects of temperature on pathogen activity, stress-induced increases in host susceptibility, or a combination of the two(Harvell et al. 2004, Harvell et al. 2007, Ward et al. 2007, Sokolow 2009). The stress-induced increase in susceptibility is a better explanation of the recent 60% mortality on reefs in the northeastern Caribbean due to white plague (WP) disease following the 2005 mass coral bleaching event, since temperatures had returned to seasonal norms by the time the disease outbreak peaked (Brandt and McManus 2009, Croquer and Weil 2009, Miller et al. 2009, Eakin et al. 2010). The effects of bleaching on disease occurrence are complicated, however. On the Great Barrier Reef, Australia, white syndrome (WS) broke out following the 2002 bleaching event (Bruno et al. 2007, Heron et al. 2010, Maynard et al. 2011). However, whereas in some areas WS prevalence subsequently declined to baseline levels, in other areas prevalence has remained high (Figure 46). Such non-linear responses make predicting disease outbreaks difficult(Sokolow 2009), and indeed while predicting bleaching events based on

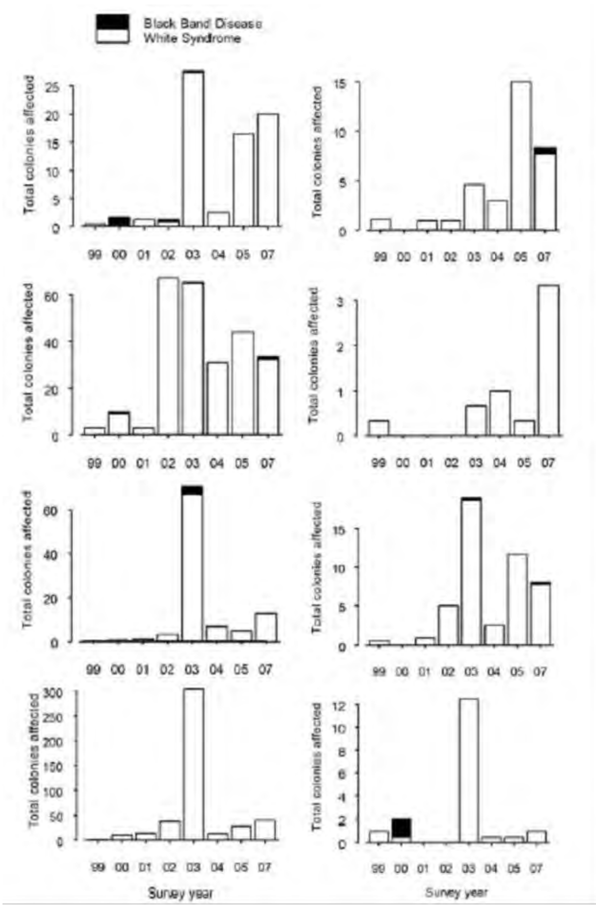


Figure 46 Coral Disease prevalence in various sectors of the GBR since 1999 (Sweatman et al. 2008, GBR Status Report 8, AIMS). Regions are (top L to bottom R): Cooktown/Lizard inner-, mid-, outer-shelf, Carins inner-, mid-, outer-shelf, Capricorn-Bunker and Swain.

temperature dose (e.g. degree heating weeks; http://coralreefwatch.noaa.gov/ satellite/index.html) is relatively reliable(McClanahan et al. 2007b, Yee and Barron 2010), predicting the likelihood of mortality following bleaching is far less so (McClanahan 2004, McClanahan et al. 2007a). At least some of this variability will likely be due to variable initial health status and the effects on antimicrobial defences(Brown and Bythell 2005, Gochfeld and Aeby 2008), influenced both by ongoing local environmental impacts (Anthony et al. 2007, Ward et al. 2007) and longer-term selection pressures (Yakob and Mumby 2011). Palmer et al. (2010) recently showed that bleaching and disease susceptibility are co-dependent on the levels of investment in a suite of immune defences**. Thus, to understand and ultimately accurately predict coral disease outbreaks due to climate change and other impacts, we need to routinely monitor for coral disease outbreaks, which have already shown profound impacts in many parts of the world**. Relying on correlations with environmental variables is unlikely to succeed, except at the broadest scales.

METHODS

Coral disease surveys were conducted in April 2011 in the Roviana-Vonavona lagoon complex using close-up 50 m x 0.63 m high-definition video transects. During the surveys 32 dives were conducted, surveying a total of 47 transects, with approximately 17 h of high-definition video recorded. Where cases of suspected disease and other syndromes were observed, close-up (polyp-scale) video was recorded to allow later classification and distinguish, for example, between tissue loss and bleaching. The survey was designed to sample within the MPAs established across the lagoon system and also the outer reef drop-offs at areas close to the MPAs. Paired transect samples were collected inside and at a representative site outside of Ha'apai, Olive, Nusa Hope, Baraulu, Nusa Roviana, Dunde, Kindu, Vaributo, Niumala and Baracipo MPAs (Figure 47 Table 16). In addition, since the degree of protection in these areas is variable, a comparison site was surveyed within the Tetepare no-take reserve, which has had high levels of protection for many years and supports comparatively far higher fish population densities than any of the lagoon system MPAs. On the drop-off areas, three transects were surveyed at 5, 10 and 20 m whereas lagoonal reefs surveyed were all at 4-6 m depth.

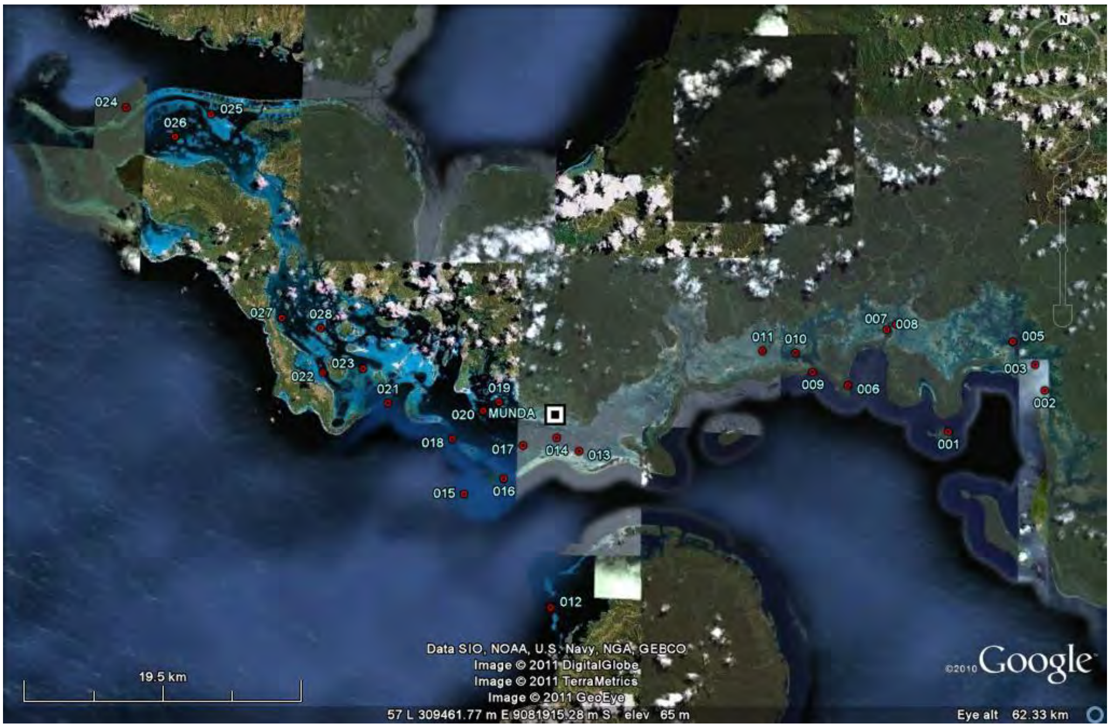


Figure 47 Locations of survey sites. Refer to Table below for GPS positions and descriptions.

Table 16 Site locations (WGS84 GPS position) and descriptions. See Fig. 1 for locations according to reference number. WS = white syndrome, Blea = bleaching, Graz = grazing damage, Mech = mechanical (anchor?) damage, UID = unidentified syndrome affecting Porites

Reference	Lat/Long	Description	Transects	Notes
001	S08°20'09.93" E157°30'08.08"	Ndoke ndoke island (drop off)	1 (20 m) 2 (10 m) 3 (5 m)	Some WS; Blea; Graz; Mech.
002	S08°18'38.80" E157°33'32.21"	Ha'apai MPA	4	Some Mech; Blea. Little/no WS.
003	S08°17'45.31" E157°33'11.74"	Outside MPA (non-MPA reference site)	5	Some WS; UID; Blea.
004	S08°17'52.40" E157°32'29.85"	Olive MPA	6	Some WS; UID; Blea.
005	S08°16'57.48" E157°32'23.79"	Outside MPA (non-MPA reference site)	7	Some Blea; Graz. Little/no WS.
006	S08°18'36.99" E157°26'33.39"	Rava Point (drop off)	8 (20 m) 9 (10 m) 10 (5 m)	Some WS; Blea; atypical bleaching pattern (bleached band); Graz.
007	S08°16'26.22" E157°28'14.89"	Nusa Hope MPA	11	Some Graz; little else.
008	S08°16'37.93" E157°27'54.36"	Outside MPA (non-MPA reference site)	12	Some Blea; lots Graz. A lot of recently dead coral.
009	S08°18'11.14" E157°25'17.69"	Baraulu drop-off	13 (20 m) 14 (10 m) 15 (5 m)	Some WS; Blea; Graz.
010	S08°17'31.54" E157°24'40.51"	Baraulu MPA	16	Some Blea; Graz; Mech. V little disease.
011	S08°17'28.68" E157°23'30.73"	Outside MPA (non-MPA reference site)	17	Little WS. Some Blea; Mech.
012	S08°26'33.67" E157°16'11.21"	Haipe Pinnacle (drop off)	18 (20 m) 19 (10 m) 20 (5 m)	Lot of WS. Some Blea; some cyanobacterial overgrowth.
013	S08°21'07.46" E157°17'04.52"	Nusa Roviana MPA	21	Little/no disease. Some Mech; Blea; trematode overgrowth.
014	S08°20'40.39" E157°16'16.39"	Outside MPA (non-MPA reference site)	22	V little disease. Some WS off-transect. Some Blea.
015	S08°22'42.17" E157°13'02.63"	Shark point (drop off)	23 (20 m) 24 (10 m) 25 (5 m)	Lot of WS; some Blea. Some *Drupella* predation.
016	S08°22'08.35" E157°14'25.89"	Dunde MPA	26	Little disease. Some WS off-transect. Some Blea.
017	S08°20'57.95" E157°15'05.33"	Outside MPA (non-MPA reference site)	27	UID; Some Blea. Little/no WS.
018	S08°20'47.16" E157°12'35.13"	Munda Bar forereef (drop off)	28 (20 m) 29 (10 m) 30 (5 m)	Some WS; Blea; Mech; some *Drupella* predation.
019	S08°19'28.18" E157°14'12.24"	Kindu MPA	31	V little disease. Some Blea. Some trematode infestation of *Porites* off-transect.
020	S08°19'47.21" E157°13'38.91"	Outside MPA (non-MPA reference site)	32	V little disease.
021	S08°19'35.16" E157°10'16.02"	Madou forereef (drop off)	33 (20 m) 34 (10 m) 35 (5 m)	A lot of cyanobacteria w/ signs of overgrowth. Some WS; Blea. *Halimeda.*
022	S08°18'34.13" E157°07'56.45"	Vaributo MPA	36	Some WS; UID; Blea.
023	S08°18'24.25"	Outside MPA (non-MPA	37	Some WS; UID; Blea.

	E157°09'21.20"	reference site)		
024	S08°09'19.68" E157°00'36.47"	Q Island forereef	38 (20 m) 39 (10 m) 40 (5 m)	Some atypical (banded) Blea; *Seriatopora* ++Blea w/ some dead; some WS
025	S08°09'30.87" E157°03'39.91"	Niumala MPA	41	Some UID on *Porites* massives.
026	S08°10'20.24" E157°02'23.89"	Outside MPA (non-MPA reference site)	42	V little disease. *P. cylindrica* dominated.
027	S08°16'41.18" E157°06'25.42"	Baracipo MPA	43	Some UID on *Porites* massives.
028	S08°17'00.50" E157°07'48.45"	Outside MPA (non-MPA reference site)	44	Some UID on *Porites* massives.
029	S08°42'43.49" E157°25'44.83"	Tetepare no-take reserve	45 (20 m) 46 (10 m) 47 (5 m)	Lots of WS; some Brown Band Disease off-transect.

REEF SUBSTRATE TYPE AND CORAL COMMUNITY STRUCTURE ANALYSIS

Reef substrate type and coral community structure was determined using Coral Point Count (CP; http://www.nova.edu/ocean/cpce/) on the HD video of each 50 m transect. Initial, high replication analysis showed an optimal point count per frame of 15 (Table 17) and an optimal frame count per transect of 20 (Figure 48), which were subsequently used throughout the analysis.

Table 17 Similarity analysis between different densities of points per frame.

Substrate type	Proportional cover			
	5	10	15	20
Turf	0.40	0.40	0.42	0.39
CCA	0.00	0.00	0.17	0.22
S	0.00	0.10	0.00	0.00
Coral Mo	0.60	0.50	0.42	0.39
Bray Curtis similarity (to 20 points)	0.78	0.78	0.945	1

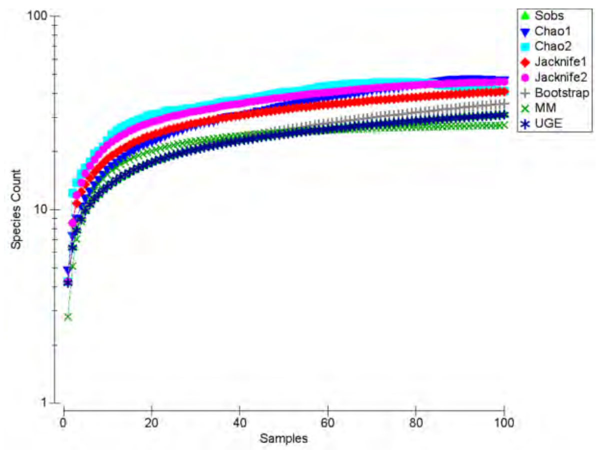


Figure 48 Rarefaction curves for cumulative substrate type diversity using various models. A frame count of 20 per transect was subsequently chosen as an optimum.

Hard corals were identified to genus and soft corals to family. All other biota and substrates were identified as: sponge, bare rock, sand, turf algae, crustose coralline algae (CCA), macroalgae, Hydrozoa, tunicates, Antipatharia, Corallimorpharia, Zoantharia, Helioporaea or Actinaria. For reporting purposes the latter 7 groups were summed as 'other invertebrates'. Coral community structure was analysed using Primer 6 using a variety of multidimensional ordination analyses and ANOSIM (Analysis of Similarity) tests.

Coral diseases and syndromes were recorded as prevalence rates (per coral colony) as well as frequencies (per transect and, by calculation, per m^2) to enable comparison with existing surveys elsewhere. To control for variations in susceptibility across coral taxa, susceptibility to bleaching and white syndrome was calculated for each genus by determining the ratio of relative syndrome prevalence to its population proportion (based on point count data) across the entire survey. This ratio was then multiplied by the proportional surface cover of each genus at a given site and summed to give a relative index of susceptibility for each site. A regression analysis of syndrome prevalence versus this site susceptibility index (a measure of host population density of susceptible genera) allowed us to control for possible differences in the availability of more or less susceptible genera as an explanation of between-site differences in syndrome prevalence. Statistical analyses between sites were carried out using General Linear Model ANOVA, except where the assumptions of normality were not met, on which case a non-parametric Kruskal-Wallis analysis was conducted.

Since a single 'snap shot' of coral disease and syndrome prevalence may not reflect long-term declines in different areas, since outbreaks can be highly variable in space and time, a summary analysis of 'Live:Dead' substrate was made, identifying recently dead coral and bare substrate as 'Dead'. While natural chronic and episodic mortality is a normal part of reef community dynamics, this measure gives a summative indicator of recent mortality and recruitment for a given site.

RESULTS

CORAL DISEASES AND SYNDROMES OBSERVED

The most widespread disease observed during the surveys was white syndrome (WS), mainly affecting *Acropora* (Figure 49) and *Pocillopora* species. This syndrome can occasionally be confused with non-disease causes such as predation, but disease cases typically showed 'classic' signs of lesion advance with progressive colonisation with filamentous microalgae and it is unlikely that many cases were misidentified. Prevalence rates have previously been linked to increased water temperatures(Bruno et al. 2007) and infected colonies show high rates of mortality.

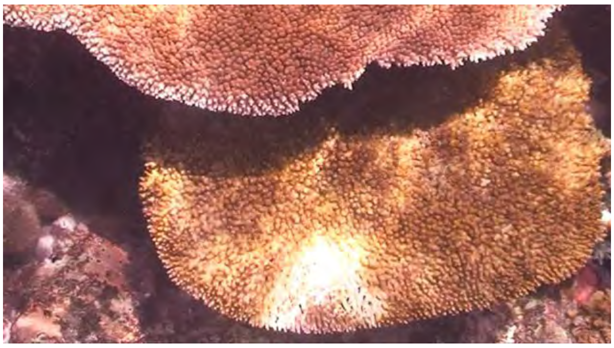


Figure 49 White syndrome on tabulate Acropora (*A. hyacinthus*). The entire table has been killed except for a small patch of tissue at bottom centre, with the lesion advancing from both left and right.

Widespread but relatively low severity bleaching was observed (Figure 50), most severely affecting branching *Seriatopora, Pocillopora* and *Stylophora* species. These are widely reported as highly susceptible genera that bleach in response to warm water events. In several areas the bleaching had led to recent mortality in these species. Although the bleaching was relatively mild and only affecting a few species, this supports the conclusion that the appearance of WS may be linked to warmer than average water temperatures. Temperatures observed at the time of surveys averaged 31-32˚C.

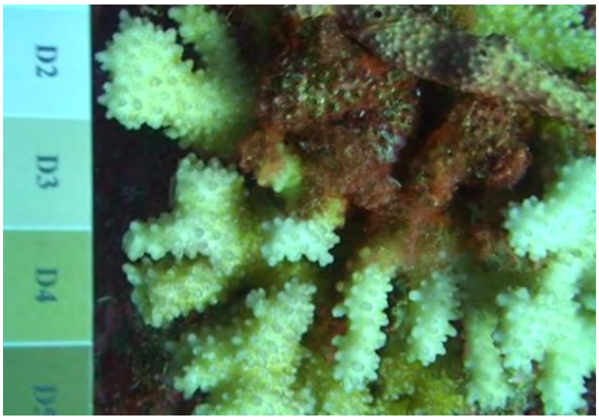


Figure 50 Typical partial colony bleaching pattern in Pocillopora eydouxi. The UQ/CRC bleaching intensity scale is shown for reference, with different parts of the coral showing paling (D4) to full white (D1) bleaching.

Two unusual syndromes were observed that were monitored over time in selected coral colonies to determine whether or not they were progressive at time of surveys. One of these was a potentially novel syndrome consisting of a patchy loss of tissue on massive Porites species (Figure 51), with a clear pink/blue line in the tissues (a characteristic immune response involving upregulation of fluorescent proteins by the coral host). In one case the patch appeared to be radiating (expanding), albeit extremely slowly (< 0.3 cm/month) but no obvious non-pathogenic cause was apparent such as mechanical abrasion, grazing fish or molluscs. This syndrome or unidentified disease (UID; Table 1) was relatively widespread in the lagoon, where massive Porites sp. are dominant. In addition a small number (n = 3) of disease and control (healthy) coral samples were collected and preserved for laboratory analysis but denaturing gel electrophoresis (DGGE) of bacterial 16S rRNA genes showed no apparent change in bacterial associates between healthy and disease lesion tissues (Figure 52). Given that another 5 cases showed no progression of the lesion over 94 days, it appears that the syndrome was not active at the time of the surveys.

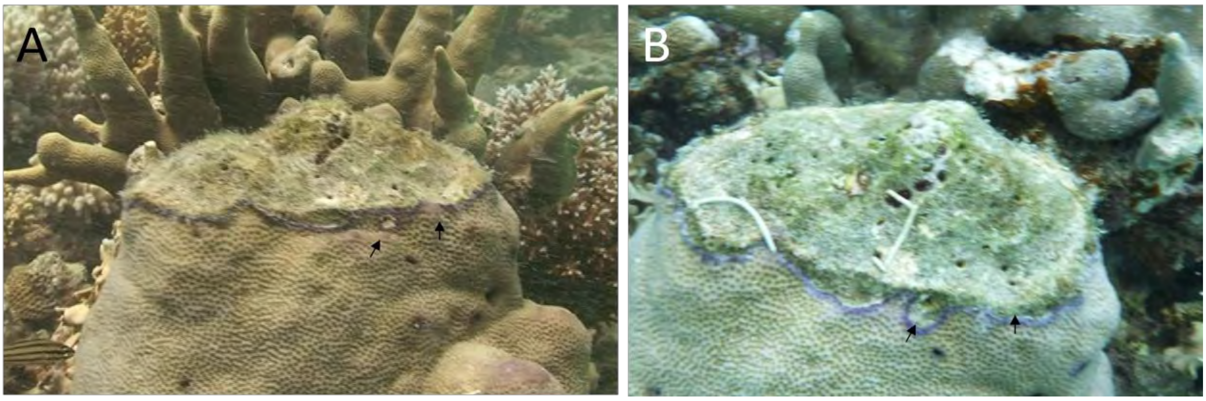


Figure 51 Repeated monitoring of a massive Porites colony on (A) 23 April and (B) 26 July 2011 (94 days apart) in the Vonavona Lagoon displaying signs of a novel disease lesion. Some areas showed no advance but others advanced approx. 1 cm over 94 days (arrows show approximate position of lesion interface in July. Five other

An atypical form of bleaching, first observed in the Marovo Lagoon (Kvennefors et al. 2010) was also observed in the Roviana-Vonavona lagoons. It consists of a broad (1-4 cm) band and/or patches of completely white-bleached tissues adjacent to normally-coloured tissues (Figure 53). Repeated photographs were taken 6 days apart of an example of atypical bleaching (20 m depth, Rava Point, Roviana drop-off). No change or progression of the bleached areas was observed and so it is not known whether this represents a deleterious condition. It was present at very low prevalence rates and is not currently a concern.

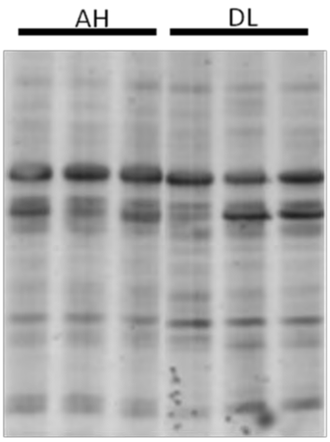


Figure 52 DGGE analysis of the unidentified Porites syndrome. Apparently healthy (AH) and disease lesion (DL) tissues showed no clear differences in associated bacterial communities.

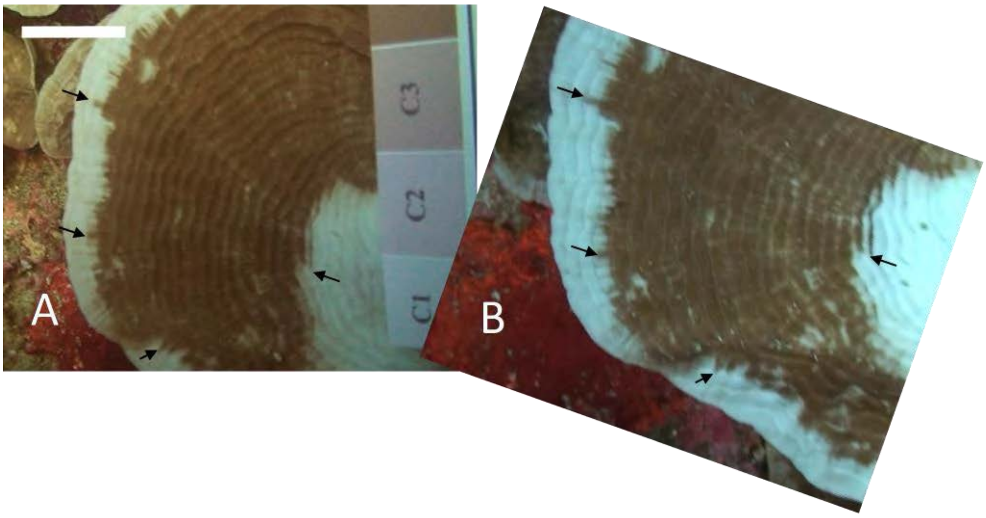


Figure 53 Atypical bleaching pattern in Pachyseris speciosa. Rava Point drop-off, Roviana Lagoon, 20 m depth. A) 19 April 2011; B) 25 April 2011. Fine-scale bleaching pattern is virtually unchanged over 6 days (note similar reference areas shown by arrows) Scale bar in A is 2cm.

Grazing damage from parrotfishes and other excavator/scraper species was relatively common throughout the survey area (Figure 55). One case of Brown Band Disease (BrB) was observed at Tetepare Reserve (Figure 54), but not on any transect surveys. No other recognised coral diseases were observed.

Figure 55 Grazing damage on Porites massive sp. Grooves characteristic of grazing parrotfish damage are visible at left.

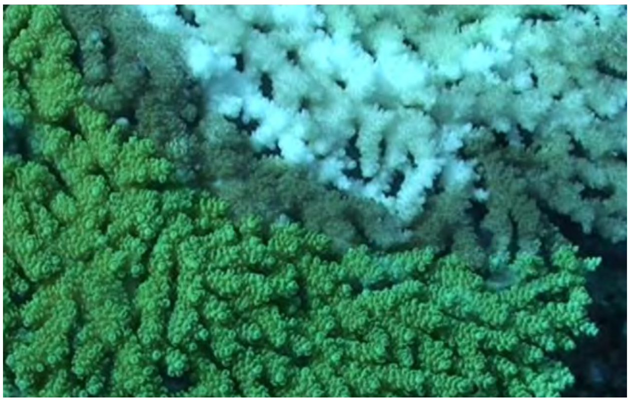


Figure 54 Brown Band Disease on tabulate Acropora, Tetepare Marine Reserve. No cases of this disease were recorded in the transect surveys.

CORAL COMMUNITY STRUCTURE AND BENTHIC GROUP COMPOSITION

Summary data for coral community structure and benthic substrate group composition are shown in Appendix 1.

Overall patterns in benthic substrate group composition showed the main differences between sites to be variations in coral cover (versus turf algal cover), which ranged from 6% (transect 35, Madou forereef) to 65% (transect 19, Haipe Pinnacle). However, coral cover was very similar between forereef and lagoon environments (32.2 ± 5.5% versus 32.7 ± 6.6% respectively). The main substrate type differences between forereef and lagoon environments were predominately sand (greater in the lagoon) versus crustose coralline algae (greater on the forereef)(Figure 56).

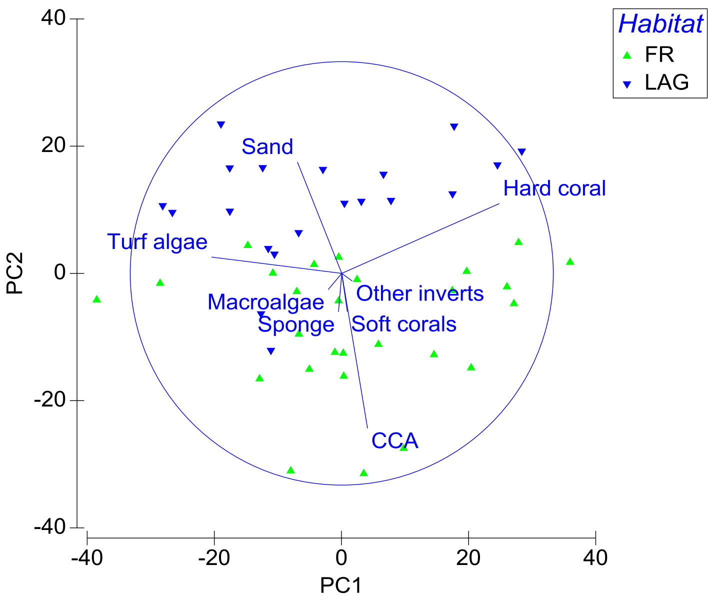


Figure 56 Principal components analysis (PCA) of major substrate cover across all transects. Sites separate along a gradient of hard coral cover versus turf algal cover (PC1) and crustose coralline algae versus sand cover (PC2). PC2 describes the main distinction between forereef (green symbols) and lagoon (blue symbols) environments.

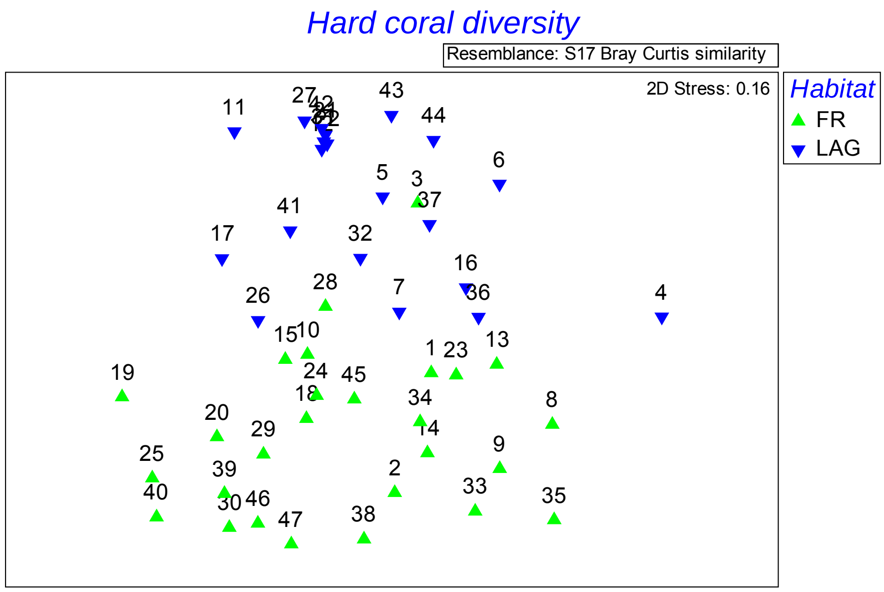


Figure 57 Multidimensional scaling ordination (MDS) of coral genus cover. FR = forereef, LAG = lagoon. Numbers refer to transect number.

Coral genus richness and diversity (Shannon H') were also very similar between forereef and lagoon sites (Appendix 1), however MDS and ANOSIM analysis showed a significant difference in community composition between the two (ANOSIM R = 0.52, p = 0.001; Figure 57). SIMPER (Similarity Percentages) analysis in PRIMER 6 showed that the main contributers to this distinction were *Porites,* which dominates the lagoon coral community and *Acropora* and *Montipora* species which dominate the forereef.

CORAL DISEASE SUSCEPTIBILITY BY GENUS

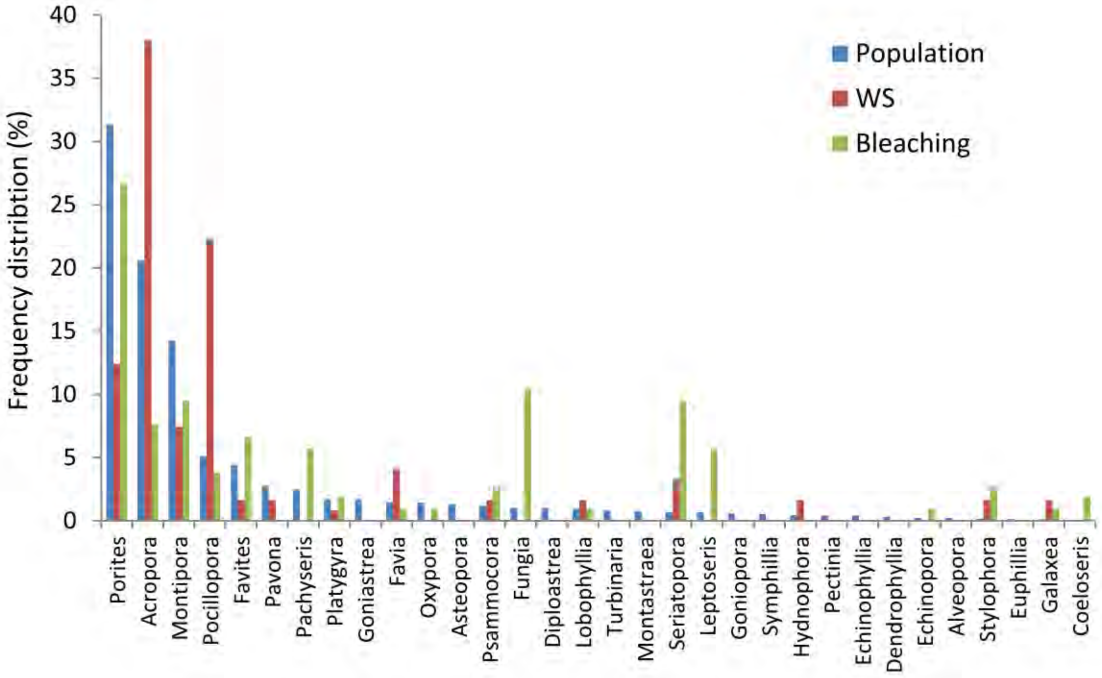


Figure 58 Frequency distributions by hard coral genus and occurrence of WS and bleaching. In addition to those displayed, 9 low-abundance genera (<= 0.1%) were recorded but with no cases of bleaching or WS. Genus-specific susceptibility was calculated as the ratio of syndrome to population frequency and this was multiplied by the percent cover of each genus to calculate a site susceptibility index based on the distribution of susceptible

There were strong differences in susceptibility to both bleaching and disease between coral genera (Figure 58). The strongest genus specificity in susceptibility was in the unidentified syndrome which only affected Porites massive species (Figure 51), however WS also showed strong genus-level specificity in susceptibility. In this case, susceptibility was defined as an index determined by the ratio of the (relative) prevalence of the syndrome within a genus to its relative prevalence within the population. *Acropora* and *Pocillopora* species showed the highest prevalence of White Syndrome (WS), which was also strongly over-represented in relation to their abundance within the population. Other genera which were less abundant also had a relative over-representation of WS, such as Favia, Psammocora, Lobophyllia, Seriatopora, Hydnophora, Stylophora and Galaxea. Porites species showed the highest bleaching prevalence, but this was lower than expected given the dominance of this genus within the community. In contrast, bleaching prevalence was strongly over-represented in Fungia, Seriatopora, Favites, Pachyseris, Leptoseris, Echinopora, Stylophora, Galaxea and Coeloseris in relation to their population abundance distribution. In fact the latter genus was rare enough that it was not recorded in point-count analyses of the transects, but accounted for almost 2% of bleaching cases observed. As has recently been reported for coral

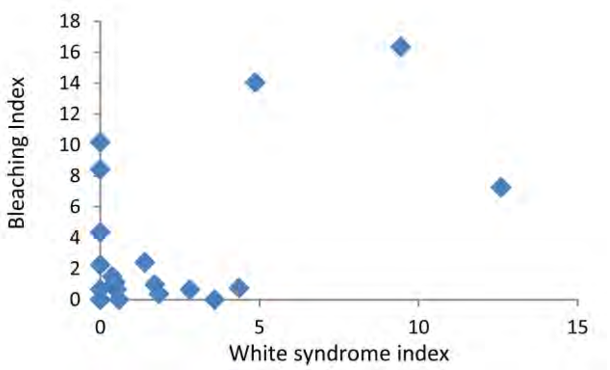


Figure 59 Bleaching versus WS susceptibility index for 41 genera recorded in the surveys. The significant (R = 0.61, p < 0.001) relationship is unduly influenced by 3 genera susceptible to both syndromes and 19 genera with no cases of either.

Families by Palmer et al (2010), there was a significant relationship between bleaching and disease susceptibility by Genus (R = 0.61, p < 0.001, Figure 59). However, this relationship was strongly influenced by only 3 genera that were highly susceptible to both bleaching and WS (Seriatopora, Stylophora and Galaxea), along with 19 genera that showed no cases of either, despite representing in total nearly 9% of the coral community. In between were several genera with high WS but low bleaching indices (Acropora, Pocillopora, Pavona, Favia, Hydnophora) and vice versa several genera with high bleaching but low WS indices (Pachyseris, Leptoseris, Fungia, Echinopora). Susceptibility to both bleaching and disease therefore appears to be the exception rather than the rule at the genus level.

Since both bleaching and WS showed genera-specific variations in susceptibility, when comparing sites it will be useful to account for coral community composition to determine the extent to which variations between sites (and related factors such as water quality or protected area status) may be due to differences in susceptibility of genera present in the community, rather than local stresses due to environmental factors. To determine this, the genus-specific susceptibility indices, above, were multiplied by the proportional area cover of each genus to provide site-specific susceptibility indices (Appendix 1). Since there is some circularity in using local susceptibility to control for between-site variability in susceptible coral distributions, a 'global index' was also calculated based on published data for the Great Barrier Reef using methods published by Palmer et al (2010)[35]. This global index correlated with local site susceptibility indices for both bleaching (R = 0.32, p = 0.019) and WS (R = 0.8, p < 0.001), supporting the relevance of the local susceptibility indices.

CORAL DISEASE AND BLEACHING IN RELATION TO COMMUNITY COMPOSITION

Across the entire survey, there was a strong positive relationship between the site susceptibility index and WS prevalence (Figure 60A), but no significant relationship with bleaching prevalence (Figure 60B). Since prevalence rates (% per coral colony) already factor in the increased number of case observations in areas of higher coral cover, the positive relationship with WS prevalence indicates a host population density effect (specifically population density of more susceptible genera) on coral disease rates, likely related to increased transmission rates and risk of disease in more densely populated areas. The lack of a relationship for bleaching prevalence indicates the lack of a host density effect, which supports the conclusion that bleaching cases observed were mainly related to environmental impacts (e.g. elevated temperatures), rather than the result of a transmissible disease.

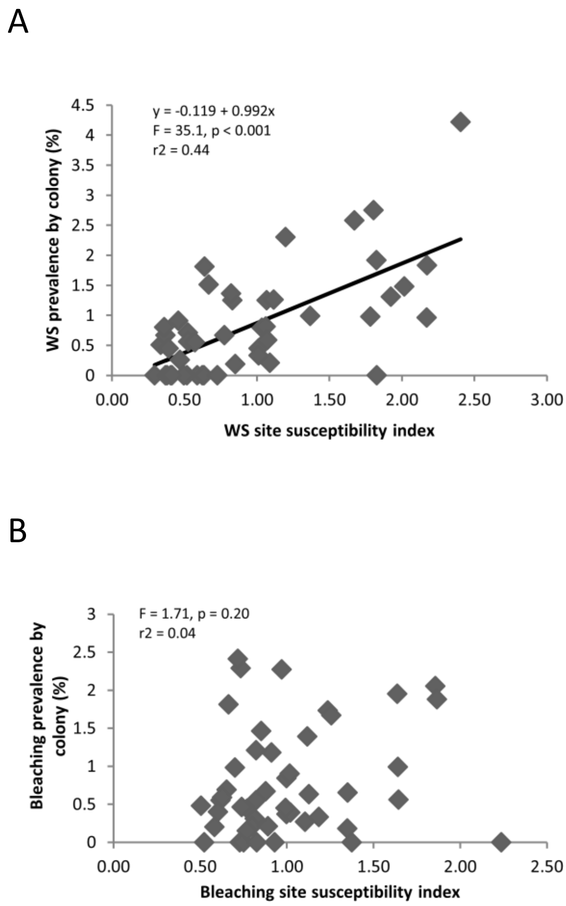


Figure 60 Relationships across the 47 survey sites between WS (A) and bleaching prevalence (B) and site susceptibility index (a factor of genera susceptibility x cover). Regression ANOVA results and fitted regression data are shown.

Multidimensional scaling (MDS) analysis of community composition showed that the greatest differences in the coral community were between forereef and lagoon sites, with the drop-offs dominated by either *Acropora, Montipora* or a combination of the two and the lagoon sites dominated by *Porites* species (Fig 16). Similarity percentages (SIMPER) analysis showed that these three genera explained ~60% of the variance between forereef and lagoon sites. The local site susceptibility to WS closely followed the abundance of *Acropora* species (Figure 61E) and the prevalence of WS was also highest in these *Acropora*-dominated sites (Figure 61F). In contrast, the patterns of bleaching susceptibility showed no clear relationships between sites (Figure 61G). Bleaching prevalence did not apparently follow these patterns in susceptibility (Figure 61H), but also showed no clear patterns between sites in relation to the coral community structure.

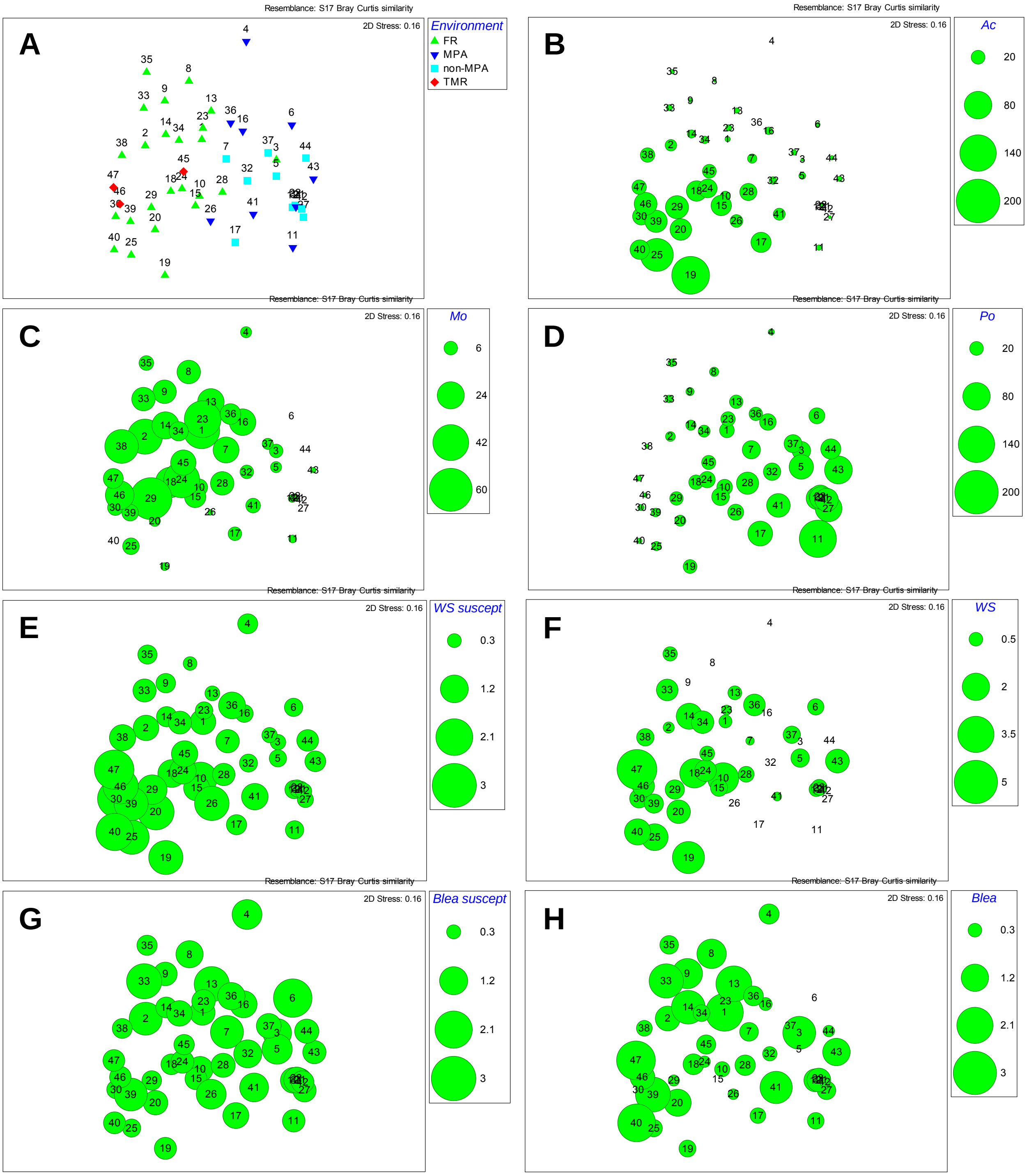


Figure 61 MDS analysis of coral genus community structure. A) Fore reef (FR) and lagoon (MPA and non-MPA) sites are distinguished. The reference site in Tetepare Marine Reserve (TMR) is highlighted in red. Numbers refer to transect number (cf. Table 1). B) Bubble plot showing *Acropora* species cover. C) Bubble plot showing *Montipora* species cover. D) Bubble plot showing *Porites* species cover. These three genera explain ca. 60% of the dissimilarity between fore reef and lagoon sites (SIMPER analysis) with either *Acropora* or *Montipora* dominating fore reef sites

and Porites dominating the lagoon. E) WS susceptibility index. F) WS prevalence rate (%). G) Bleaching susceptibility index. H) Bleaching prevalence (%). There was an overall significant difference in coral community structure between environments (ANOSIM R = 0.33, p = 0.001), with significant pairwise differences between fore reef and lagoon (p = 0.001), but not between MPA and non-MPA sites in the lagoon (p = 0.45). There was also no significant difference between non-protected fore reef sites and the offshore TMR (p = 0.88).

DISEASE AND SYNDROME PREVALENCE IN LAGOON VERSUS FOREREEF SITES

The prevalence of all syndromes apart from the unidentified syndrome (UID) on *Porites* massive species was higher at offshore, forereef sites than in lagoon sites (Figure 62), although differences in grazing damage were not significant. The greater prevalence of Porites UID in the lagoon was undoubtedly due to the dominance of *Porites* species in the lagoon environments.

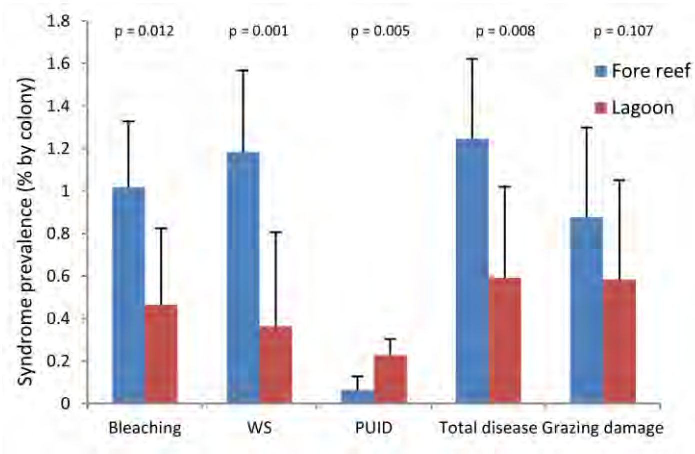


Figure 62 Syndrome prevalence (mean ± 95% CL) by colony (%) between forereef and lagoon sites. Results (p) for non-parametric Kruskal-Wallis tests are shown for each syndrome.

The higher bleaching prevalence on the forereef was not due to higher population densities of more bleaching-susceptible genera, however, since the site-specific bleaching index was actually higher in the lagoon, although the differences were not significant (F = 2.76, p = 0.10). This observation is therefore consistent with bleaching cases representing either a mild bleaching event or the early stages of a more major bleaching event, with temperature elevations in relation to ambient variations being more serious in forereef environments. In contrast, the higher prevalence of WS in forereef environments could be explained by differences in population abundance of WS-susceptible genera. The site susceptibility indices were significantly higher on the forereef (1.2 ± 0.25) than in the lagoon (0.64 ± 0.29)(F = 12.4, p = 0.001). If the residuals of the regression of WS prevalence vs. site susceptibility (Figure 60A) were compared, rather than the WS prevalence rates, then there was no significant difference between forereef and lagoon sites (F = 1.94, p = 0.17). This analysis therefore shows no significant difference between the two environments, once the different population abundances of WS-susceptible species are taken into account. Higher WS frequencies have previously been detected at offshore versus inshore sites on the GBR, but this is the first time that such inshore-offshore effects have been explained by differences in abundance of more- or less-susceptible host species.

This inshore versus lagoon gradient, whereby WS prevalence increased with increasing water quality offshore, was also mirrored in an E-W gradient of increasing water quality, which occurs because the lagoons are more open and better flushed towards the west. There was a weak but significant relationship between E-W location and WS incidence (F = 5.86, p = 0.02, r^2 = 0.12), with disease incidence increasing towards the west (i.e. increasing with higher water quality). However, this relationship was again not significant when location was regressed against site susceptibility-corrected disease rates (F = 0.13, p = 0.72), implying that this relationship was also due to an increase in the abundance of WS-susceptible coral taxa towards the clearer waters to the west.

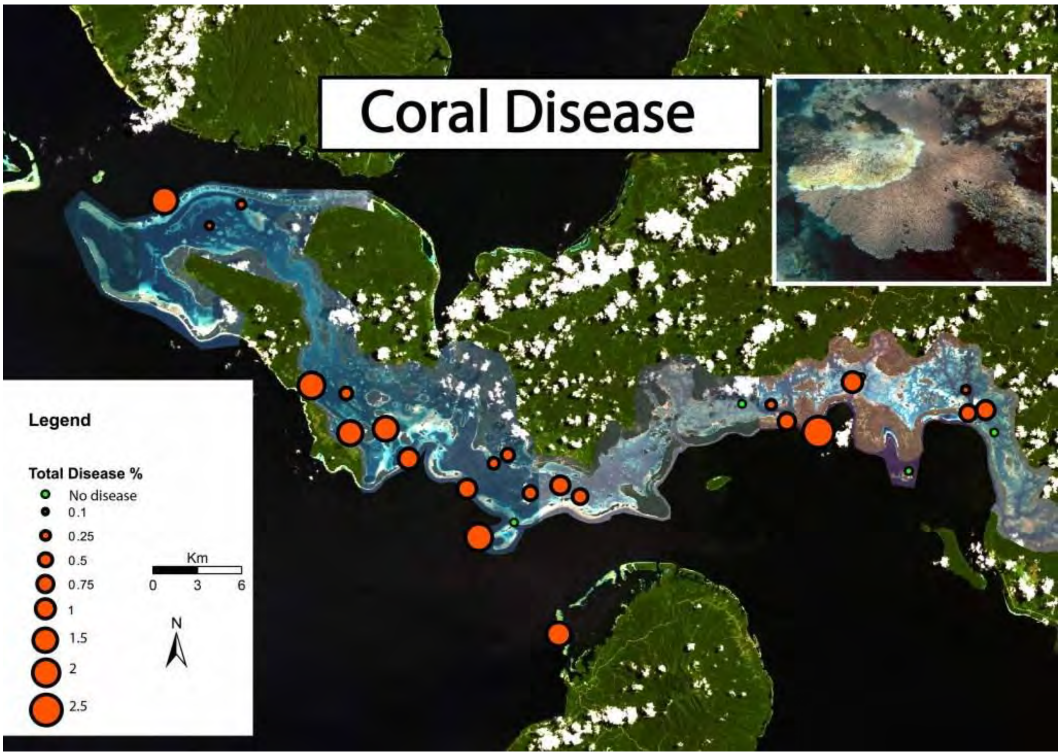


Figure 63 Spatial distribution of total disease prevalence across the Roviana region

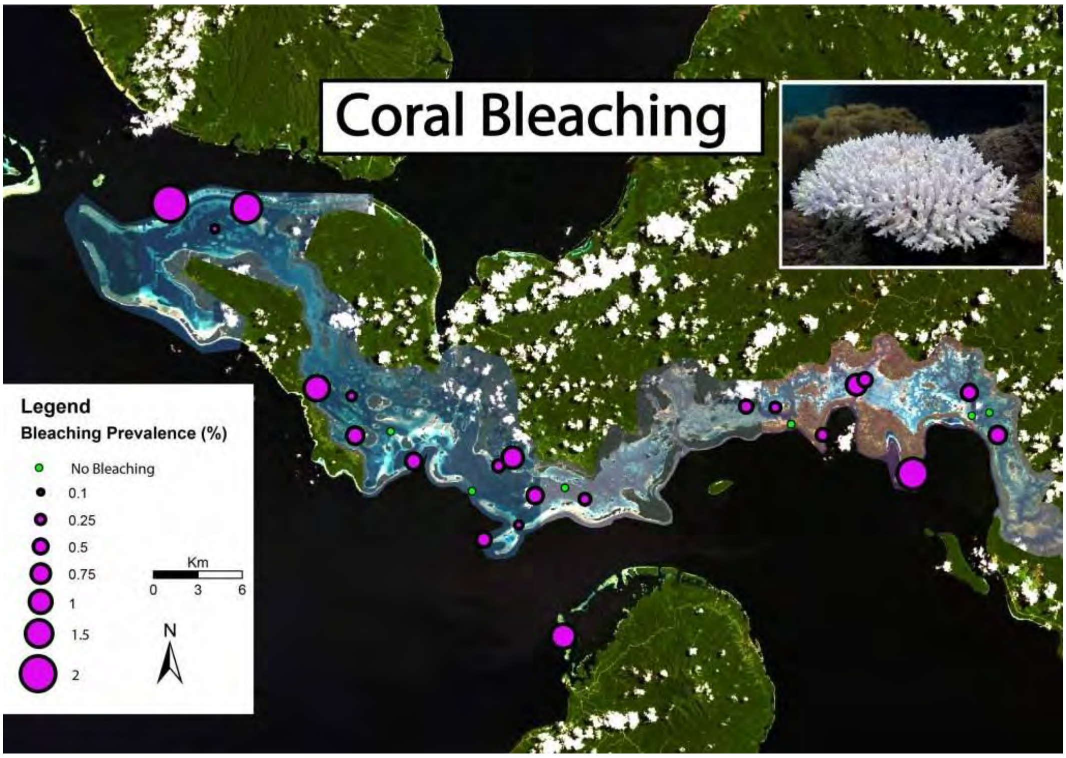


Figure 64 Spatial distribution of bleached coral colonies across the Roviana region

MARINE PROTECTED AREA (MPA) EFFECTS

There were no significant differences in any disease or syndrome inside versus outside the MPAs (Figure 65). However, the current levels of protection and operation of the MPA network is uncertain. Nusa Hope MPA is one that is being well-implemented, and in this case all indicators showed that the health of the MPA was better than that of the non-MPA reference site (compare transect 11; MPA versus 12; non-MPA, Appendix 1).

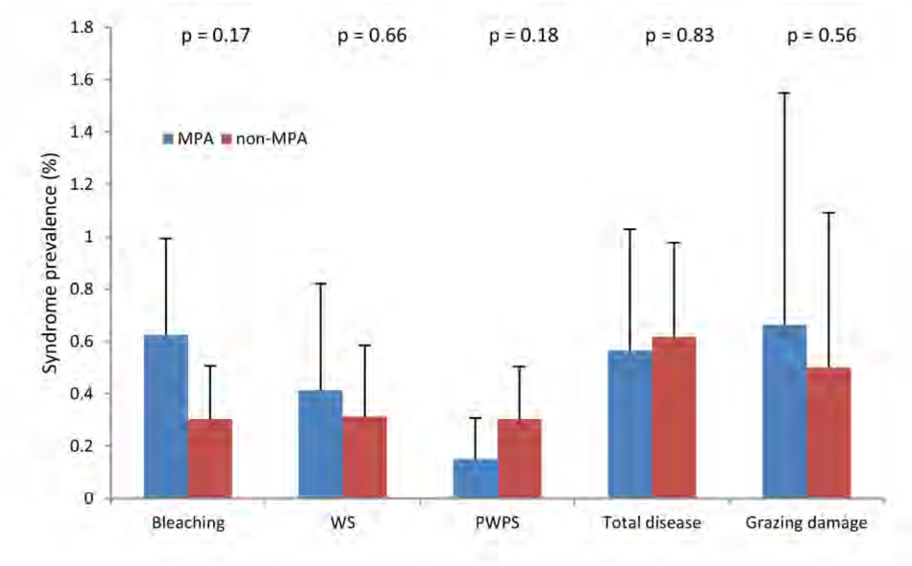


Figure 65 Syndrome prevalence (mean ± 95% CL) by colony (%) between MPA and paired reference sites outsite the MPA. Results (p) for paired samples t-test are shown for each syndrome

CONCLUSIONS

1. Coral disease diversity was generally low across the sites surveyed with only one previously-recognised coral disease (white syndrome, WS) encountered across 47 transects throughout the survey area.

2. Disease prevalence rates were also relatively low, although WS prevalence rates of >1% in offshore drop-offs was a concern, given the rapid rates of lesion progression and high frequency of mortality reported for this disease.

3. A mild bleaching event was ongoing at time of surveys, mostly affecting susceptible *Fungia, Seriatopora, Favites, Pachyseris, Leptoseris, Echinopora, Stylophora, Galaxea* and *Coeloseris* species. The bleaching susceptibility across taxa broadly followed those shown elsewhere and patterns of bleaching prevalence were not correlated with host population densities, suggesting the event was mainly a direct environmental impact rather than effects of transmissible diseases. Bleaching was higher in offshore drop-off areas and this could not be explained by any greater abundance of bleaching-susceptible genera in these environments. This suggests that the relative temperature stress effect was greater in the offshore areas.

4. WS prevalence was higher on the offshore drop-off reefs and towards the clearer waters of the lagoons at the western end of the survey area. Unlike bleaching prevalence, WS prevalence was strongly related to the abundance of WS-susceptible genera (mainly *Acropora* and *Pocillopora*, but also *Favia, Psammocora, Lobophyllia, Seriatopora, Hydnophora, Stylophora and Galaxea*). This relationship implies a host-density effect, likely indicative of higher disease transmission rates in

areas with higher cover of susceptible species. Residuals analysis showed that the significant inshore-offshore and E-W increases in WS prevalence could be explained by the greater host-density of WS-susceptible species in these areas.

5. Two unusual syndromes (focal bleaching patterns and an unidentified syndrome on massive *Porites* species) were further investigated by photo-monitoring and, in the latter case, analysis of bacterial DNA profiles. Neither syndrome showed significant advance rates and no differences could be detected in bacterial DNA profiles between healthy and disease lesion tissues. We conclude that the focal bleaching patterns do not represent a progressive disease and the *Porites* syndrome appears to have arrested by the time of the survey, although the presence of significant lesions indicate that a disease or unusual grazing mortality occurred in the recent past.

6. No significant differences in syndrome or disease prevalence could be detected inside and outside of the existing network of MPAs within the lagoons, so the MPAs do not currently appear to act to improve or reduce coral resistance or alter species composition in favour of more or less-susceptible taxa. The lack of significant differences in grazing damage also suggests that scraper and excavator herbivore populations are not significantly higher inside the MPAs. However, this overall lack of significant differences may be due to the variable levels of implementation of protection measures. In one MPA, Nusa Hope, where management activities are known to be implemented well, it was notable that very low bleaching and disease levels were recorded and coral cover and diversity was much higher than at the reference site outside the MPA.

Recommendations

1. Because of the widespread and relatively high prevalence of white Syndrome (WS) in the reefs of the Roviana-Vonavona lagoons and offshore reefs, it would be advisable to establish some long-term monitoring stations to track progress and assess the potential threats to coral ecosystem structure and function. Alternatively, an early warning system might be established using existing dive centre staff. This disease represents a significant threat to the reef system and is strongly linked to sea temperature increases.

2. The surveys suggest that the reef system is already being impacted by climate change and because of the additional impacts, the need to reduce ongoing human impacts is greater than before. An obvious, locally-manageable impact is anchor damage, and it would be wise to investigate possible interventions to reduce this damage.

3. Although macroalgal overgrowth is not generally an issue, there are some areas of significant macroalgal growth. Any possible methods to reduce fishing effort on parrotfishes and other herbivores (education programmes, improved uptake of MPA restrictions) should be undertaken to minimise the risk of a widespread phase shift.

4. While the MPA network may be a useful tool for fisheries management, at present there do not appear to be any additional benefits arising from the MPAs relating to improved climate change resilience or adaptation in the benthic communities. It would be useful to review possible management alternatives (for example anchor damage initiatives as above) to attempt to introduce relatively cost-effective additional interventions and practices to improve climate change mitigation and adaptation. Given the issues with WS impacts, the creation of additional MPAs in offshore areas is an important consideration. While there was not enough statistical replication to determine the effects of MPA implementation, in the one area which is known to be well-implemented (Nusa Hope), there was much lower disease and bleaching and higher coral cover. Higher grazing rates also indicate higher herbivore populations, suggesting higher resilience to phase-shifts to macroalgal domination. It is therefore strongly recommended that implementation of MPA procedures is maintained across the existing MPA network.

Transect	Site No.	E-W loc	Depth (m)	Location (lagoon/ forereef)	MPA?	Dominant hard coral families (>10% relative abundance)	Coral colony count (per 50 x 0.63 m transect)	Coral colony population density (m^{-2})	Hard coral cover (%)	Hard coral genus richness (S)	Hard coral diversity (Shannon H')	Hard coral dominance (Simpson D)	Live:Dead coral index	Soft coral cover (%)	Soft coral family richness (S)	Macroalgal cover (%)	Crustose coralline algae (%)	Sponge cover (%)	Turf algae (%)	Sand (%)	Other invertebrates (%)	Global coral community susceptibility index (0-1; least-most)	Local (Solomon Islands) WS susceptibility index	Local (Solomon Islands) bleaching susceptibility index	Bleaching prevalence (% by colony)	WS (% by colony)	Porites WPS (% by colony)	Total disease (% by colony)	Grazing damage (% by colony)
1	1	1	20	FR	N	Mo, Po	220	7.0	25	6	1.05	0.44	1.40	19	3	11	12	12	18	0	3	0.68	1.01	0.97	2.27	0.45	0	0.45	2.73
2	1	1	10	FR	N	Mo, Ac, Po	303	9.6	25	8	1.41	0.34	0.87	5	1	5	12	19	29	1	5	0.73	1.01	1.64	0.99	0.33	0	0.33	1.32
3	1	1	5	FR	N	Po, Go, Mt	405	12.9	28	12	1.93	0.23	1.24	5	3	4	25	13	23	3	1	0.55	0.37	1.24	1.73	0	0	0	1.23
4	2	1	4	LAG	MPA	Gn, Fa, Fv, As	306	9.7	19	7	1.80	0.19	0.70	0	0	15	0	5	25	33	2	0.53	0.62	1.35	0.65	0	0	0	0
5	3	1	4	LAG	N	Po, Fv	219	7.0	43	11	1.77	0.28	0.90	0	0	4	0	2	36	3	0	0.60	0.46	1.38	0	0.91	0	0.91	1.37
6	4	1	4	LAG	MPA	Po, Pv, Le	282	9.0	31	10	1.97	0.18	0.55	0	0	2	1	1	50	7	2	0.54	0.52	2.24	0	0.71	0	0.71	0
7	5	1	4	LAG	N	Po, Mo	535	17.0	39	18	2.33	0.15	1.63	0	0	10	0	7	24	11	8	0.66	0.85	1.64	0.56	0.19	0	0.19	0.19
8	6	2	20	FR	N	Pa, Mo, Pv, Po, Eh	216	6.9	30	10	1.98	0.16	2.20	4	4	5	40	7	14	0	0	0.60	0.29	1.12	1.39	0	0	0	1.85
9	6	2	10	FR	N	Mo, Fv, Po	137	4.3	17	8	1.67	0.24	0.64	2	2	8	41	5	27	0	0	0.60	0.59	0.85	1.46	0	0	0	1.46
10	6	2	5	FR	N	Pc, Po, De, Ac, Mo	271	8.6	31	9	1.83	0.20	1.88	2	2	5	15	21	17	0	9	0.74	1.67	1.00	0.37	2.58	0	2.58	1.11
11	7	2	4	LAG	MPA	Po	227	7.2	59	9	0.83	0.68	2.58	0	0	0	0	1	23	17	0	0.70	0.52	0.77	0.44	0	0	0	3.96
12	8	2	4	LAG	N	Po, Lo	356	11.3	23	6	0.84	0.61	0.43	0	0	0	2	4	55	15	1	0.68	0.53	1.00	0.84	0.56	0.56	1.12	2.53
13	9	3	20	FR	N	Pa, Mo, Po	195	6.2	34	10	1.94	0.17	1.15	17	3	1	8	11	30	0	0	0.64	0.34	1.86	2.05	0.51	0.51	1.02	0.51
14	9	3	10	FR	N	Mo, Po, Go, Ac	221	7.0	21	10	1.80	0.22	1.38	7	3	0	41	6	15	0	10	0.62	0.64	0.66	1.81	1.81	0	1.81	0.45
15	9	3	5	FR	N	Ac, Po, Mo	378	12.0	44	12	1.93	0.20	3.67	0	0	1	29	11	12	0	4	0.74	1.03	0.73	0	0.79	0	0.79	1.32
16	10	3	4	LAG	MPA	Pv, Po, Mo	369	11.7	49	12	2.20	0.14	1.33	0	0	0	0	6	15	6	1	0.55	0.49	1.11	0.27	0	0.27	0.27	0.27
17	11	3	4	LAG	N	Po, Ac, Pa, Tu	257	8.2	57	7	1.48	0.26	2.28	0	0	3	0	1	4	14	0	0.67	0.63	1.02	0.39	0	0	0	0
18	12	4	20	FR	N	Ac, Mo, Po	434	13.8	39	11	1.67	0.25	3.08	2	3	4	26	12	13	4	1	0.76	1.20	0.65	0.69	2.3	0	2.3	0
19	12	4	10	FR	N	Ac, Po	437	13.9	65	10	0.96	0.60	6.53	6	1	0	16	4	10	0	3	0.83	1.80	0.74	0.46	2.75	0	2.75	0
20	12	4	5	FR	N	Ac, Pc, Fv, Po	338	10.7	41	11	1.73	0.24	1.20	0	0	2	12	7	34	0	2	0.78	2.02	0.91	1.18	1.48	0	1.48	0.3
21	13	4	4	LAG	MPA	Po	320	10.2	16	3	0.20	0.92	0.30	0	0	2	6	5	19	18	0	0.69	0.38	0.82	0.31	0	0.63	0.63	0.63
22	14	4	4	LAG	N	Po	451	14.3	23	6	0.81	0.62	0.81	1	1	1	1	26	18	19	0	0.67	0.37	0.75	0	0.67	0.22	0.89	0
23	15	5	20	FR	N	Mo, Po, Ox, As	388	12.3	35	10	1.68	0.25	1.21	5	3	1	6	14	28	7	2	0.67	0.47	0.83	0	0.26	0	0.26	0.26
24	15	5	10	FR	N	Mo, Ac, Po, Fv	479	15.2	49	10	1.83	0.20	3.20	10	1	0	11	10	15	3	2	0.71	1.07	0.80	0.21	1.25	0	1.25	0.21
25	15	5	5	FR	N	Ac, Pc	416	13.2	52	7	0.99	0.55	6.78	2	1	5	17	13	8	0	4	0.83	1.82	0.50	0.48	1.92	0	1.92	0
26	16	5	4	LAG	MPA	Po, Ac, Pc	545	17.3	20	5	1.26	0.33	0.57	0	0	3	3	32	31	0	7	0.82	1.83	1.35	0.18	0	0	0	0
27	17	5	4	LAG	N	Po	543	17.2	26	3	0.19	0.93	0.81	1	1	0	8	16	31	15	1	0.70	0.40	0.82	0.55	0	0.55	0.55	0.37
28	18	5	20	FR	N	Po, Ac, Mo	448	14.2	45	11	1.72	0.24	3.46	6	1	4	13	16	13	4	0	0.71	0.78	0.88	0.67	0.67	0.45	1.12	0.89
29	18	5	10	FR	N	Mo, Ac, Po	504	16.0	52	8	1.46	0.29	5.03	18	1	0	12	6	10	0	2	0.77	1.37	0.58	0.2	0.99	0.2	1.19	0.4
30	18	5	5	FR	N	Ac, Pc, Mo	313	9.9	21	6	1.27	0.35	0.55	11	1	2	22	7	37	0	0	0.86	2.17	0.52	0	0.96	0	0.96	0.64
31	19	5	4	LAG	MPA	Po	221	7.0	18	3	0.18	0.93	0.34	0	1	0	5	2	45	21	0	0.70	0.39	1.02	0.9	0.45	0	0.45	1.36
32	20	5	4	LAG	N	Po, Ac, Di, Mo	304	9.7	18	6	1.28	0.39	0.59	9	1	0	14	22	27	5	1	0.69	0.50	1.19	0.33	0	0.33	0.33	0
33	21	6	20	FR	N	Mo, Po, Ms, Ac	160	5.1	14	8	1.74	0.24	0.30	5	1	14	5	5	47	7	3	0.71	0.83	1.87	1.88	1.25	0	1.25	4.38
34	21	6	10	FR	N	Di, Po, Mo, Ac	221	7.0	20	8	1.78	0.20	1.00	17	2	20	14	8	20	0	2	0.72	0.82	0.99	0.45	1.36	0	1.36	0
35	21	6	5	FR	N	Mo, Po, Ac, Hy	183	5.8	6	4	1.24	0.32	0.10	8	1	7	6	7	54	8	1	0.66	0.57	0.62	0.55	0.55	0.55	1.1	0.55
36	22	6	4	LAG	MPA	Po, Mo, Fv, Pv, Fa	318	10.1	21	11	1.93	0.18	0.71	0	0	1	0	4	28	42	1	0.57	1.12	1.13	0.63	1.26	0.31	1.57	0
37	23	6	4	LAG	N	Po, Mt, Fv	249	7.9	31	11	1.98	0.19	1.09	0	0	2	1	10	19	27	0	0.59	0.36	0.93	0	0.8	0.8	1.6	0.4
38	24	7	20	FR	N	Mo, Ac	247	7.8	22	6	1.11	0.42	1.46	3	3	1	14	37	14	7	0	0.73	1.06	0.60	0.4	0.81	0	0.81	0.4
39	24	7	10	FR	N	Ac, Mo	307	9.7	30	8	1.44	0.37	0.98	1	2	0	8	19	27	11	1	0.84	1.78	1.64	1.95	0.98	0	0.98	0
40	24	7	5	FR	N	Ac, Pc	218	6.9	18	5	0.81	0.60	0.35	1	1	1	2	10	28	13	5	0.87	2.17	0.73	2.29	1.83	0	1.83	0
41	25	7	4	LAG	MPA	Po, Ac, Hy	478	15.2	42	14	1.85	0.26	1.64	0	0	0	0	13	20	18	2	0.68	1.09	1.26	1.67	0.21	0	0.21	0.42
42	26	7	4	LAG	N	Po, Pv	665	21.1	21	2	0.31	0.83	0.54	0	1	1	0	7	21	31	1	0.67	0.41	0.77	0.15	0	0.15	0.15	0.15
43	27	6	4	LAG	MPA	Po, Pv	331	10.5	58	13	1.79	0.27	2.47	0	0	0	0	8	13	10	1	0.56	0.67	0.82	1.21	1.51	0.3	1.81	0
44	28	6	4	LAG	N	Po, Pv, Pl	469	14.9	40	12	1.81	0.22	1.01	0	0	0	3	5	18	13	0	0.60	0.73	0.89	0.21	0	0.43	0.43	0
45	29	8	20	FR	MPA	Mo, Po, Ac	169	5.4	26	8	1.68	0.22	0.90	4	2	4	2	25	29	1	9	0.72	1.07	0.63	0.59	0.59	0	0.59	0
46	29	8	10	FR	MPA	Ac, Pc, Mo	306	9.7	50	11	1.68	0.24	12.42	4	1	1	2	10	4	0	29	0.79	1.92	0.70	0.98	1.31	0	1.31	0.65
47	29	8	5	FR	MPA	Pc, Ac, Mo	166	5.3	29	11	1.86	0.21	0.70	0	1	2	6	4	41	0	16	0.82	2.40	0.72	2.41	4.22	0	4.22	3.01

Appendix 1. Summary data from transect surveys.

MARINE RESOURCES AT RISK TO CLIMATE CHANGE

The highly dynamic nature of Roviana in terms of water quality (specifically temperature and salinity) has likely built a high level of resilience into marine organisms that will help to reduce impacts of climate change. On a regional scale, fluctuations in climate and marine water quality in Roviana is predominantly driven by El Nino Southern Oscillation (ENSO). ENSO driven changes in sea surface temperature (SST), rainfall and sea level are generally more significant than projected global climate change impacts on those parameters within the next 50-100 years. This existing exposure to ENSO driven fluctuations in SST, rainfall and sea level will add to the resilience of marine ecosystems under future climate change scenarios. In addition, the Roviana people are dynamic and harvest a broad range of marine species. This diversity of food sources provides an inherent resilience to climate change impacts on any specific species. What is more relevant in the Roviana context is climate change impacts at the ecosystem or habitat scale. Whilst tropical marine ecosystems are already dynamic and resilient (Nyström and Folke 2001), there will be variable impacts of climate change on different ecosystems.

MANGROVE

Mangrove ecosystems are particularly vulnerable due to sea level rise. As sea level rises, the seaward fringe of mangrove forests will become inundated and die. Due to the variation in breathing roots amongst mangrove species this will impact different species in different ways. Species such as Rhizophora are likely to be less susceptible due to their high breathing roots. In some cases, mangrove ecosystems will be able to expand landward. The ability for mangroves to expand landward depends on the fine scale coastal topography. In areas of steep topography, the expansion landwards is expected to be less than the seaward inundation hence a net loss. In areas with large flat topography landward of mangroves forests this landward expansion may in fact results in net gain of mangrove area post sea level rise. In addition, the re-distribution of sediment as a result of altered supply and hydrodynamics may provide new mangrove habitats and limit the inundation of existing forests, however this is theoretical and difficult to predict spatially.

SEAGRASS

Seagrass ecosystems are likely to be influenced by three climate change parameters; sea level rise, increased CO_2 concentration and increased seawater temperature. The upper tidal range of seagrass is typically mean sea level, hence as sea level rises new areas of shallow intertidal habitat will become available for seagrass colonisation. The lower depth range of seagrass is governed by light availability and specific for different species. Generally seagrass would gradually contract from deeper areas as sea level rises and light availability reduces. The balance between contraction at the deep edge and expansion into shallow areas is dependent on bathymetry. Elevated CO2 concentrations are likely to increase the productivity of seagrass and hence lower their light requirements-negating some of the contraction due to sea level rise. It is difficult to predict the impact of seawater temperature on seagrass in Roviana. Shallow seagrass meadows are currently exposed to a range in seawater temperatures from 20- 38 degrees, and hence are expected to be somewhat resilient to increases of 1-2 degrees expected under climate change scenarios. Currently in Roviana it appears seagrass range and distribution is primarily restricted due to nutrient availability, with seagrasses dominating in areas of poorer water quality and evidence of recent expansion as a result of elevated terrestrial sediment inputs (logging). Therefore it is unlikely that climate change will significantly impact seagrass meadows in Roviana.

Coral Reef

The primary climate impacts on coral reefs in Roviana will be increased coral bleaching and disease from higher seawater temperatures and increased coral mortality from acidification of seawater. This increased coral mortality will be particularly sever on outer reefs around barrier islands in Roviana due to the lack of exisiting variability in seawater temperature and pH. The inherent high variability in temperature and pH of Lagoon reefs will likely limit the climate impacts on these systems. The influence of acidification on reefs within lagoon environments regularly flushed with freshwater is unknown, however regional scale predictions indicate corals in the Solomon region will start to be impacted by acidification by 2050. In Roviana it would seem likely that coral bleaching, disease and acidification impacts will yield ideal substrate for algal growth and hence herbivorous fishes may be favoured under climate change scenarios.

Pelagic

The primary resource of interest in pelagic waters surrounding Roviana is Tuna, specifically; skipjack, island bonito and yellowfin. Tuna stocks are highly influenced by sea water temperatures, with high biomass of tuna found in areas of sharp gradients in water temperature. These water temperature gradients and tuna biomass is expected to be significantly impacted by climate change, with the majority of projections indicated an eastwards shift in tuna biomass. Hence Solomon waters can expect a reduction in tuna stocks under climate change scenarios. However it should be noted these projections are for commercial quantities of tuna. With a purse-seine vessel catching 20-200 tonnes of tuna per day, small decreases in tuna stocks can have a significant impact on profit margins. However in the subsistence context of Roviana fishermen typically paddle 1-5 km out to schools of tuna and catch 5-30 fish in a few hours before returning home. These tuna schools can have 1-100 tonnes of fish, with only a small percentage visible feeding on the surface. Hence the subsistence harvest of these tuna stocks as a percentage of standing stock is negligible, and therefore if standing stocks decrease by 10-30% under climate change scenarios it is unlikely to influence the subsistence harvest of tuna by Roviana people.

Management actions

Broad management actions over Roviana

Outputs from all scientific assessments have been specifically tailored towards providing practical advice to the community based marine resource management initiatives of the Roviana Conservation Foundation. Primarily the outcomes of scientific research have been incorporated in marine reserve design through a participatory process, rather than simply report delivery. Throughout all aspects of this project key decision makers within the Roviana community have been included in the design and implementation of the field work. This approach proved useful to directly communicate the scientific process and outcomes to the Roviana community and importantly provide opportunities for input of traditional knowledge into the process. Final outcomes of each biophysical research activity were presented spatially using GIS and printed onto large format colour maps for easy interpretation by community members. This process proved particularly useful in communicating scientific results in an appropriate manner. These maps and key findings were then taken to each village by Roviana Conservation Foundation staff and discussed in local language with the local community members.

It is generally understood that changes in SST and acidification will lead towards decrease in coral survival and a transition towards macro-algal dominated systems. The two key factors that determine the balance between coral and algae are water quality and herbivory. Therefore the best action local management groups can take is to manage water quality and herbivorous fish populations to increase the resilience of coral reefs from these algal phase shifts.

Given it is likely reef fish communities are likely to be more severely impacted by climate change than pelagic fish communities it is recommended that subsistence and artisanal harvests should, where possible, focus harvest pressure on pelagic fish. By reducing pressure on reef fisheries the key ecosystem processes such as herbivory will help to build the resilience of coral reefs to climate change impacts.

Surveys of mangrove forests indicated a high level of human disturbance around the coastal mangrove fringe. Generally this disturbance was associated with clearing for coconut or other agroforestry plantations. It is advisable to limit this clearing of mangroves where possible. It is understood the clearing is often

SPECIFIC MANAGEMENT WITHIN MARINE RESERVES

There are currently 23 marine reserves within the Roviana and Vonavona lagoon systems. This reserve network has been predominantly designed around traditional ecological knowledge and customary marine tenure systems. Whilst this local knowledge and tenure needs to continue to be the focus of the Roviana reserve network, there are some limitations that were observed as part of this study.

Figure 66 Marine reserves in Roviana and Vonavona lagoons

Offshore Reefs: There are currently no reserves that protect offshore reefs on the outside of the barrier islands or on small offshore islands. Given these reefs have higher coral diversity and are expected to be vulnerable to climate impacts of coral bleaching and disease it would be advisable to include them in the marine reserve network. This will maintain essential ecosystem processes on these reefs and maximise their resilience to climate perturbations. These offshore reefs are likely to be important refugia during disturbance events such as bleaching for a number of coral and fish species that are not found within the lagoon system.

Connectivity: Limited reserves (except Nusa Hope) that connect freshwater, mangrove, seagrass and reef habitats. Where possible we suggest reserves should include at least three of these four ecosystems. Particularly include mangrove areas with flat coastal topography to the landward edge to maximise opportunities for mangroves to keep pace with sea level rise. Seagrass habitats are under-represented in the marine reserve network. We suggest considering the inclusion of a part of the extensive seagrass bed to the east of Sasavele passage. This area has adjacent mangroves on the inside edge of the barrier island, an expansive seagrass meadow, small pools with coral fringes and is adjacent to the deep Sasavele passage.

Passages: Only the Nusa Hope reserve includes an area of a main passage between the lagoon and open sea. These passages are a critical part of the marine reserve network. Firstly, reefs within passages are exposed to a high variation in water temperature from 22-35 degrees as the area is the junction between cool fresh water, warm lagoonal waters and constant open ocean waters. This variability makes corals in passages more resilient to increases in water temperatures under climate change. Secondly, passages are important spawning areas for many fish species due to the high currents transporting larvae and hence by protecting these areas you are able to maximise the spill-over effect of the reserves in nearby areas and also protect fish during their most vulnerable time.

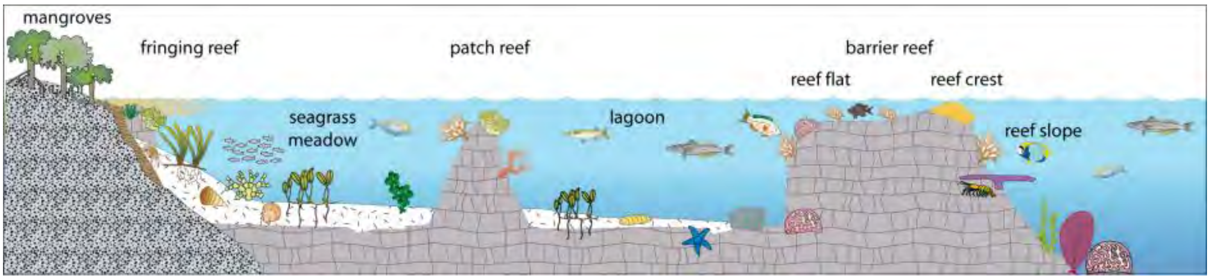


Figure 67 Conceptual diagram of a various habitats in Roviana Lagoon

CHAPTER 4

COASTAL FOREST VULNERABILITY ASSESSMENT

Norm Duke

Jock Mackenzie

Key Messages

- Mangrove ecosystems in Roviana are generally diverse, healthy and high biomass
- Mangrove biomass highest inshore, close to major river systems on New Georgia
- Major local threat to mangrove ecosystems is cutting associated with villages and plantations
- Sea level rise will impact some areas of mangroves more than others- depending on coastal topography and barriers to migration
- Dieback of mangroves in Rikiriki passage associated with land subsidence and sediment liquefaction following 2007 earthquake
- Extensive baseline video data of Roviana coastline collected that will be useful to assess future changes against

MANGROVES OF ROVIANA LAGOON – BIOMASS, BIODIVERSITY, CONDITION AND THREATS

OBJECTIVE

To Identify and map mangrove locations, condition and threats in Roviana Lagoon

METHODS

SHORELINE VIDEO ASSESSMENT METHOD (S-VAM)

Continuous digital video recording of mangrove shorelines was undertaken using the MangroveWatch S-VAM approach ((Duke and Mackenzie 2010, Mackenzie et al. 2011).

VIDEO IMAGERY DATA COLLECTION

Continuous digital video imagery of shoreline habitats was collected using a Sony Handycam HDR-XR200VE from a shallow-draft boat travelling parallel to the shoreline at a distance of ~50 m (or greater depending on tree height) and at a speed between 4 and 10 kts. The video camera was positioned to record directly perpendicular to the direction of travel at all times. A concurrent GPS 2-second interval track was recorded while filming. The GPS and Handycam were time synchronised such that video time matched the GPS time to the nearest 1 second. Voice recording of observations on mangrove species composition, structure, condition and threats were made during recording with local observations and context provided by a local boat driver.

VIDEO IMAGERY ASSESSMENT

The GPS 2-second interval track latitude and longitude were matched to video clip time in an excel spreadsheet. The video was used as a continuous visual line transect of shoreline habitats with random-stratified sampling. The time between two latitudes and longitudes was used as the sampling interval. Mangrove forest features visible in the video at each sampling interval were recorded against the subsequent lat/long. Point features were recorded using presence/absence. Continuous features were recorded to the point at which a change occurred. If a change in a continuous classification occurred within a sampling interval, the classification that represented the greatest proportion was used.

The average sampling interval distance was 4 m, with few time intervals greater than 2 seconds.

Shoreline Features Assessed

The following shoreline features were assessed using criteria-based visual classification.

Mangrove Forest Structure

The presence of mangrove forest zones (Low, Medium and High) were recorded with height, tree size growth form, and species composition used to indicate zone presence.

For each zone observed, an estimate of canopy height, stem density (openness), zone width and dieback intensity was recorded. Dominant canopy species were also recorded. Dominant species were determined from visual cues such as leaf colour, size and angle, bark colour and texture and root structures.

The overall condition of the forest was determined by weighting the dieback intensity score for each zone using the width score, such that the condition of the forest was proportional to the relative contribution of each zone to the overall forest width.

Mangrove Forest Classification Criteria

Mangrove Zone Classification

Low Zone: Low stature (<7 m tall) mangroves dominated by sprawling multi-stemmed *Rhizophora spp*. or stands of young Sonneratia located at the seaward fringe.

Mid Zone: Medium height (10 to 25 m tall) upright trees, dominated by *Rhizophora apiculata*, *Bruguiera gymnorhiza*, *Lumnitzera littorea* and *Sonneratia alba*.

High Zone: Large trees (15 to 30 m tall) in established forest bordering the landward fringe dominated by *Bruguiera gymnorrhiza*, *Rhizophora apiculata*, *Lumnitzera littorea* and *Heritiera littoralis*.

Mangrove forest height estimates were classified in the video using relative height classes (Table 18). Validation was achieved from actual heights measured and cross-referenced with a number of measurements.

Table 18 Mangrove Forest Height Estimate Classification (m).

	Short (1)	Medium (2)	Tall (3)	Very Tall (4)
Zone 1 (Low)	1.5	3	5	7
Zone 2 (Mid)	5	10	15	20
Zone 3 (High)	15	20	25	30

Mangrove forest width estimates were classified in the video using relative width classes (Table 19). Width measurements were assigned from cross-referencing with actual width measurements from Google Earth imagery.

Table 19 Mangrove Forest Width Estimate Classification (m).

	1	2	3	4
Zone 1 (Low)	15	30	60	120
Zone 2 (Mid)	25	50	100	200
Zone 3 (High)	25	50	100	200

Stem density classification represents the density relative to recorded stem densities for each zone in ground-truth plots (Table 20). It was assumed for this study, that measured stem densities were the site maximum stem densities relative to height.

Table 3. Mangrove Forest Stem Density Classification (% Maximum potential stem density).

Table 20 Mangrove Forest Stem Density Classification (% Maximum potential stem density).

	Dense (1)	Partially Open (2)	Open (3)	Very Open (4)
Zone 1 (Low)	100	75	50	25
Zone 2 (Mid)	100	75	50	25
Zone 3 (High)	100	75	50	25

Relative forest condition scores were based on visual estimates of the proportion of dead trees and trees with severe dieback (Table 21).

Table 21 Mangrove Forest Condition Classification (% Dieback).

	Healthy (1)	Some dead/ unhealthy trees (2)	Many dead/ unhealthy trees (3)	All dead/ unhealthy (4)
Zone 1 (Low)	0	1-50	51-99	100
Zone 2 (Mid)	0	1-50	51-99	100
Zone 3 (High)	0	1-50	51-99	100

An overall condition score (Table 22) was generated with score weightings applied for each zone based on the relative contribution of each zone to the overall forest area (width).

Table 22 Overall Condition Score Classification.

	All Healthy (1)	Few dead/ unhealthy trees (2)	Many dead/ unhealthy trees (3)	Most dead/ unhealthy trees (3)	All Dead (4)
% Dead tree and Dieback Intensity	0	1-30	30-60	60-99	100

Mangrove Forest Processes and Human Influence

Mangrove forest processes (Erosion, Recent Depositional Gain and Canopy gaps) were recorded from the video. Where canopy gaps and mangrove dieback was observed, these were classified as either human related, subsidence related or storm related. Storm related gaps were mostly assumed to be caused by lightning (Duke 2001). Historical mangrove loss and removal was also recorded where visible.

Mangrove Forest Process Classification

Natural Loss

Erosion. Sharp elevation change at waters edge, exposed roots, fallen/ leaning trees

Natural Canopy Gaps. Large canopy gaps with standing dead, often affecting an entire mangrove zone. *Lightning* - Small circular gaps with standing dead, as described by Duke (2001).

Human Disturbance

Human Related Canopy Gaps. Small open canopy gaps with no standing dead, evidence of limb removal and cut stumps, fallen trees, sometimes with a clear access path to the sea.

Recent Mangrove Removal. Mangrove stumps present, often with newly planted coconut or other seedlings.

Historical mangrove loss. A clearly defined linear boundary between human landuse and mangrove forest indicating mangrove replacement. Often mangrove seedlings observed attempting to recolonise the area.

Mangrove Gain

Depositional Gain. Presence of dense seedlings at seaward fringe. Or, a distinct height gradient decrease to seaward edge with dense stands of young saplings at the seaward fringe.

Shoreline Features – Structures

The presence of structures along the shoreline, including businesses, houses, pig-pens and toilets was recorded.

Data Validation and Cross-referencing

During the video survey, a laser hypsometer (MDL LaserAce) was used to determine canopy height at regular intervals from the boat to allow cross-referencing and to provide specific height class intervals.

Height, width and stem density were cross-referenced against known areas and stem densities from biomass plots (see biomass ground-truth). Width classification was additionally cross-referenced with Google Earth imagery (ca. 2006) to provide specific width class estimates. Investigations of some canopy gaps and dieback areas were made during the survey to support visual observations from the boat and video assessment. Local knowledge was used to verify observations. All observations were cross-referenced with voice recordings during the survey. Dominant species composition was cross-referenced with the biodiversity survey results.

GIS – Spatial Representation of Video Track Along the Shoreline

To enable quantification of shoreline distance and mangrove forest biomass, the video track was snapped to the coastline using the ArcGIS 9.3 Spatial Analyst "Near" tool. The Roviana coastline (Aust. Defence Force Mapping Program) was segmented into 10 m point intervals. The shoreline feature data from the video track was matched to the nearest point on the shoreline so that the imagery seen in the video was matched to its respective position on the shoreline. The shoreline was redrawn using Hawths "Points to Line" tool in ArcGIS 9.3, with each line segment representing 10 m of shoreline.

Data Analysis – Mangrove Forest Biomass Estimates

Mangrove forest biomass estimates were determined using on-ground measurements of tree height, stem diameter and stem density from ground-truth plots in Roviana lagoon and existing data from nearby Choiseul (Albert et al. *in prep..)* to generate height-stem diameter relationships based on growth form and height-stem density relationships. These relationships were applied to video classification height and stem density classes, to determine estimates of stem diameter and stem density. Derived stem diameters were incorporated into standard mangrove biomass allometric equations, using species specific wood densities based on recorded dominant species and scaled-up using height-stem diameter relationships to determine an estimated biomass per m^2. The width of the forest and 10 m coastline section was used to estimate area occupied by each zone to determine total mangrove forest area and provide an estimate of total mangrove forest biomass. Biomass was only estimated for 'Mid' and 'High' mangrove zones as low zones were generally multi-stemmed sprawling *Rhizophora* for which locally relevant data was not substantial enough to provide a rigorous biomass estimate. It is likely that the low zone, being low in stature and often restricted in width has only a small proportional contribution to the overall forest biomass.

Estimates of mangrove forest biomass traditionally rely on allometric equations using 'dbh'' as the independent variable to estimate biomass per stem. Plot-based stem densities are then used to provide an estimate of mangrove biomass (kg/m^2) across a mangrove area. Tree height has not been used for these measures in the past as it was difficult to measure under a mangrove forest canopy. However, similar exponential relationships between tree height and tree biomass exist as for stem-diameter and biomass (Fromard et. al, 1996). It is only possible to estimate tree height from the video. To determine biomass using the S-VAM approach a local height-diameter relationship was required. This was determined using data collected from ground-truth and subsidence effect assessment plots in and near Roviana lagoon. Plot data was supplemented with additional data from plots used to determine mangrove forest biomass in nearby Choiseul (Albert et al, 2012 *in prep.*). A separate height-diameter relationship was determined for each growth form present in dominant species represented along the Roviana shoreline, as growth form is likely to significantly influence biomass allocation to the main stem. Where too few species were represented in ground-truth plots, a general equation based on all available data was applied. Species under-represented in plots also occurred infrequently as dominate species.

The following allometric exponential relationships for stem diameter based on height were determined from the data.

Equation 1 Species: *Dolichandrone spathacea, Excoecaria agallocha, Inocarpus fagifer, Pemphis acidula*).

Log(D) = 0.499 + 0.042*log(h) (R^2*=0.86, n=423)*

Equation 2 Growth form: Pneumatophore/Emergent Root Species: *Bruguiera gymnorhiza, Sonneratia alba, Avicennia spp.,*

Log(D) = 0.473 + 0.042*log(h) (R^2*=0.893, n=244)*

Equation 3 Growth form: Buttress Root Species: *Xylocarpus granatum, Heritiera littoralis, Ceriops tagal*

$$\mathbf{Log(D) = 0.584 + 0.042*log(h)}\ (R^2=0.761,\ n=41)$$

Equation 4 Growth form: Prop roots Species: *Rhizophora* sp.

$$\mathbf{Log(D) = 0.678 + 0.034*log(h)}\ (R^2=0.842,\ n=172)$$

Equation 5 Growth form: Columnar trunk Species: *Lumnitzera littorea*

$$\mathbf{Log(D) = 0.678 + 0.034*log(H)}\ (R^2=0.794,\ n=132)$$

These equations can be substituted for height in the allometric biomass equations modified from Komiyama et al. (2000) for each of the dominant species represented in the video classification.

Equation 6 Stem Biomass - Above Ground Biomass (kg)

$$W_{Top} = 2.51*p*D_x^{2.46}$$

Where; *p= species specific wood density,* D_x*= species relevant stem diameter equation. See* Table 23.

Equation 7 Stem Biomass - Below Ground Biomass (kg) (7)

$$W_R = 0.199*p^{0.899}*D_x^{2.22}$$

$$\mathbf{W} = \text{Eqn. 6} + \text{Eqn. 7}$$

To determine mangrove forest biomass for each zone per m^2, equation 8 was used to determine stem density per m^2. Stem density (sd) was multiplied by the video stem density score (VSDS) to determine total stem density factored for canopy openness. The number of stems per m^2 represented by each dominant species was determined by equation 9. The biomass per m^2 was determined by multiplying the stem biomass for each represented species by the proportional stem density (sd_p) (Equation 10).

Equation 8. Stem Density

$$\mathbf{Log(sd) = 0.042 - 0.058*log(h)}\ (R^2=0.785,\ n=19)$$

Equation 9. Proportion of stems for each species

$$Sd_p = (sd*VSDS)/\ DS_n$$

Where; DS_n = number of dominant species represented, VSDS = Video Stem Density Score, sd = Stem Density

Equation 10. Biomass (kg m^{-2})

$$\textbf{Biomass} = (SB_{(Species1)} * Sd_p) + (SB_{(Species\,i)} * Sd_p) \ldots\ldots$$

To calculate estimated total biomass for each mangrove forest zone on 10 m segment of coastline the site biomass was multiplied by the width score times 10.

$$Z_x\ \textbf{Biomass}_{(T)} = SB * VWS * 10$$

Total Mangrove forest biomass was calculated as the sum of the biomass for each forest zone represented.

$$\textbf{Biomass}_{(T)} = Z_x\ \textbf{Biomass}_{(T)} + Z_i\ \textbf{Biomass}_{(T)} + \ldots\ldots$$

Table 23 Mean wood density (ρ in kg/m3) of common mangrove species in Roviana Lagoon

Species	Mean Wood Density	Source References
Aegiceras corniculatum	700	4
Avicennia marina	765	1, 3, 4
Bruguiera gymnorhiza	780	1, 4, 5, 6, 7, 8
Ceriops tagal	872	1, 4, 6, 9
Dolichandrone spathacea	500	4
Excoecaria agallocha	418	1, 2, 4
Heritiera littoralis	848	1, 4
Inocarpus fagifer	550	10
Lumnitzera littorea	640	4
Pemphis acidula	1165	10
Rhizophora apiculata	827	4, 5, 6, 7, 8
Rhizophora stylosa	855	3, 5
Scyphiphora hydrophylacea	900	4
Sonneratia alba	638	4, 6, 8
Xylocarpus granatum	605	1, 4, 5, 6, 8

References: 1. (Cause et al. 1989); 2. (Phillips 1959); 3. (Boland 1984); 4.(Panshin 1932); 5. (Clough and Scott 1989); 6. (Komiyama et al. 2005); 7. (Tamai 1986); 8. (Komiyama. 1988); 9. (Komiyama et al. 2000); 10. (Soewarsono 1990).

Results

The application of S-VAM, in particular, has provided unique insights into the condition and pressures faced by human and natural communities along shorelines of Roviana Lagoon.

Mangrove Presence, Extent and Structure

A total of 198.1km of shoreline was surveyed in Roviana Lagoon, representing the entire inner perimeter of the lagoon. Mangroves were recorded along 141 km (71%) of shoreline with 117km (83%) of this being mangrove forest (Mid and High Zone present) (Table 24). Only 6% of mangroves observed were sparse stands, suggesting that where mangroves occur they form established fringe or forest stands.

The dominant species in the lagoon are *Rhizophora apiculata* and *Bruguiera gymnorhiza*. *Rhizophora stylosa* and *Rhizophora apiculata* are the most common lower zone dominant mangroves. *Rhizophora apiculata* is the most common mid-zone dominant mangrove species and *Bruguiera gymnorhiza* is the most common high intertidal zone dominant mangrove species (Table 24).

Table 24 Common dominant species for each mangrove zone along the Roviana Shoreline. (a = absent).

Dominant Species	% Low Zone	% Mid Zone	% High Zone
Bruguiera gymnorhiza	3	41	**83**
Heritiera littoralis	*a*	*a*	7
Lumnitzera littorea	2	11	10
Rhizophora apiculata	**47**	**71**	35
Rhizophora stylosa	**52**	1	*a*
Sonneratia alba	16	23	*a*
Xylocarpus granatum	*a*	2	29

Based on width estimates, there is approximately 1042.92 ha of mangrove in the lagoon of which 851.7 ha is established forest. This figure represents 1.6% of the total 64,200 ha of Solomon Island mangroves reported by Gilman et al. (2006).

Mangroves are more extensive along the inner lagoon, New Georgia coastline compared to barrier islands shorelines, with only 24% of total mangrove area on outer island shoreline (Table 25). The most extensive mangroves are located in the inner eastern lagoon, where four large rivers flow into the lagoon.

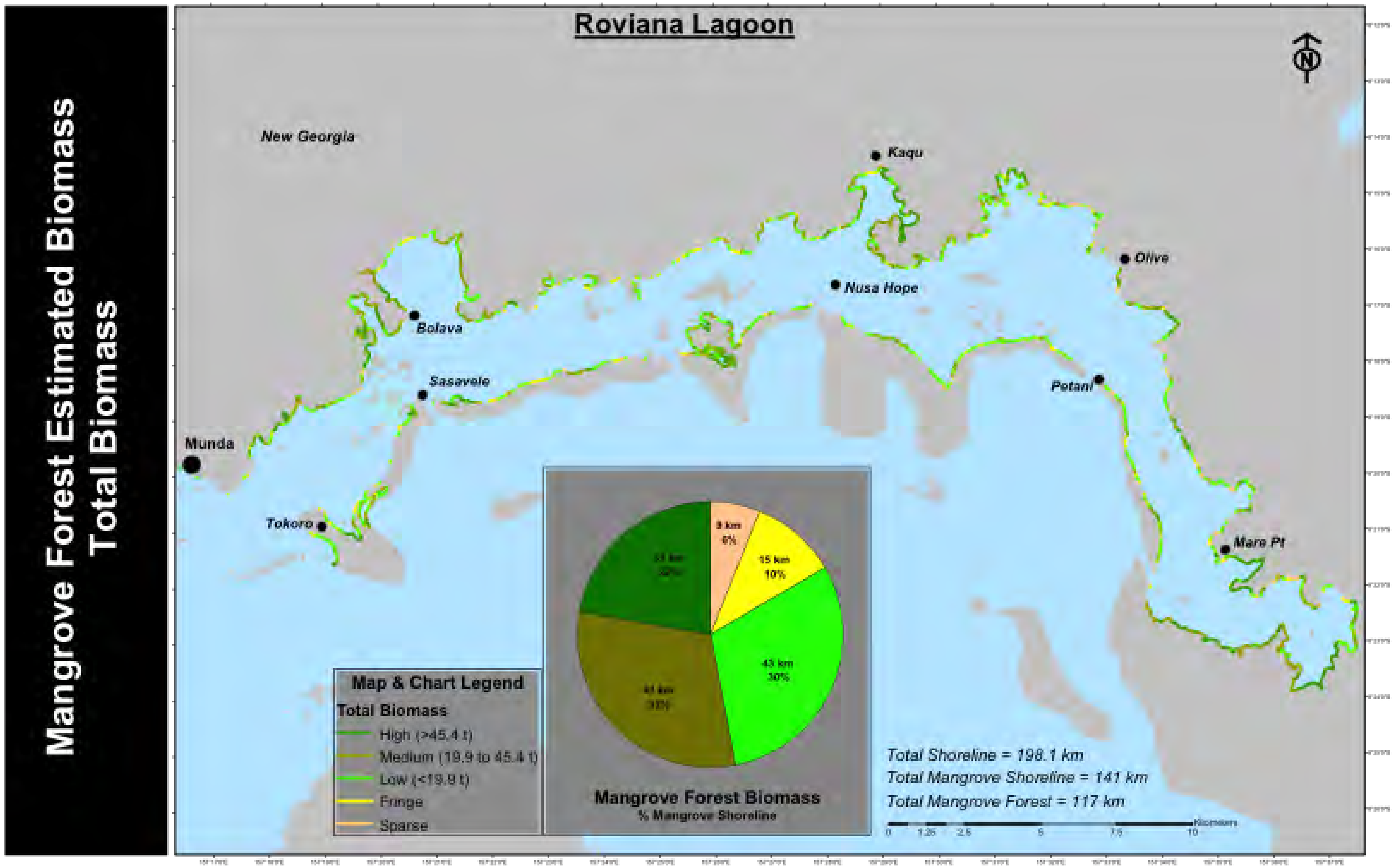


Figure 68 Biomass of mangrove forests in Roviana Lagoon.

Table 25 Estimated Mangrove Area (ha) in Roviana Lagoon (excluding Vonavona).

Estimated Total Mangrove Area (ha)			
1042.92			
East		**West**	
513.29		529.63	
Inner		**Outer**	
788.36		254.55	
West	**East**	**West**	**East**
380.77	407.6	132.5	122.0

Most mangrove areas along the Roviana shoreline are structurally complex with 22% having a high, mid and low low zone present and 51% having 2 zones present. Mid-zone mangroves are present in 78% of mangrove areas. 63% areas. 63% of mangroves have a dense, sprawling *Rhizophora* fringe. High intertidal forest is more frequent on on inner shoreline compared to outer barrier islands. There is a higher proportion of lower zone mangroves on on barrier islands (Table 26). Mid-zone mangroves are the most extensive zone, especially in the inner lagoon. Mangrove mean height and width is generally less on barrier islands, with the exception of the low zone, which is slightly wider (

Table 27).

Table 26 Mangrove Forest Structure. Proportion of each zone present along the shoreline of the inner and outer lagoon.

Mangrove Zone	% Mangrove	
	Inner	**Outer**
Low Zone	66	74
Mid Zone	80	75
High Zone	52	35
Total Mangrove (km)	**94.2**	**37.7**

Table 27 Mangrove Forest Structure. Mean height and width of mangrove zones.

	Mean Height (m)		Mean Width (m)	
	Inner	**Outer**	**Inner**	**Outer**
Low Zone	4	3.8	21	22.5
Mid Zone	20	19	56	47
High Zone	27.3	26.5	49	44

Mangrove Forest Biomass

Mangrove forests in the lagoon have high biomass. Figure 68 shows the distribution of total mangrove biomass along the lagoon shoreline. The total biomass figure is used at it accounts for mangrove area, tree height and stem density. The map of total biomass indicates that total biomass per 10 m section of the coastline is highest along the New Georgia shoreline and the majority of high biomass areas occur within protected embayments compared to more exposed coastline.

There is an estimated 398 Mt DW (Mega-tonnes) of mangrove forest biomass in Roviana lagoon with a mean total biomass of 34t DW per 10m section of forested coastline. This is equivalent to 184.84 Mt C (mega-tonnes of carbon) or 678.36 Mt CO_2 equiv., or 15.78 t C and 57 t CO_2 equiv. respectively. The range of total biomass for a 10m section of forest was estimated to be between 1.11t and 183t.

Biomass per unit area (t DW ha^{-1}) is on average 444.74t DW ha^{-1} with a range of 4.46 to 115.25 74t DW ha^{-1}. There is greater biomass per unit area of mangrove on inner lagoon shorelines than outer shoreline (458.3 t DW ha^{-1} and 368 t DW ha^{-1}) (Figure 69). This is a function of outer lagoon island mangroves being less well developed than those on the inner coastline (

Table 27)

Distance from river mouths has a significant effect on mangrove forest biomass (Figure 69, Figure 70), especially for above ground biomass.

Figure 71 shows the distribution of maximum above-ground standing mangrove biomass (AGB DW t ha^{-1}) along Roviana lagoon shoreline. This map differs from the map of total biomass as it does not account for width. This shows similar trends to total biomass but highlights that that even where mangroves are restricted in width, they still have high biomass.

High biomass (both total and site average) mangrove areas are closely linked to their position from river mouths and shoreline aspect. With higher biomass on shoreline close to river mouths and on coastline facing away from the general southerly aspect (inner shoreline) and north-east aspect (outer shoreline) (Figure 72, Figure 73).

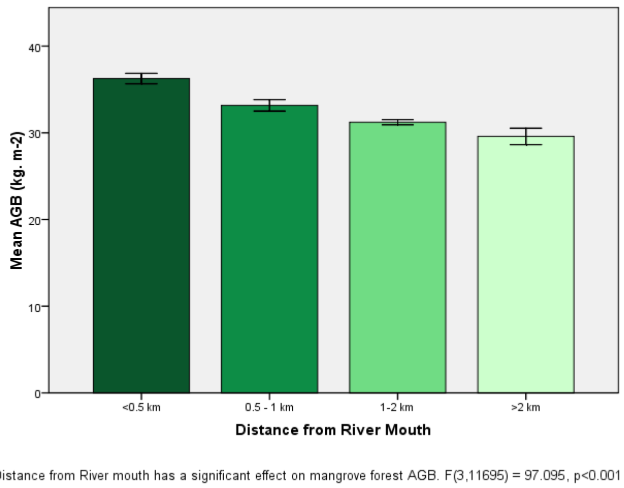
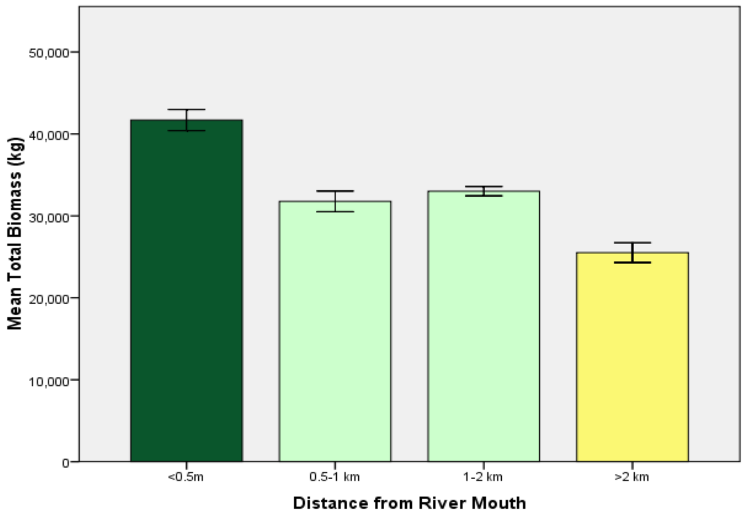


Figure 69 Mean above ground biomass with increasing distance from river mouths.



Distance from river mouth has a significant effect on total mangrove biomass.F(3,11695) = 103.561,p<0.001

Figure 70 Mean total biomass with increasing distance from river mouths.

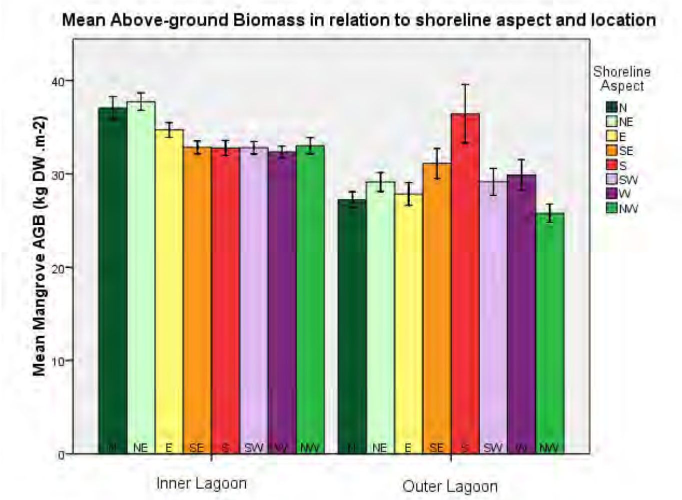


Figure 71 Mean above ground biomass in relation to shoreline aspect and location.

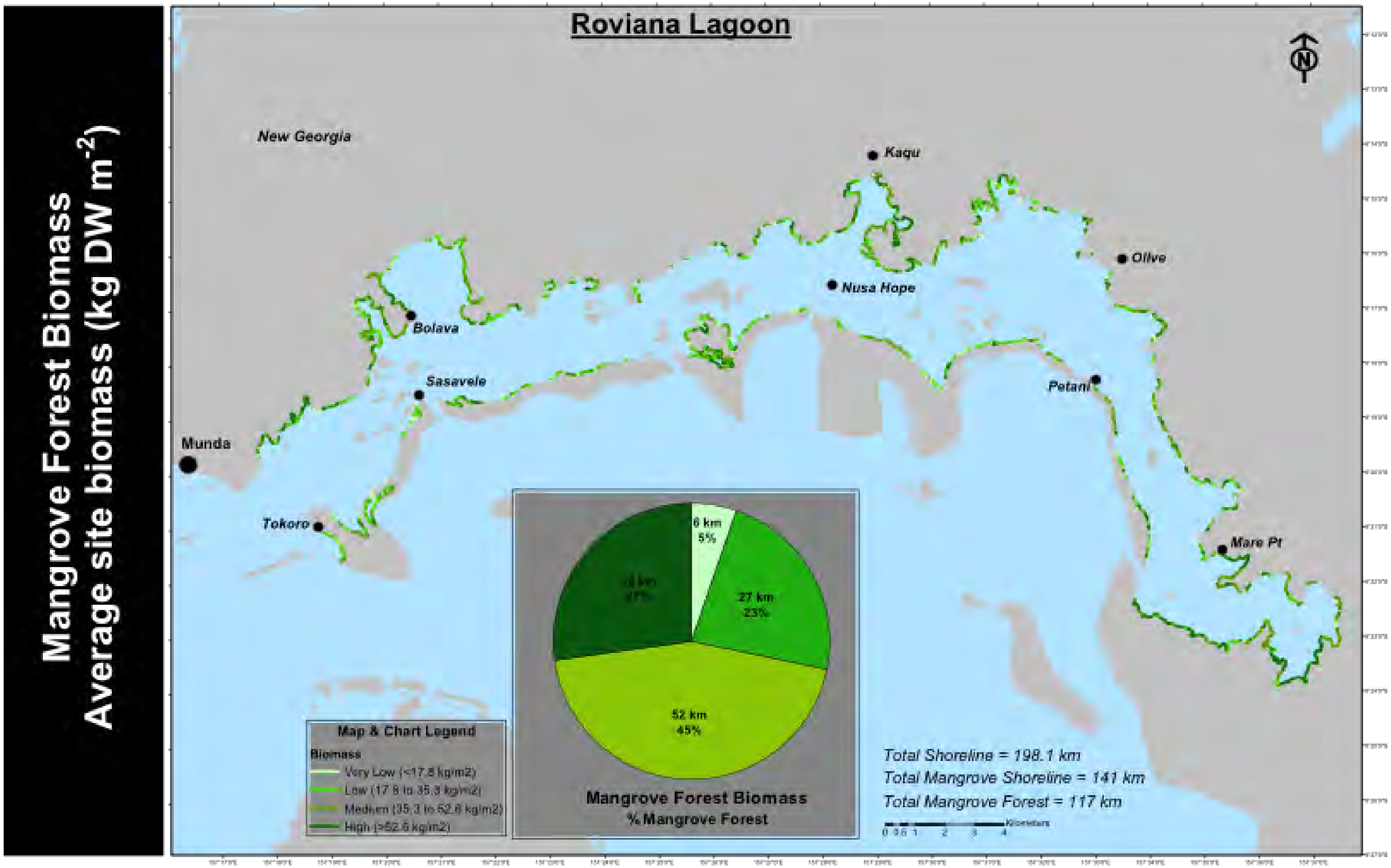


Figure 72 Mangrove forest biomass across Roviana Lagoon.

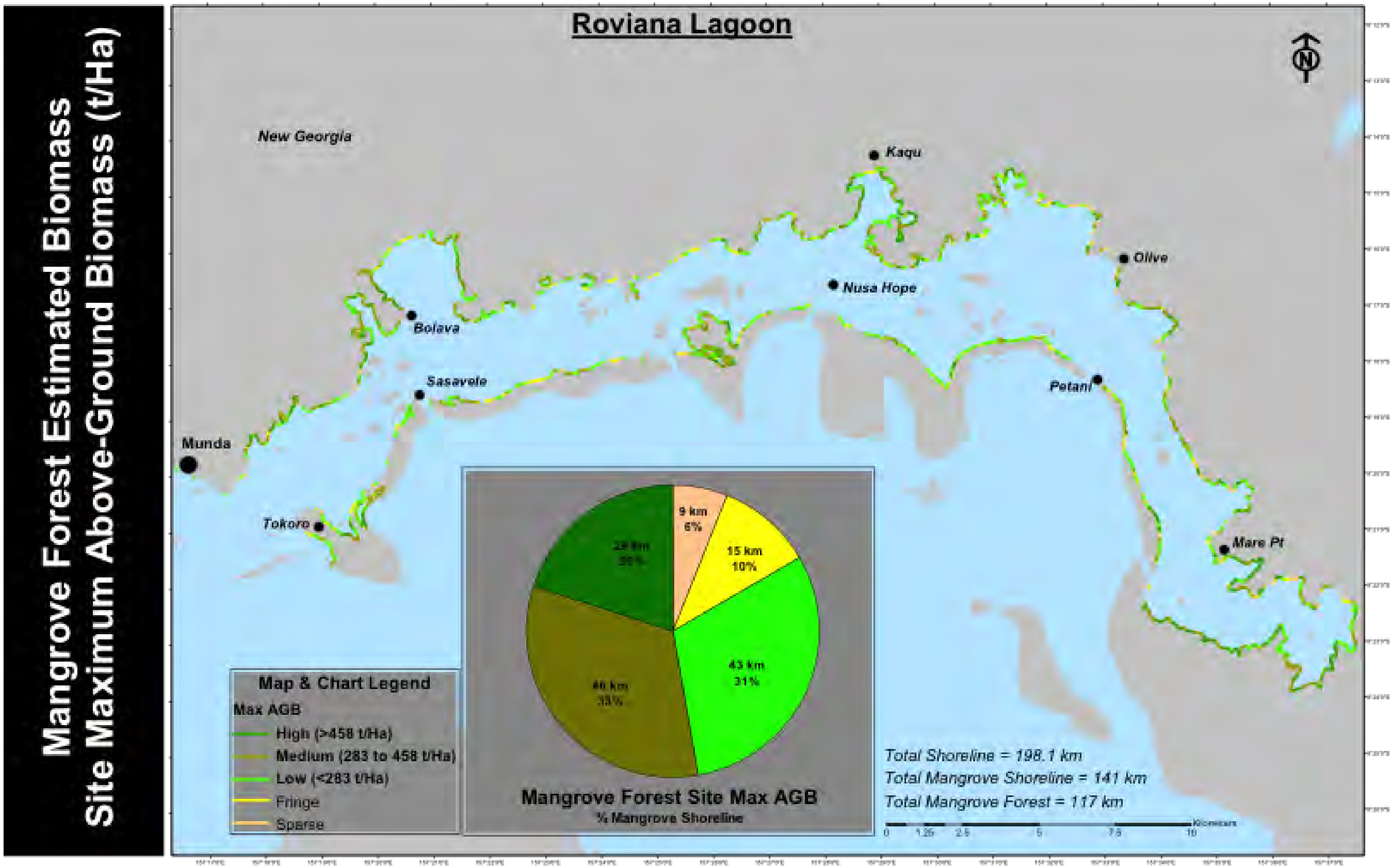


Figure 73 Estimated mangrove forest biomass – site maxima.

Mangrove Forest Condition

Mangroves in Roviana lagoon appear relatively healthy, compared to nearby Vona Vona lagoon, and Riki Riki Channel. Figure 74 shows the overall condition of mangroves in Roviana lagoon and Figure 75 shows the mangrove condition in each zone. These maps indicate that where mangroves do show signs of dieback it is generally restricted to one zone and it is of a low frequency relative to the total forest. The condition of mangroves in Roviana lagoon is a stark contrast to those in nearby Riki Riki channel, where subsidence effect from the 2007 caused widespread mangrove death and dieback. However, it is notable from the condition map that more dieback was present in mangrove areas closer to Munda and Riki Riki Channel, compared to areas further away. Subsidence effect was observed in mangroves in protected embayments with similar conditions to those in Riki Riki Channel near Munda and Bolava (see Dieback section). The condition of mangroves was significantly worse, although still relatively healthy, in the western lagoon compared to the eastern lagoon, with high intertidal mangroves on the outer-west coast most affected. Overall, mangroves in the high intertidal zone were observed to have the most dieback relative other zones with mangroves in the mid-zone the least affected.

Threats to Roviana Mangrove Forests

Natural and human related disturbances was observed to be affecting mangroves along the Roviana lagoon shoreline, noting particular threats from sea level rise (Figure 76-Figure 80). Overall, human disturbance was observed to be a bigger influencing factor on mangroves than natural disturbance. Total human disturbance to mangroves, was observed along 21.5 km (11% of shoreline). The majority of this disturbance was noted to be historical removal and replacement of mangroves for human land use, encroachment by human landuse and damage to removal of fringing mangroves near or in front of human landuse (collectively referred to as cleared). 57% of clearing was directly associated with existing coconut or garden plantations with a further 35% for what appeared to be preparation for planting. The remaining 8% of clearing was associated with logging camps and villages. Cutting and wood harvesting was infrequently observed affecting only 1.6 km (1.2%) of mangrove forest.

Two types of natural mangrove forest disturbance were observed; subsidence and lightning. Subsidence was observed to affecting mangroves mostly along the inner coastline of the western lagoon (78%), in small protected embayments. Light gaps, potentially caused by lightning were observed mostly on the inner lagoon (2.56 km mangroves affected), with relatively few light gaps on the outer barrier islands (0.26 km mangroves affected). There was 9.8 km of unhealthy mangroves for which the cause of dieback could not be determined from the video.

Sea level rise associate with climate change or land subsidence is perhaps the greatest long term threat to the mangroves of Roviana. The ability for mangroves to persist and flourish under sea level rise scenarios of 50-100 cms over the next century will largely depend on coastal topography and existence of barriers to landwards migration. Figure 76-Figure 80 indicate the relative exposure of mangroves in different areas of Roviana to sea level rise.

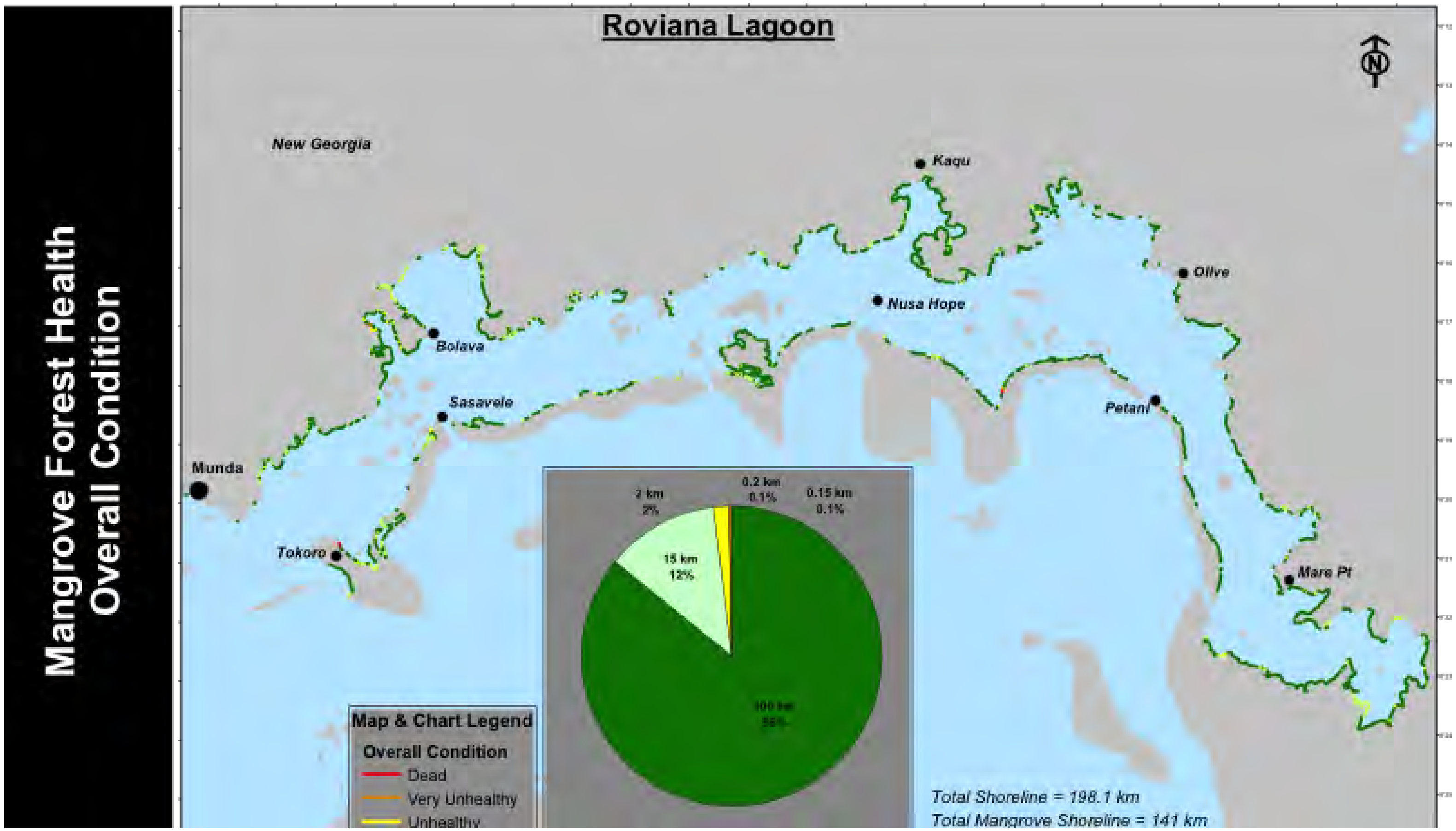


Figure 74 Mangrove forest condition – overall score.

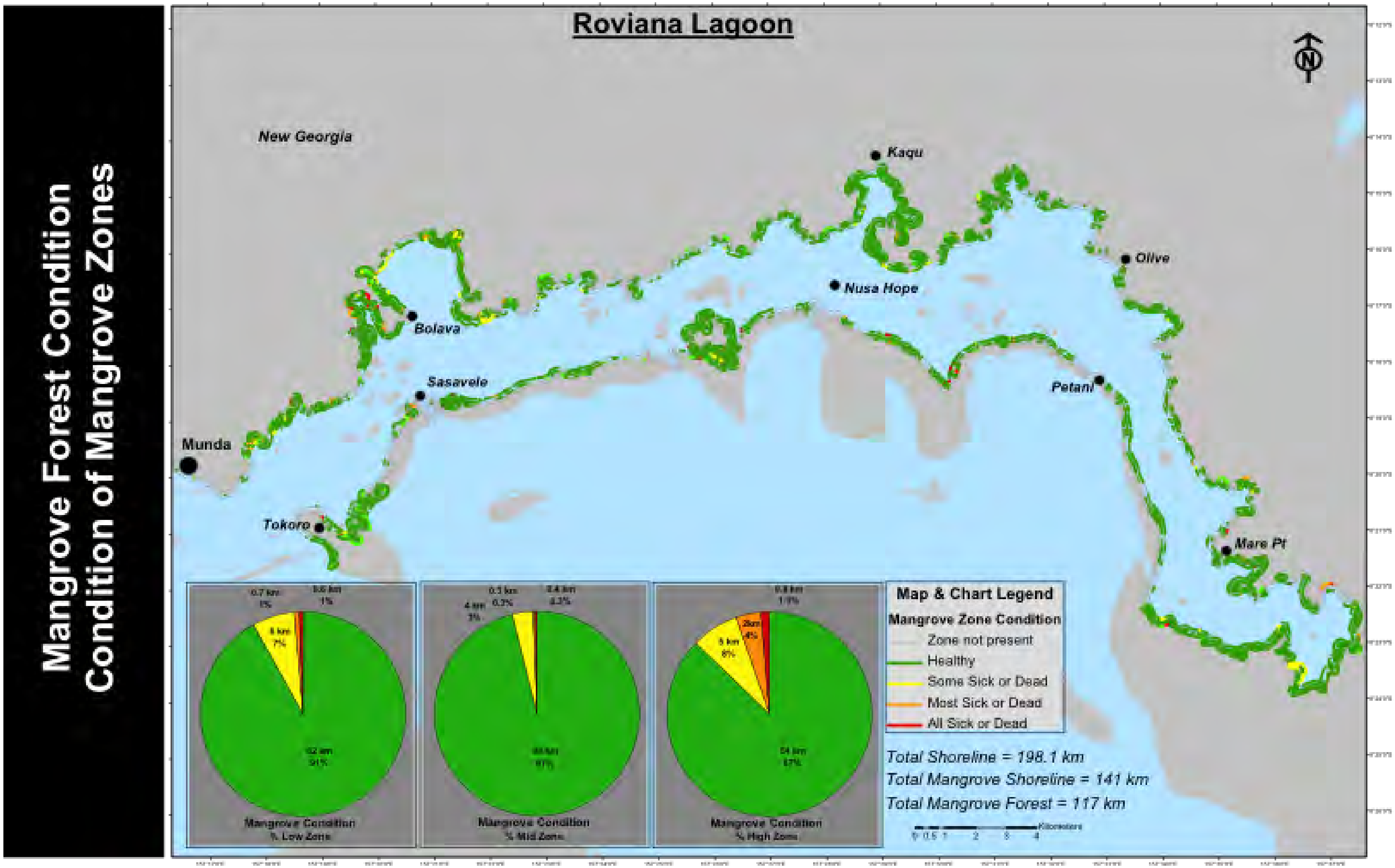


Figure 75 Mangrove forest condition – zones.

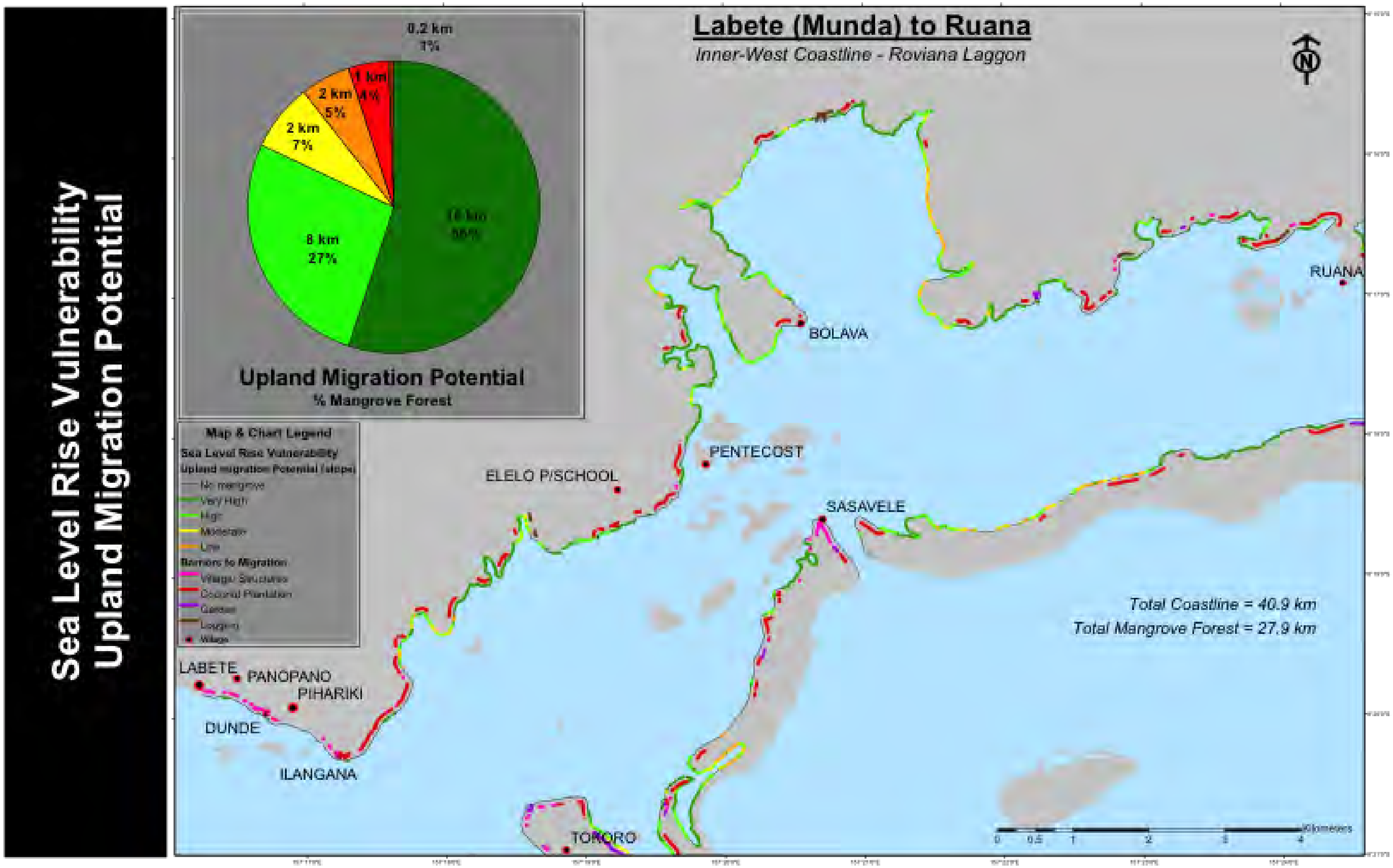


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Figure 76 Vulnerability of Roviana Lagoon shorelines – Labete to Ruana.

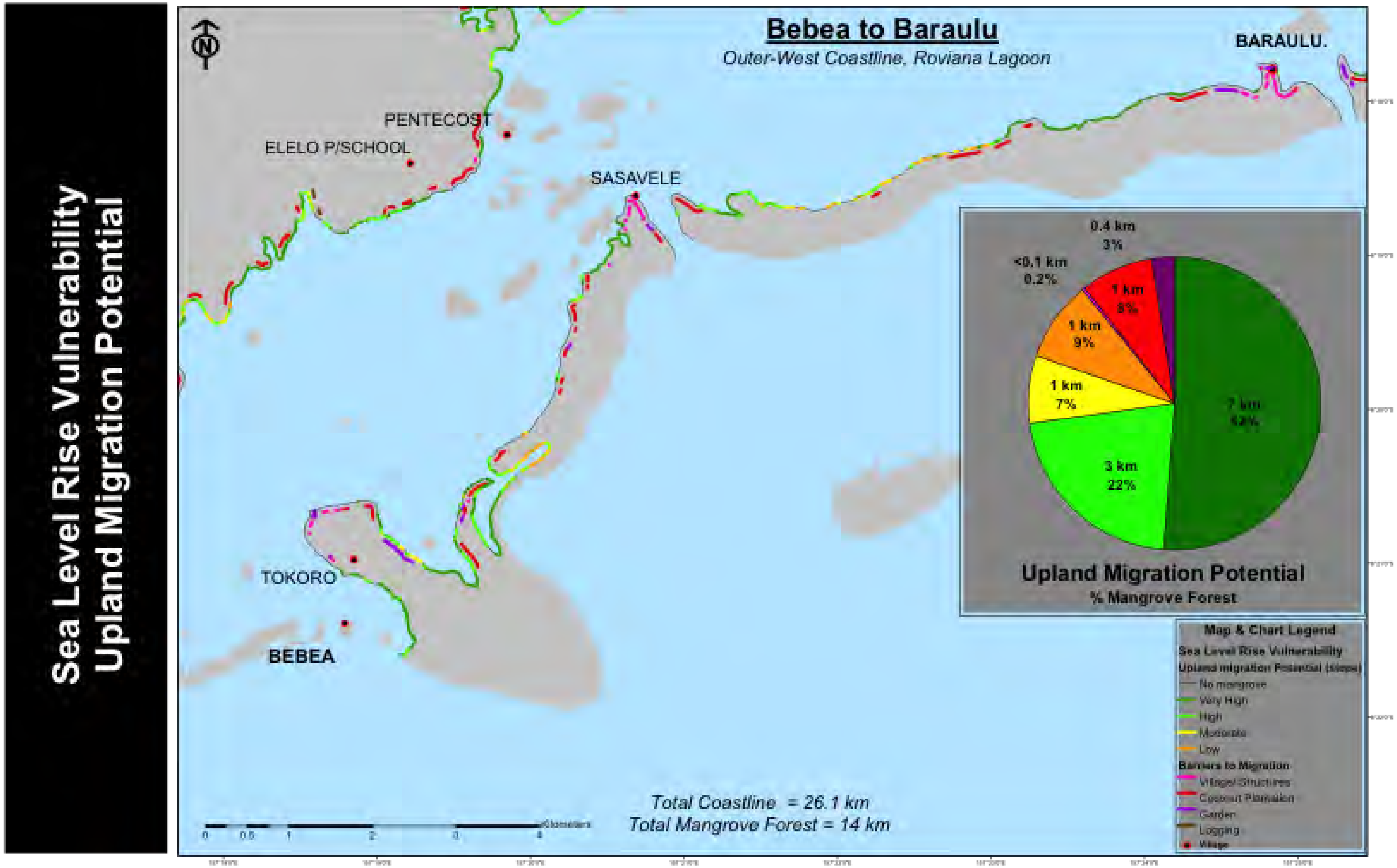

Figure 77 Vulnerability of Roviana Lagoon shorelines – Bebea to Baraulu.

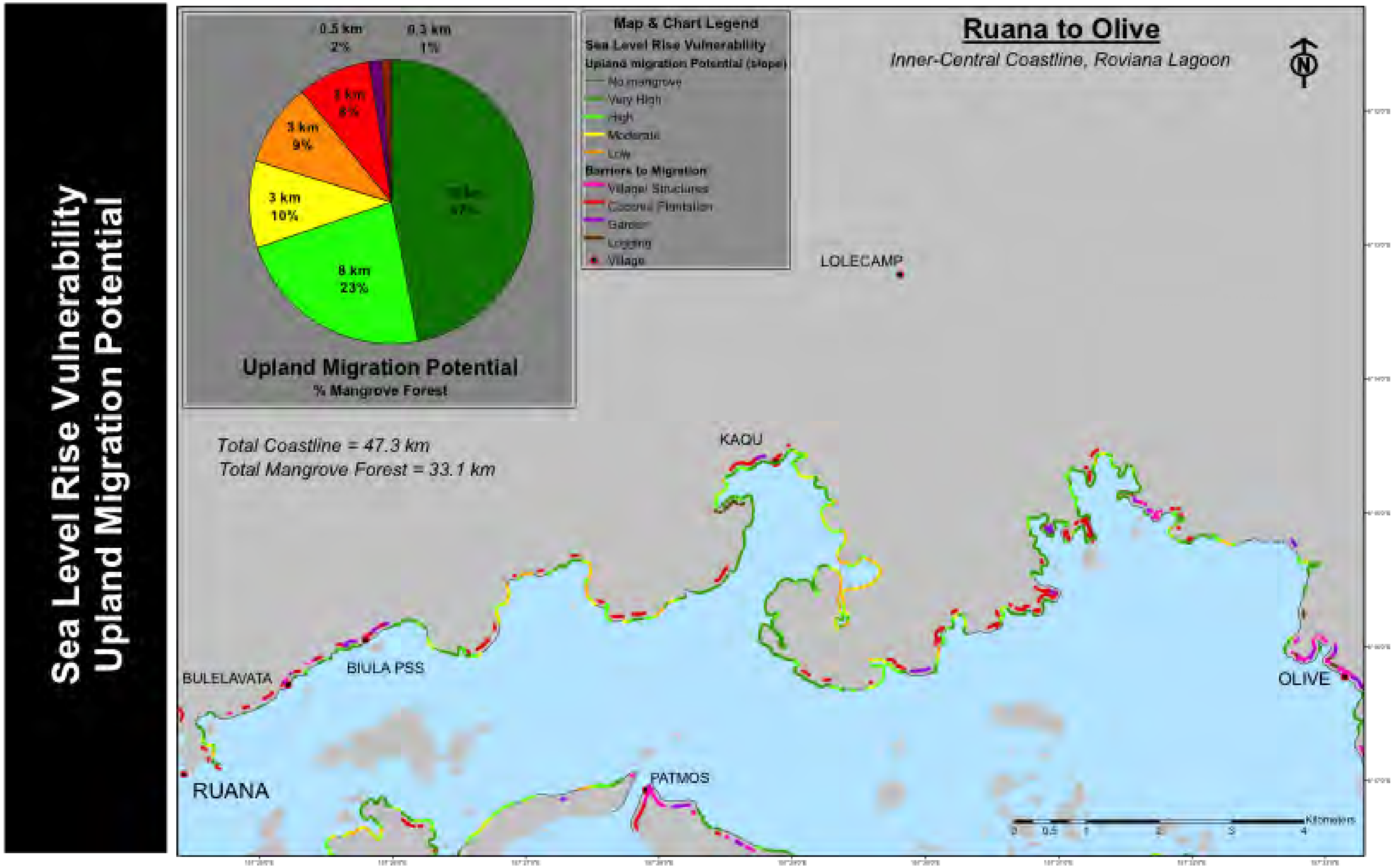

Figure 78 Vulnerability of Roviana Lagoon shorelines – Ruana to Olive.

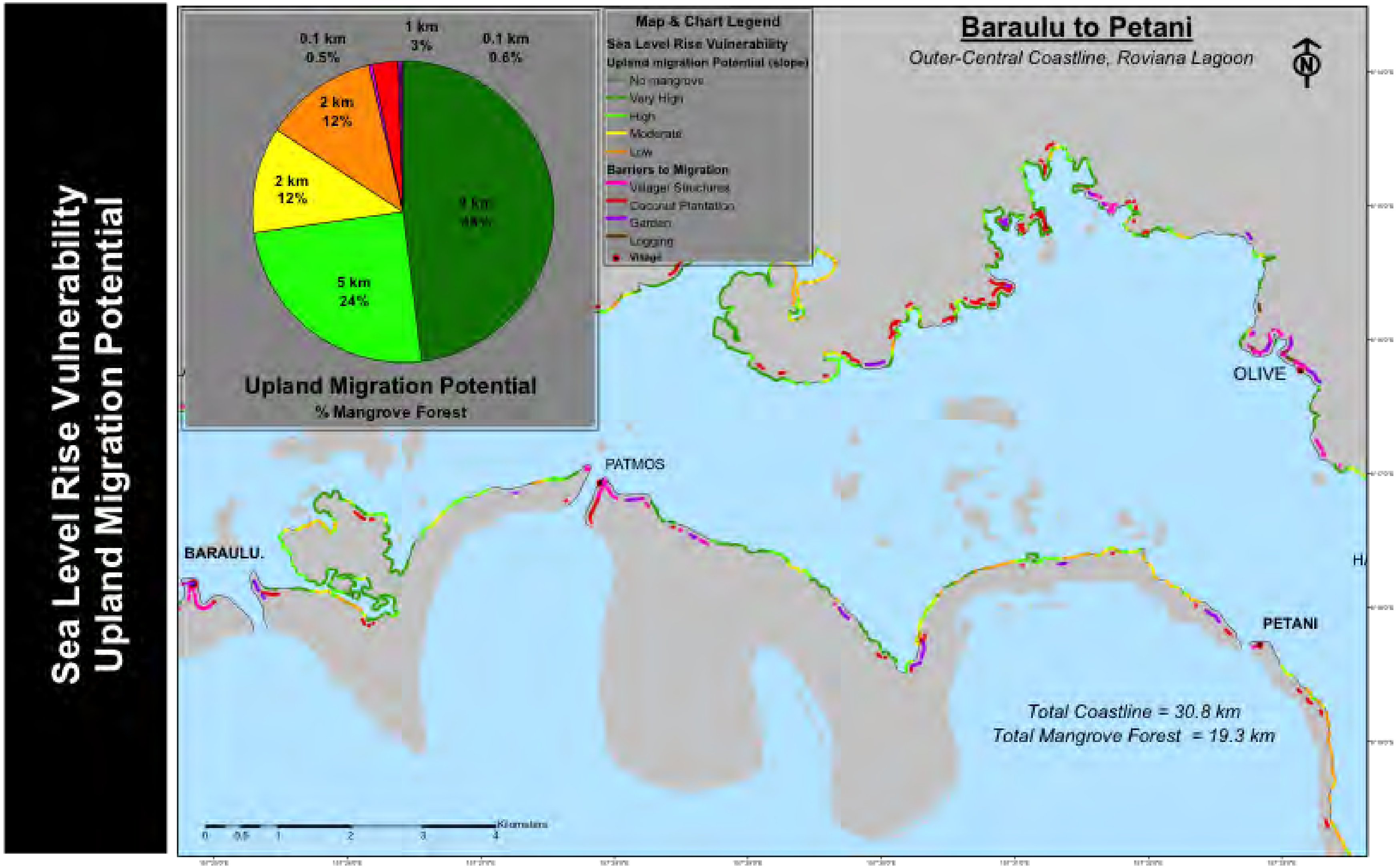

Figure 79 Vulnerability of Roviana Lagoon shorelines – Baraulu to Petani.

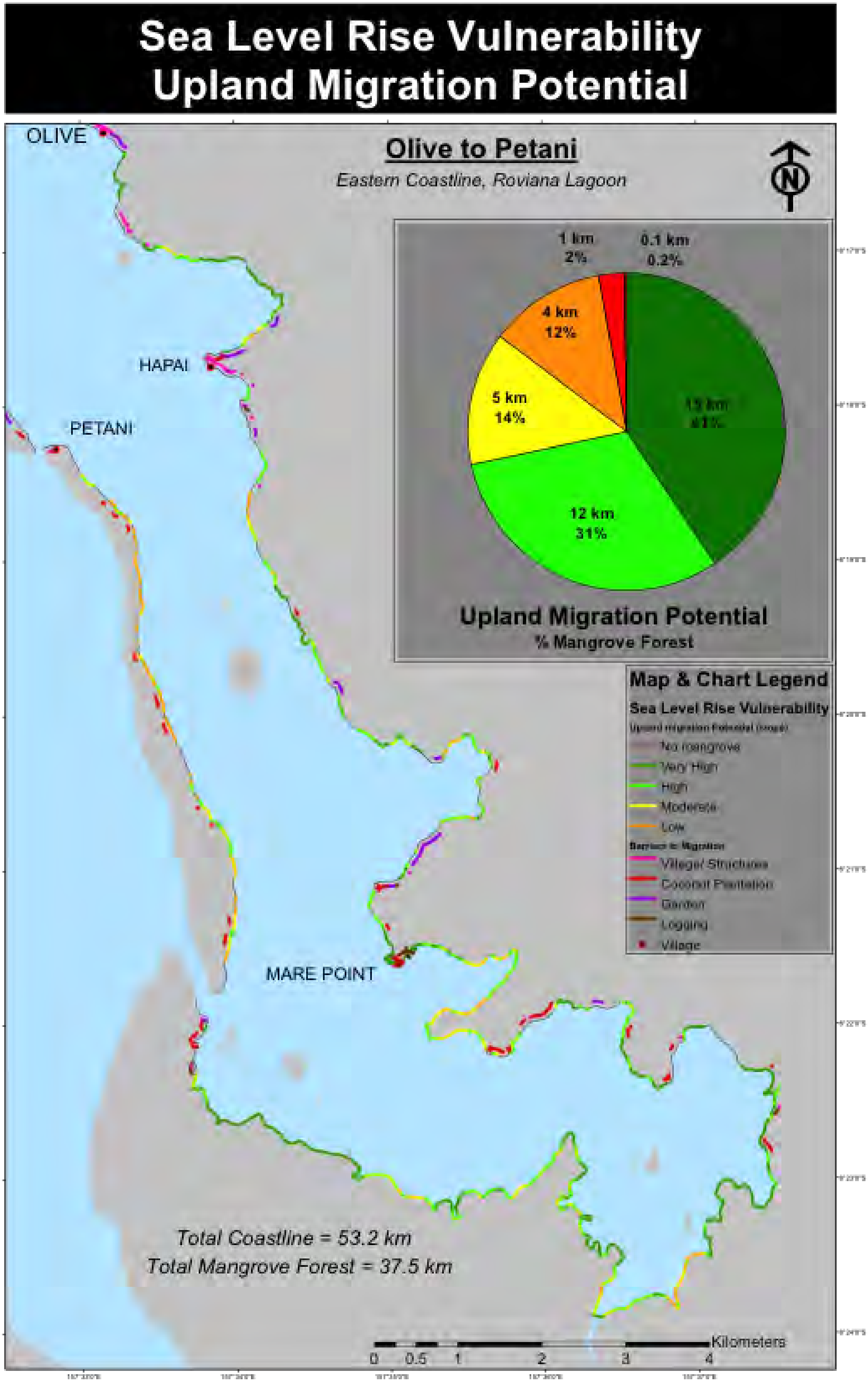

Figure 80 Vulnerability of Roviana Lagoon shorelines – Olive to Petani.

MANGROVE DIEBACK IN RIKIRIKI PASSAGE

OBJECTIVE

To evaluate the notable occurrences of mangrove dieback observed in Rikiriki passage near Munda and Noro on the western end of New Georgia Island, Western Province.

INTRODUCTION

Several occurrences of mangrove dieback in the Noro-Munda area may be related to the April 2007 earthquake. Patches and fringes of forested stands were observed dying from around March 2008 (Figure 81).

Figure 81 Mangrove dieback observed in Rikiriki Passage, NW of Munda during April 2008 (Photo: Bruno Manele).

These mangrove dieback sites appeared to be excessively flooded, rather than uplifted and dry as for Ranongga island nearby (Albert et al. 2007). This prompted the suggestion that these instances of dieback might be caused by substrate subsidence as a consequence of the earthquake, one year earlier. The nature of this subsidence, its likely occurrence, and a description of the condition of mangrove vegetation across a selection of affected and unaffected tidal profiles are given.

These studies were undertaken as part of a larger investigation assisting local people to be better prepared for anticipated changes to their shorelines, with increased sea level, plus more severe storms, sea surges and tsunami waves. In that respect this case study of die-back as a result of land subsidence is a useful indicator to understand the pressures to and changes within mangrove ecosystems as a results of climate change driven sea level rise.

Methods

Study Area

The study area was the complex coastline of the Munda-Noro area and Roviana Lagoon of Western Province (Figure 82; Table 28). Affected areas appear localised with distinct dieback patches observed in the western part of Roviana Lagoon, mostly to the west of Munda.

Figure 82 Map of the study area showing areas of observed dieback in 2008, plus the 12 transects established for the study in 2011.

Table 28 Locations of observed mangrove dieback recorded photographically during 2008, prior to this investigation (see Fig. 2). Sites have been grouped and ranked by greatest severity in four groupings (#).

#	Location	Latitude			Longitude			Observ	Year	M
1	Lulu Goldie Inlet middle	8	17	43.39	157	13	42.96	Bruno	2008	4
1	Lulu Goldie Inlet north	8	16	16.21	157	13	3.13	Bruno	2008	4
1	Lulu channel north	8	18	9.41	157	14	9.44	Norm	2008	7
1	East side Mbanga Island	8	18	27.73	157	13	26.27	Norm	2008	7
1	Lulu Goldie Inlet middle	8	17	43.39	157	13	42.96	Norm	2008	7
1	Lulu Goldie Inlet north	8	16	16.21	157	13	3.13	Norm	2008	7
1	Island in S Noro channel	8	17	33.96	157	11	59.9	Norm	2008	7
2	Noro N estuary upstream	8	13	21.47	157	13	43.07	Norm	2008	3
2	Noro N estuary upstream	8	13	17.96	157	13	48.35	Bruno	2008	4
3	Mbiula N inlet upstream	8	17	33.69	157	19	48.62	Norm	2008	3
3	Inlet west of Mbiula	8	18	42.55	157	18	41.77	Norm	2008	7
4	Island offshore from Munda	8	20	31.75	157	22	2.14	Norm	2008	7

TRANSECTS

Assessments were made using 12 transects (also see Figure 82) from a selection of six having mangrove dieback (Transects 1-6), and six without dieback (Transects 7-12). Transect sites with dieback were categorised as either having dieback from the fringe to inner stands, or those with distinct surviving fringes fronting dieback within inner stands (see Figure 83).

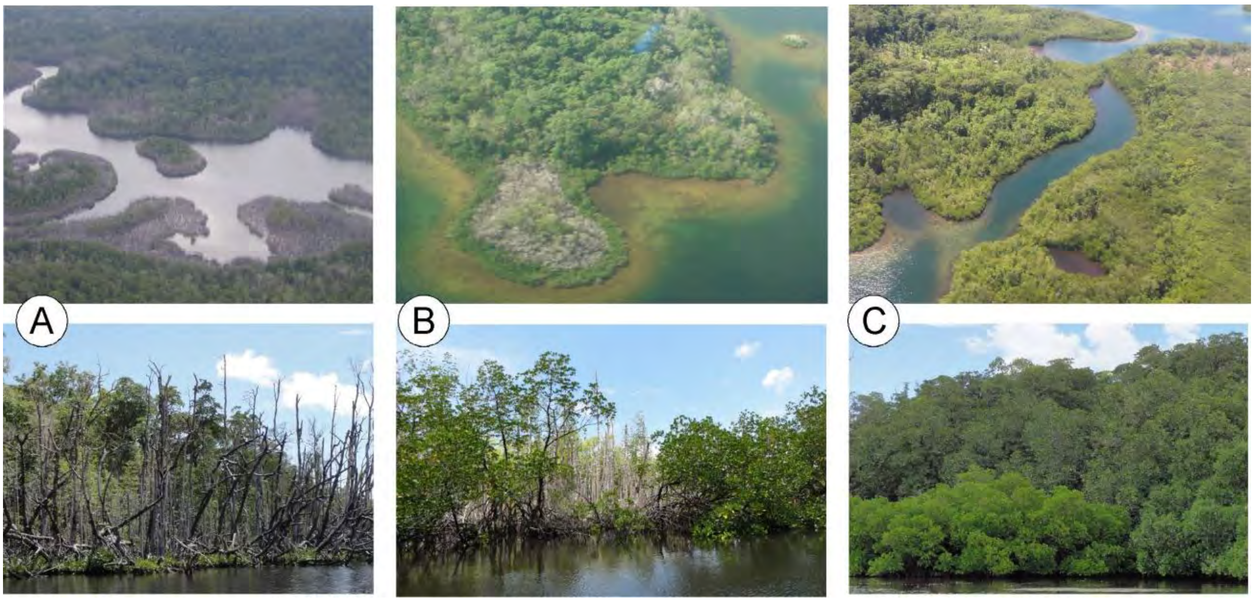

Figure 83 Aerial and ground level views of the three mangrove dieback treatments observed in the study area: including: A. dead fringe to waters edge (X 3); B. dieback with notable living fringe (X 3); and, C. healthy with no obvious dieback (X 6).

The key descriptive characteristics of each transect, with location coordinates are listed in Table 29. Measurements taken along transects included ground levels using a dumpy level and staff, species, tree height, stem diameter, tree health and presence of seedlings. Health of individual trees was scored as healthy normal, unhealthy or dead.

Table 29 Transects used to compare dieback and non-dieback mangrove profiles. Profiles, where possible, covered up to three mangrove zones from Low, Mid to High. Zones were largely identified based on vegetation types for characteristic assemblages of mangrove species – RS (Rhizophora stylosa), RA (Rhizophora apiculata), CT (Ceriops tagal), BG (Bruguiera gymnorhiza), LL (Lumnitzera littorea), XG (Xylocarpus granatum).

Tr	Site Name	Latitude	Longitude	Tream't	Dist. m	Low	Mid	High
1	1 Lulu channel	-8.301550	157.237298	Dieback	90.0	RS	RA, CT, BG	LL, BG, XG
2	7 Goldie	-8.294204	157.224973	Dieback	88.1		RA, CT, BG	LL, BG, XG
3	4.1 Ba rikki	-8.302818	157.231909	Dieback	53.3	RS	RA, CT, BG	LL, BG, XG
4	3 Mbanga island	-8.308731	157.218093	Dieback, live fringe	36.8	RS	RA, CT, BG	LL, BG, XG
5	4.2 ba rikki	-8.302818	157.231909	Dieback, live fringe	50.1	RS	RA, CT, BG	LL, BG, XG
6	2 Bebea Is	-8.314114	157.224304	Dieback, live fringe	75.0	RS	RA, CT, BG	LL, BG, XG
7	5 Zeegaree	-8.297229	157.428093	All live, normal	33.5	RS	RA, CT, BG	LL, BG, XG
8	6 wp48	-8.298160	157.432131	All live, normal	26.7	RS	RA, CT, BG	LL, BG, XG
9	8 Qualasa	-8.286337	157.418621	All live, normal	30.1	RS	RA, CT, BG	LL, BG, XG
10	J10 - Hura1	-8.287084	157.360240	All live, normal	79.5		RA, CT, BG	LL, BG, XG
11	J11 -Hura2	-8.281766	157.374016	All live, normal	57.1		RA, CT, BG	LL, BG, XG
12	J9 - Hura3	-8.281836	157.358001	All live, normal	53.5		RA, CT, BG	LL, BG, XG

High Water Reference

To achieve a common reference between the 12 transect profiles, we used the overnight high water level. For this investigation, this high water level was assumed to be equal across the wider study area. The high water level each night was recorded using a practical, low-tech device we called a High Water Measuring Bottle (Figure 84) fixed at each location using cable ties or string to either a dedicated stake, or a convenient erect stem or root. The Bottles provided a low cost means of accurately recording highest water levels in these open lagoon sites prone to small (< 30cm) waves from wind fetch and passing vessels; plus the effects of frequent rain squalls. The correct vertical positioning of Bottles was critical – as it anticipated the high water level later that night. The preferred level was to have the high water occur approximately half way up the High Water Measuring Bottle.

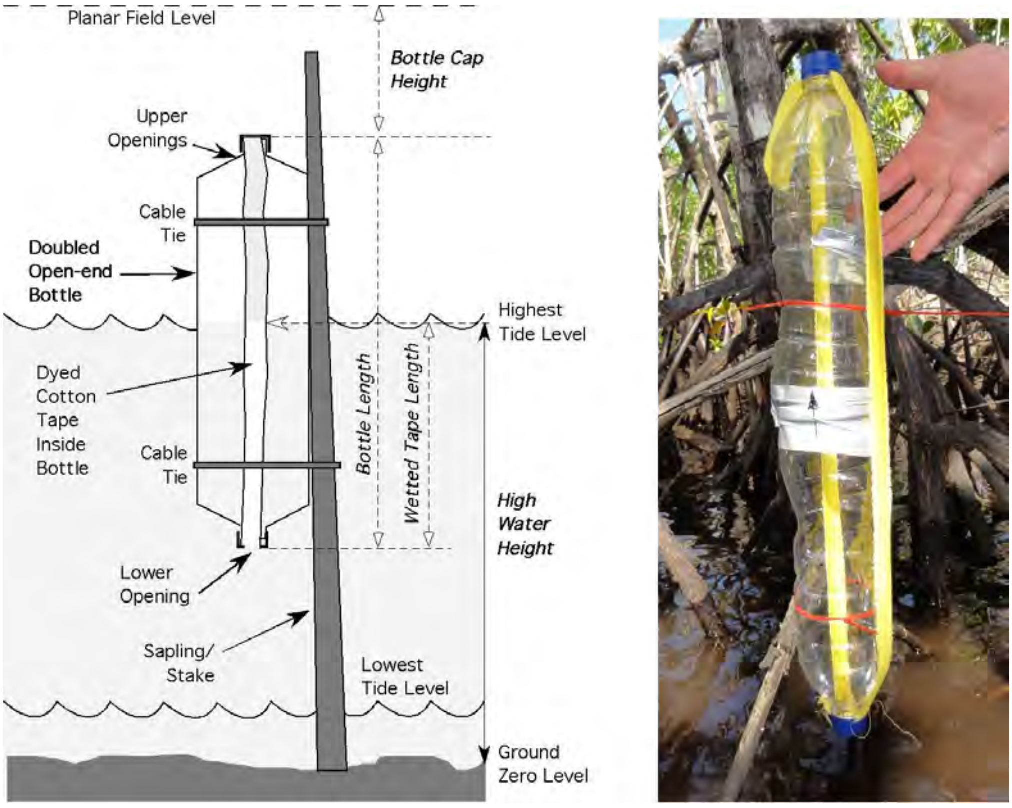

Figure 84 The High Water Measuring Bottle used to record overnight High Water levels during this investigation. These functioned very well despite notable wave action and heavy rain during this study.

Transects were measured on different days because it took up to three hours to travel to and measure each transect. In most cases, three replicate Bottles were deployed at each station.

Bottles were constructed at least a day before deployment at both Munda and at respective transects over four consecutive days from 21-24 March 2011. Bottles were made from two 1.5 L clear plastic water drink bottles with bases cut off. The two top end portions were joined together using gaffer tape. Holes were made in the cap at the lower opening, and around the neck of the upper opening (Figure 84) – to allow water to flow in/out, and air to exit/enter readily. Dyed cotton strips about 1-2 cm wide were strung within the Bottle between the two ends – fixed by upper and lower caps. Each white cotton strip was dyed yellow using water-soluble food colouring – dried prior to installation. Bottle combined lengths ranged from 51.7-64.0 cm long. After retrieval, cotton strips were removed and measured from the lower end up to the extent of full removal of dye, and to the highest wetted level. The average of these two measures was used as the Wetted Tape Length in this treatment.

Table 30 Transect/Treatment related measurements of elevation for each Planar Field Reference to respective High Water Reference Levels.

March					Elevation Down from Transect Planar Level (T)		Change at Munda Base Station (M) from Day 1	Level
Date	Day	Transects/Treatment		Name	HW Ref	SEx1	Tide Incr	SEx1
21	1	1	Dead	1 lulu channel	0.852	0.018	0	
23	3	2	Dead	7 goldie	0.865	0.023	0.089	0.009
22	2	3	Dead	4.1 ba rikki	0.857	0.004	0.046	0.015
22	2	4	Live Fringe	3 banga island	1.318	0.006	0.046	0.015
22	2	5	Live Fringe	4.2 ba rikki	0.857	0.004	0.046	0.015
22	2	6	Live Fringe	2 Bebea Is	0.814	0.012	0.046	0.015
23	3	7	Live	5 zeegaree	0.789	0.003	0.089	0.009
23	3	8	Live	6 wp48	0.815	0.007	0.089	0.009
24	4	9	Live	8 qualasa	0.862	0.008	0.076	0.024
24	4	10	Live	J10 - Hura1	0.897	0.133	0.076	0.024
24	4	11	Live	J11 -Hura2	0.853	0.01	0.076	0.024
24	4	12	Live	J9 - Hura3	1.191	0.051	0.076	0.024

Estimates of each High Water Reference measure from the Planar Field to Highest Water Level (T) calculated as the distance from the Planar Field to the Bottle Top plus the Bottle Length, minus the Wetted Tape Length. The Munda Base Station was used to quantify the difference between each overnight High Water level – with the reading for the first day taken as zero (M). Values for each transect, with respective error terms, are listed in Table 30.

Figure 85 shows the respective formulae used to estimate the Common Planar Reference value (X') using respective measures taken for distances between each transects' planar field to the substrate ground levels from around the high water zone to the water edge – crossing the mangrove forested zone.

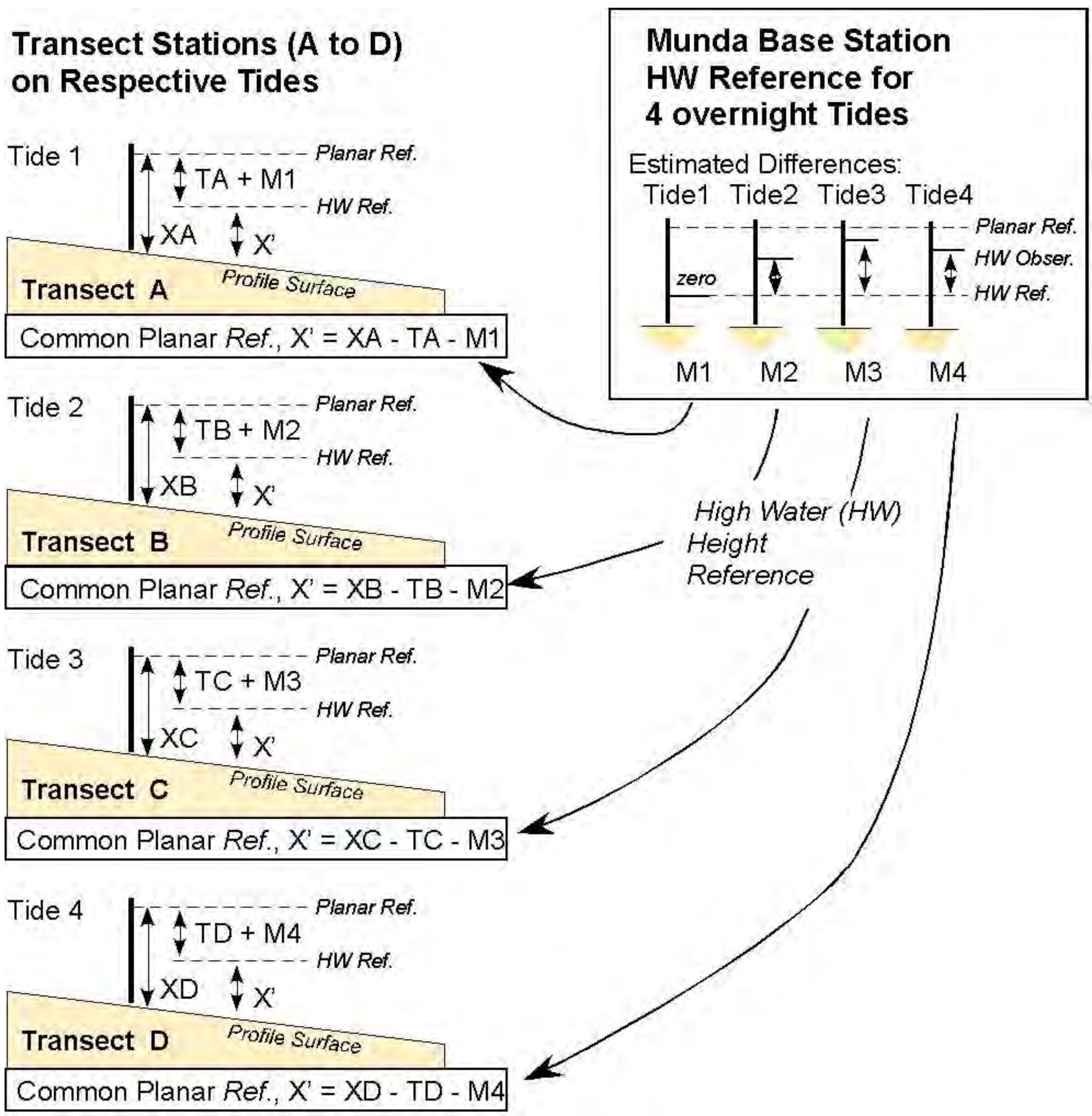

Figure 85 The method used in this investigation for transferring a standardised reference across all transects measured during different days across the study area. Three replicate High Water Measuring Bottles were deployed each day at the Munda Base Station and respective transect locations.

Shoreline Video Assessment Method (S-VAM)

To quantify the full extent of dieback within Riki Riki Channel, continuous geo-referenced video recording of shoreline was undertaken using the S-VAM method. Video time and GPS time were matched to ensure time of the video matched a specific GPS latitude & longitude (+/- 10 m). Target features were qualitatively scored from the video using criteria-based assessment at 2-second intervals (~ every 4 m). Data was spatially represented using ArcGIS 9.3. The video track was snapped to coastline (Australian Defence Force Mapping Project) points spaced at 10 m intervals using the "Near" tool in ArcgGIS 9.3. Data points were converted to 10 m line sections using Hawth's Tools "Point to Line tool" in ArcGIS 9.3 This allowed quantification of the total distance of coastline represented by each feature.

Vegetation condition and dieback severity was recorded for each mangrove zone visible in the video from the channel. The dieback was qualitatively assessed to provide a relative "Subsidence Effect" score using the following classification criteria;

Severe: Most (>75%) of trees dead

Moderate: Some (25%-75%) of trees dead

Little: Some (1-25%) of trees dead

None: All trees healthy

Mangrove zones (see Table 31) were identified by position on the tidal profile, species, structure, height and tree size.

Low: Multi-stemmed *Rhizophora* species at the waters edge up to 6m tall and having a sprawling appearance.

Lower-mid: *Rhizophora apiculata* dominated communities with upright stature and up to 10m tall

Mid: *Bruguiera gymnorhiza, Rhizophora apiculata* and *Ceriops tagal* dominated communities, 10-20m tall with upright stature.

High: *Bruguiera gymnorhiza, Xylocarpus granatum* and *Lumnitzera littorea* with and *Heritiera littoralis* , 20-30m tall with upright stature, adjacent to the terrestrial fringe.

RESULTS

NATURAL MANGROVE ASSEMBLAGE ZONES

Natural mangrove vegetation zones (sites without dieback) were notable and distinct as displayed in Table 31; noting that error terms clearly show distinct elevations match the distinct mangrove species assemblages.

Table 31 Mangrove assemblage zones and matching HW Reference Levels, plus error terms in mangrove transect sites without dieback (Transects 7-12). Mangrove species include: RS (Rhizophora stylosa), RA (Rhizophora apiculata), CT (Ceriops tagal), BG (Bruguiera gymnorhiza), LL (Lumnitzera littorea), XG (Xylocarpus granatum).

	Mangrove Zone	Dominant Species	HW Ref. Elevation (m)	SE X 1
Edge T Terrestrial		Coco, Pand plus	-0.003	0.031
Upper H	High Upper		-0.289	0.067
H	High mean	LL, BG, XG	-0.382	0.028
Lower H	High Lower		-0.443	0.036
Upper Mid	Mid Upper		-0.453	0.042
M	Mid mean	RA, CT, BG	-0.535	0.024
Lower Mid	Mid Lower		-0.662	0.039
Upper Low	Low Upper		-0.802	0.035
L	Low mean	RS	-0.964	0.059
Lower Low	Low Lower		-1.169	0.040

MANGROVE ZONES AND DIEBACK

Transect profiles shown in Figure 6 (A, B, C & D) indicate the tendency for occurrences of dieback to occur at elevation levels lower than expected for respective species assemblages (as proxies for zones). This is seen in Figure 86 C &D showing the natural condition without dieback, and compared with transects with dieback in graphs Figure 86 A &B.

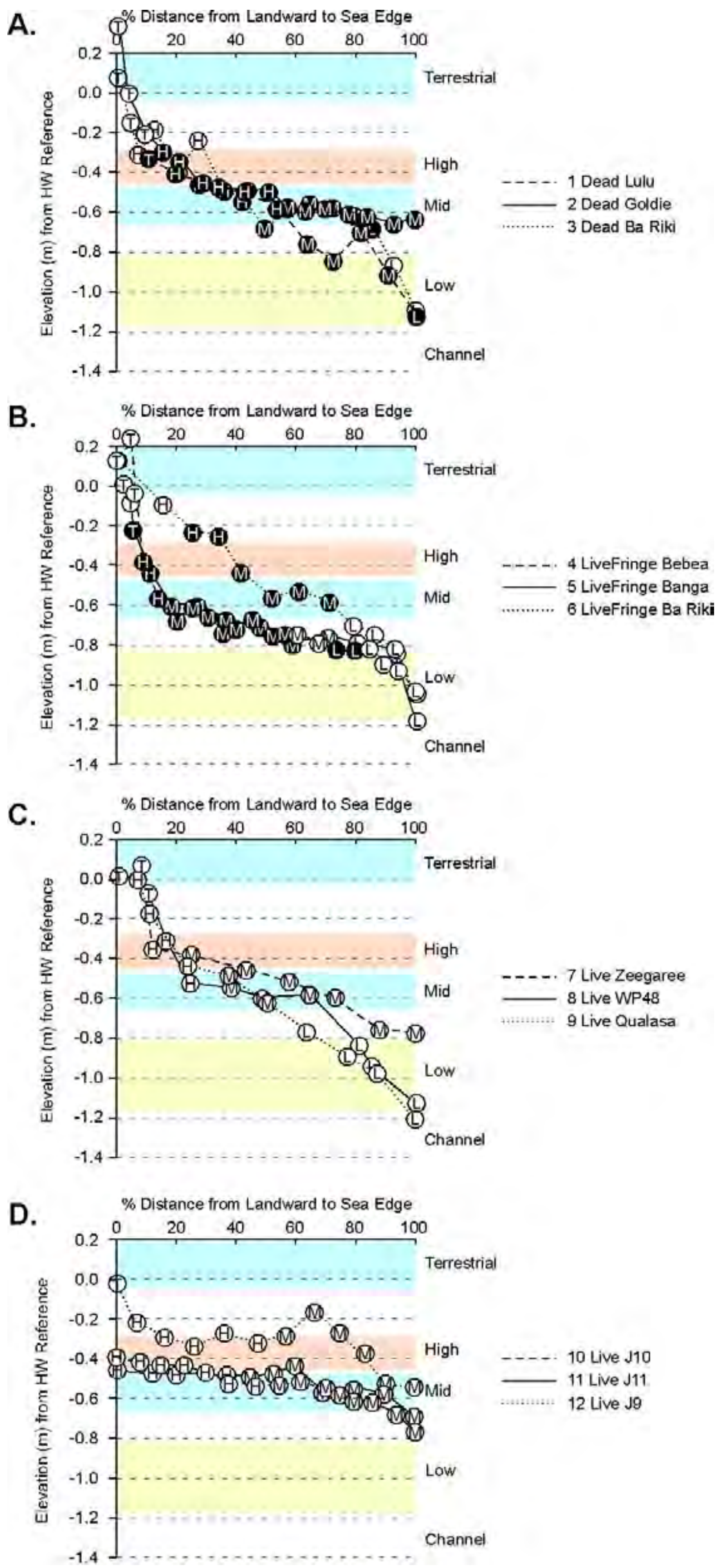

Figure 86 Representations of the 12 transects showing: relative elevation and shape of profiles (elevation in metres, zero reference at high water on first day – 21 March 2011); zonal position marked by vegetation assemblages (High = H; Mid = M; Low = L; Terrestrial = T); and dieback state (dieback = solid black circles; no dieback = white circles). Transect lengths were standardised (%) from distances listed in Table 29. Zones positioned from non dieback transects, see Table 31.

These data are summarised in Figure 87. The results show a largely variable and complex picture, although most differences show lower elevations in dieback sites at respective zones. And, variations depend on particular vegetation zones. For instance, there was notable separation of both dieback treatments in mid zone areas, comparing living natural sites with either dieback state. Mean subsidence measures were 12.9 cm for all live to dieback with living fringe, and 16.9 cm for all live to mostly dead. By contrast, there were notable overlaps and poor discrimination in low and high intertidal sites, and terrestrial edge sites.

For sites of dieback across most of the profile, there was negative differences (subsidence) observed in all zones from high, mid and low – respectively 3.8, 16.9 and 4.5 cm – mean of 8.4 cm. Although, differences in high and low zones were not significant considering the error values. For sites with living fringes, the results were mixed with all zones, except the mid zone, showing no significant change from live zone transects.

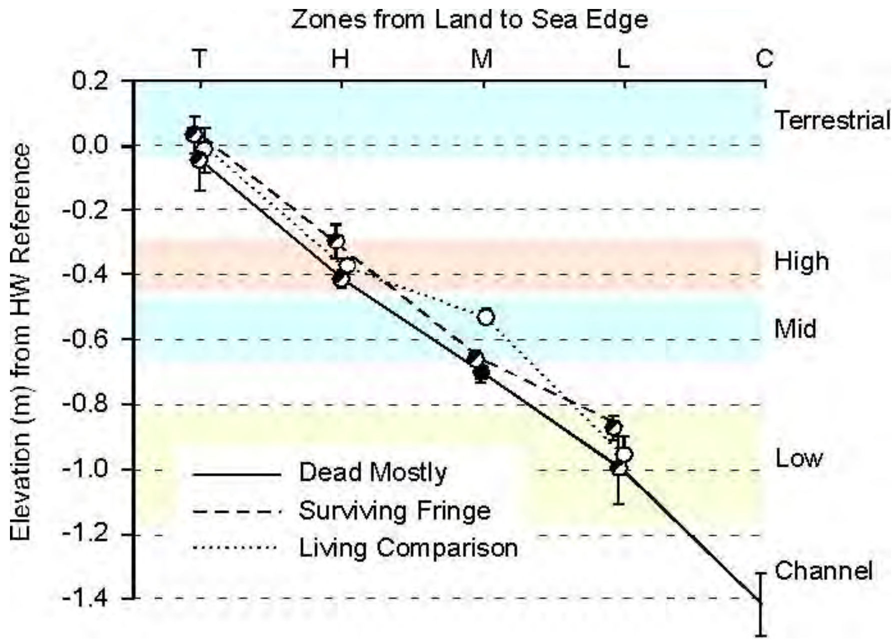

Figure 87 Summary of data from all 12 transects for three groupings (Dead Mostly 3, Surviving Fringe 3; Living Normal 6) with: zonal positions marked by vegetation assemblages (High = H; Mid = M; Low = L; Terrestrial = T); dieback state (mostly dead = solid black circles; mixed dead and dying = black/white circles; no dieback = white circles). Error bars based on standard error of mostly 3 replicates.

Extent of Dieback within Riki Riki Channel

The S-VAM assessment results show that dieback is widespread throughout the channel, with an increasing effect visible upstream and more severe effect along protected shoreline. The data from the survey is mapped in Figure 88. The greatest subsidence effect was observed in the lower-mid zone (94% affected, 65% severely affected) and the Mid zone (93% affected, 36% severely affected). The low *Rhizophora* zone was the least affected (56% affected, 12% severely affected). The level of severe, total loss of the low Rhizophora zone may be underestimated in this study due to decomposed trees and submerged stumps not being visible in the video. Only 7km (out of a 23.4km total shoreline) of low zone mangrove was recorded. The High mangrove zone was the least severely affected zone with only 8% recorded as severely affected and the majority (70%) of subsidence effect classed as “Little effect”.

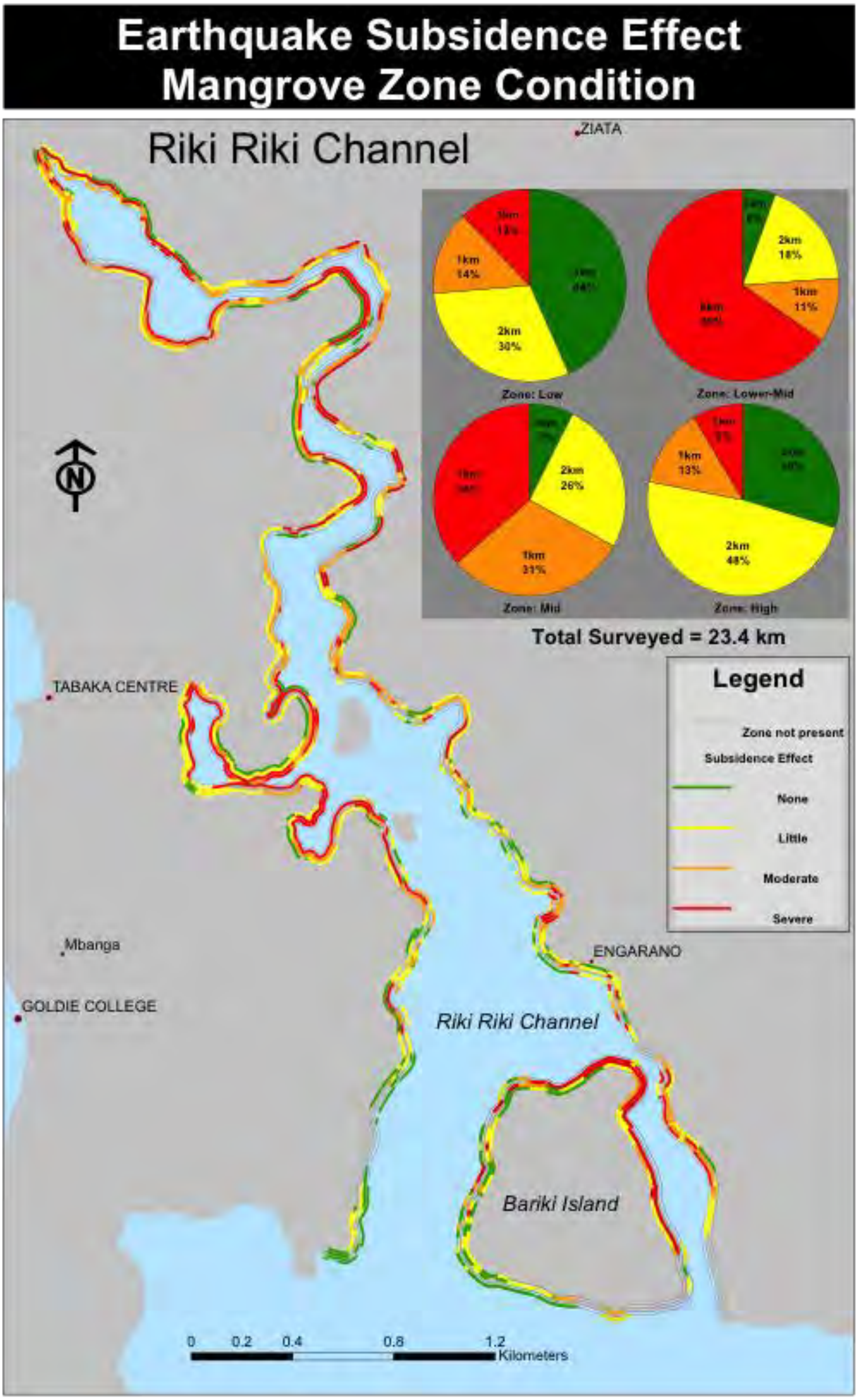

Figure 88 Map of subsidence effect observed in mangrove zones in Riki Riki Channel.

Discussion

Subsidence was observed in areas of mangrove dieback compared with areas of healthy mangroves in the Roviana-Munda-Noro area of Western Province, Solomon Islands. And, by their timing one year after the quake, it would appear these instances of mangrove dieback were likely consequences of the 2007 earthquake, albeit an understandably delayed response.

However, the subsidence observed was not uniform across transects and across the range of mangrove zones. For instance, it was significant that subsidence was greatest in the mid mangrove zone and that this effect was observed throughout the Riki Riki channel. This raised the important question, why might the mid zone be more vulnerable to earthquake subsidence?

The hypothesis best able to explain this occurrence and current observations, is that there are consequences of the earthquake causing the land in this area to shake severely. Our observations support the observation that there was no net change in elevation of the larger island and surrounding land mass. If this had been the case, there would have been a more even distribution of base subsidence estimates across all mangrove zones and the terrestrial edge. Our observations notably show no significant differences in terrestrial edge and high intertidal zones.

In view of these considerations, the earthquake shaking appears to have resulted in liquefication and settling of porous mangrove sediments – causing subsidence in localised patches within intertidal areas. The variable differences observed in different locations and zones, maybe explained by the corresponding differences in shallow intertidal sediments. There was no undertaking in this study to characterise underlying sediments, but his would be most useful in the future. Such a study is highly recommended for any on-going investigation of this distinctive mangrove dieback phenomena.

In the meantime, there are a number of associated observations and useful generalisations to be made in support of the hypothesis. Mangrove sediments are characterised by having numerous holes, cavities and air spaces created in part due to depositional processes, but these are further enhanced by burrowing fauna and decayed buried wood. The zone most likely to have the deepest porous layers would be the mid zone. The subsidence levels recorded may therefore be indicative of the depth of underlying peat layers – coupled with the severity of shaking during the earthquake.

Furthermore, the living fringe zone often observed in several locations of mangrove dieback may be the result of sediments in this low zone often being more compact as a result of wave and wind exposure. It is notable that most sites in this condition do face more open and exposed wider fetches of water (deduced from images listed in Table 28). Sites having no living fringes appear always to occur within enclosed estuaries and along narrower channel waterways. The area of most extensive mangrove dieback is notable for having no living fringes in the low zone. This instance occurs within the confines of the Lulu Channel running to the north-west alongside Mbanga Island to the west of Munda (Figure 83 A). By contrast, sites along the southern side of Mbanga Island facing the exposed lagoon waters have the distinctive living fringe seen in Figure 83 B.

Blaber & Milton (1990), observed that in Riki Riki channel, *Rhizophora* dominated communities were associated with unconsolidated mud and *Brugueira* communities were associated with more densely packed sand. Mud is more likely to experience autocompaction and liquefecation than sand, and consequently more severe dieback was observed in lower-mid *Rhizophora apiculata* stand. From Figure 88, it can be observed that dieback is more frequent and severe in upstream sections of the channel and in protected embayments, areas where more organic, unconsolidated muds are more likely to occur.

This preliminary investigation has been useful for a number of reasons. First, we have been able to characterise and explain an important occurrence of unusual mangrove dieback in the Munda area. Second, we have demonstrated that even a small rise in sea level (between 5 and 17 cm) has dramatic consequences on mangrove health and survival. Mangrove species appear very sensitive to changes in sea level. Lastly, from this study it appears that mid to lower-mid Rhizophora stands on muddier substrates are more susceptible to earthquakes than other mangrove zones. This has implications for catchment management throughout the Pacific Ring-of-Fire Region. As increased forest logging leads to increased sediment runoff and sediment deposition in the mangrove coastal fringe, areas of mangrove experiencing greater rates of terrestrially derived sediment inputs are potentially more at risk of similar earthquake subsidence as those observed in Riki Riki channel.

Future investigations need to consider the consequences of change with respect to species and their natural zonal range, rather than thinking of fringing mangroves as a single entity.

CHAPTER 5

WATER QUALITY

Alistair Grinham

Simon Albert

Badin Gibbes

KEY MESSAGES

- Temperature of lagoon waters highly variable over time and with depth
- Areas close to passages have greatest variability in water temperature
- Presence of harmful bloom forming phytoplankton species
- Water quality of Roviana influenced by high sediment and nutrient inputs from catchment
- Water quality poorer in central and eastern Roviana
- Generally water quality better than global averages
- Light penetration to benthic habitats better offshore but variable with rainfall
- Highest phytoplankton productivity in inshore areas associated with higher nutrient.
- System vulnerable to increases in nutrient input

WATER QUALITY ASSESSMENT OF ROVIANA AND VONAVONA LAGOONS

Water quality is defined as a measure of the condition of a water body relative to the needs of one or more species (Johnson et al. 1997). This is an open ended definition and is commonly focussed on the needs and use by humans. Generally, water quality is measured in terms of relative change against reference conditions. However, in Roviana and Vonavona Lagoons there is no historical water quality monitoring and it is not possible to generate reference site indicators. A first step in this process is a baseline assessment of the water bodies and to this end a survey of water quality conditions across Roviana and Vonavona lagoons was conducted from June 28-July 9 2010. The primary aim of this work was to generate a detailed snapshot of water quality encompassing the whole region ensuring a wide spectrum of habitats were captured in both Roviana and Vonavona Lagoons.

In total 120 sites (Figure 89) were assessed for a range of water quality parameters using a multiparameter water quality instrument (RBR XR-620, Ontario, Canada). Water column profiles were collected at each site were the instrument was lowered to the benthos or to a depth of 50 m in open ocean sites. Sampling rate was set to once every 3 seconds, yielding water quality data approximately every 5 cm between the surface and the benthos. Parameters sampled using were: conductivity, temperature, depth, pH, oxidative redox potential (Redox), dissolved oxygen, chlorophyll fluorescence, turbidity and photosynthetically active radiation (PAR). In addition, water clarity was estimated at each site using a Secchi disc which was lowered until no longer visible and the depth recorded. Total suspended solids and chlorophyll samples were collected at each site with a known volume of water filtered through GFF filters, filters were removed and stored frozen until analysis. Total suspended solids were analysed gravimetrically with a detection limit of 4 mg L^{-1}. Chlorophyll was estimated using the spectrophotometric method following Lorenzen (1967) after extraction with 90% acetone.

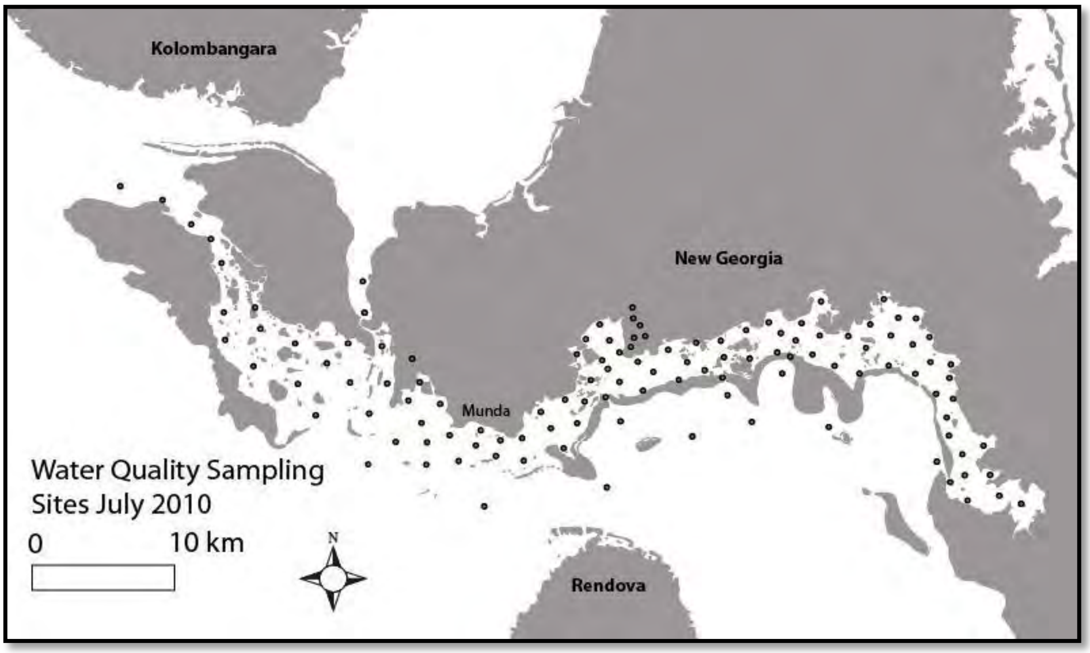

Figure 89 Baseline water quality sampling sites July 2010

WATER TEMPERATURE

SPATIAL VARIABILITY IN WATER TEMPERATURE

The baseline survey showed relatively high variability in many parameters monitored across the sites and lagoons as well as with water depth. These dynamic changes are best exemplified by water temperature. Maximum water temperature ranged over 3 ^{o}C, across all sites sampled (Figure 90) with Roviana Lagoon having generally higher maximum water temperature relative to Vonavona Lagoon. This is potentially a consequence of higher water residence time within Roviana Lagoon.

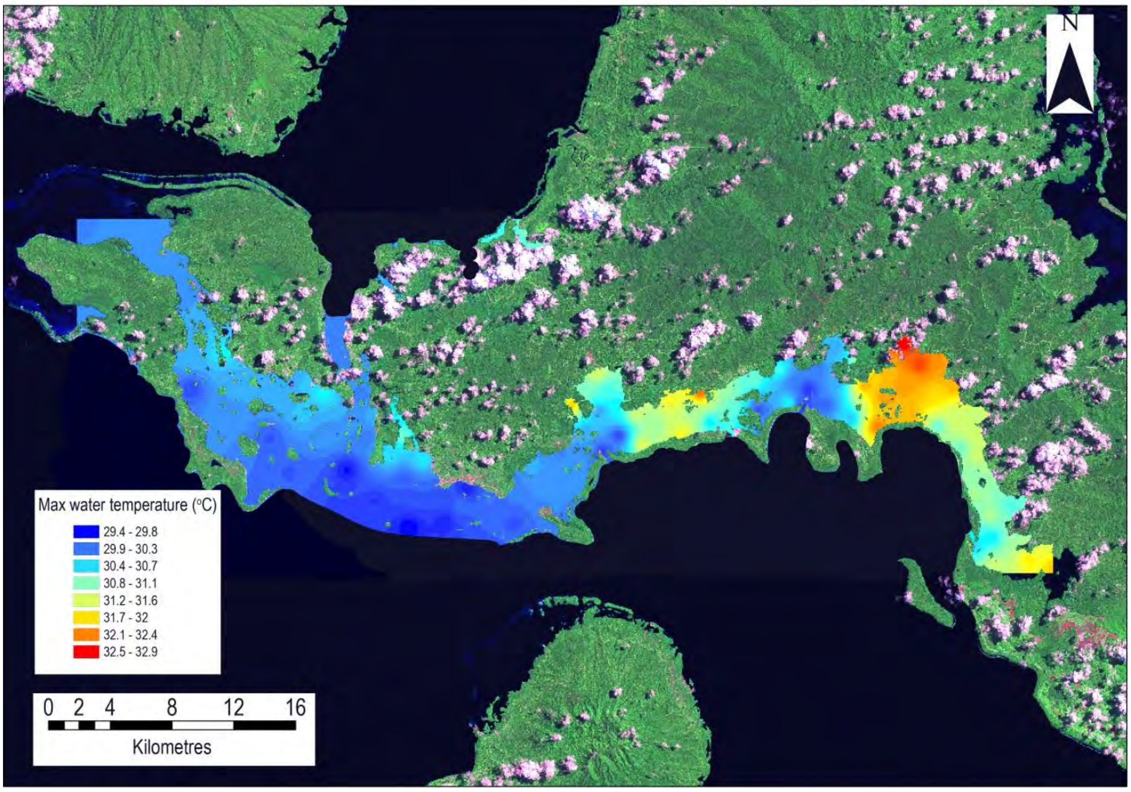

Figure 90 Large scale variability in maximum water temperature observed during July 2010 baseline water quality assessment.

VERTICAL VARIABILITY IN WATER TEMPERATURE

A large range in water temperature was found in vertical water profiles from lagoon sites especially adjacent areas of catchment inputs. These could be in excess of 3 ^{o}C at a single site (Figure 91) with strong thermal stratification observed compared with profiles collected from offshore sites. Offshore sites ranged less than 0.2 ^{o}C with very little stratification observed at these sites.

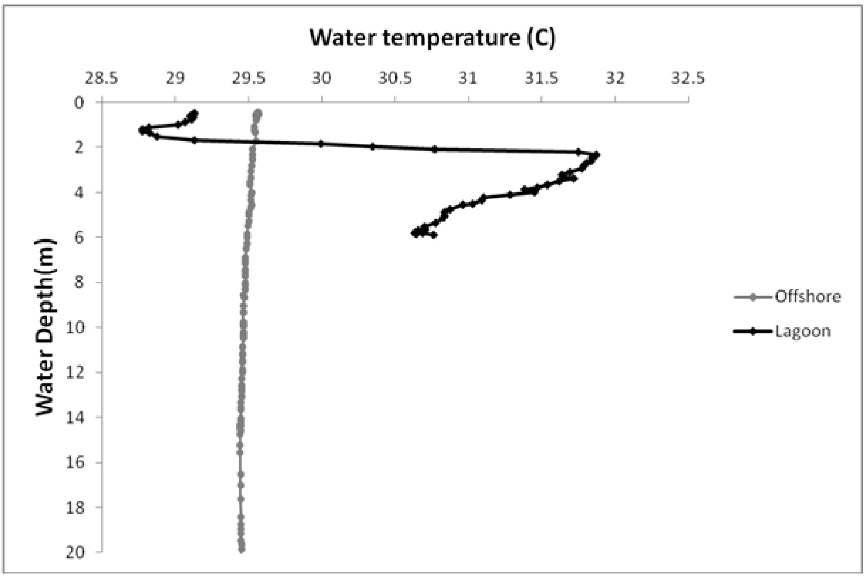

Figure 91 Rapid changes in water temperature profiles at lagoon sites versus relatively uniform profile from offshore site.

TEMPORAL VARIABILITY IN WATER TEMPERATURE

To further investigate this spatial and temporal variability in water temperature a series of short- and long-term monitoring programs were initiated. Long term monitoring of shallow water temperature (<2 m) using temperature loggers (HOBO Pendant, Bourne, USA) at selected lagoon and offshore sites commenced in March 2011 and logged temperature every 15 min. Generally surface waters were warmer in the lagoon relative to offshore waters (Figure 92) however the magnitude of this difference varied greatly. A diurnal signal can be observed in both lagoon and offshore but could range over 3 ^{o}C in the lagoon compared with less than 1 ^{o}C offshore (Figure 92). It is interesting the strong impact that rainfall has in modifying this pattern as shown between 05/08 and 15/08 (Figure 92) where large scale rain events reduced both absolute and range of water temperature in both lagoon and offshore sites.

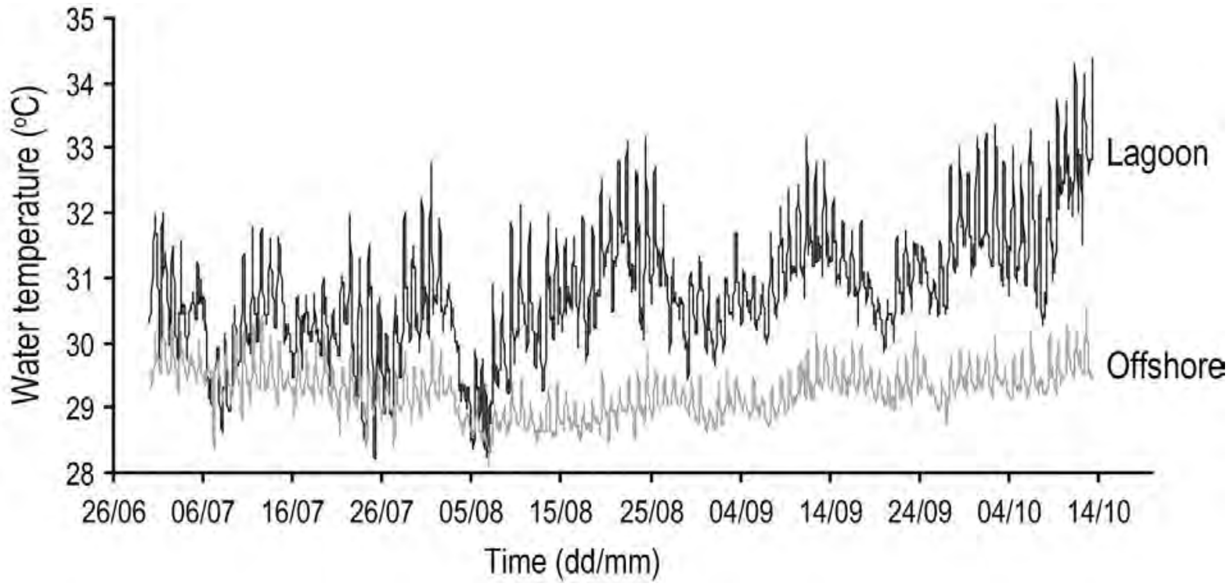

Figure 92 Long term water temperature monitoring at 2 m depth from lagoon and offshore sites from June to October 2011.

Differences in water temperature profiles were also observed with the lagoon. A series of thermistor chains were deployed at a selected inshore, mid-lagoon and ocean passage site. These logged temperature at discrete through the water column over a 10 day period in July 2010 at a sampling rate of 1 min (Figure 93

A – C). Inshore had relatively higher average water temperature (Figure 93 A) compared with mid lagoon (Figure 93 B) and ocean passage (Figure 93 C). The mid lagoon appeared to have the greatest range in surface water temperature compared with both inshore and ocean passage (Figure 93).

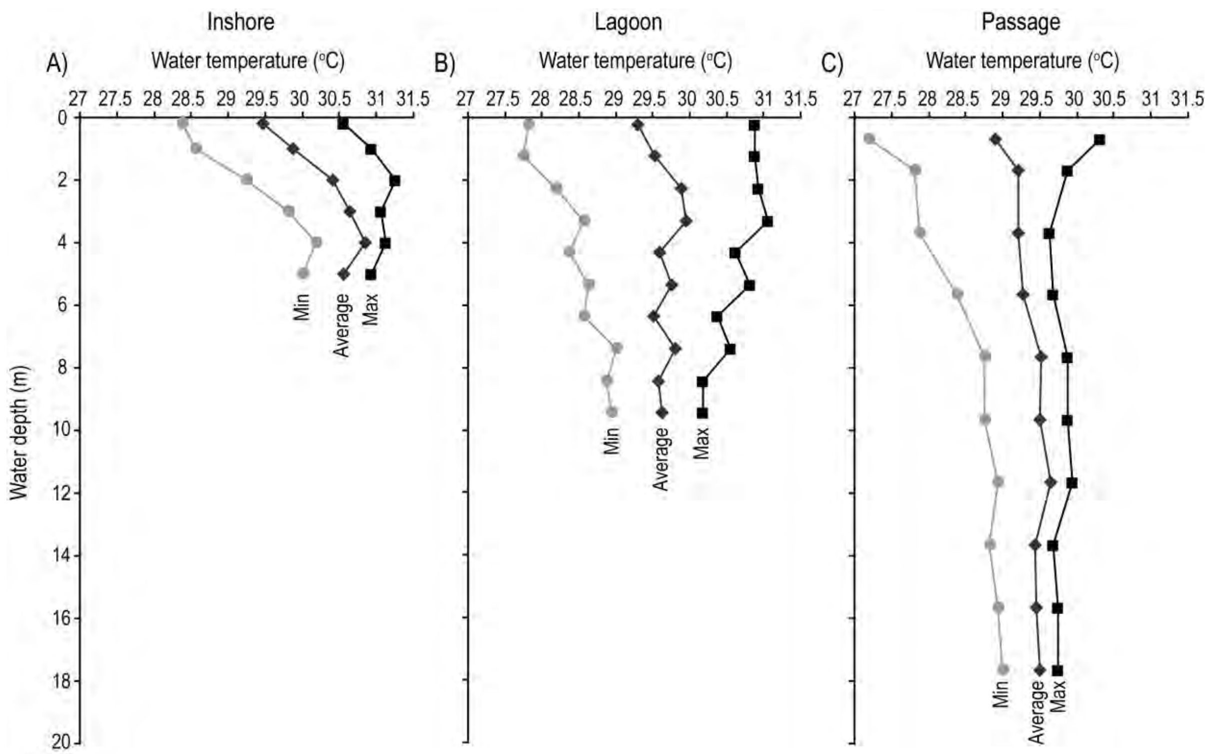

Figure 93 Average and range of water temperature from high frequency sampling of discrete depths at A) inshore, B) lagoon and C) passage sites.

The use of range and average data does not reflect rapid changes in surface waters at the ocean passages. The strong diurnal pattern in water temperature changes is evident (Figure 94 A), likely driven by a combination solar heating and tidal mixing. However, catchment inflows can also directly effect surface waters clearly shown on 02/07 (Figure 94 A) where high catchment runoff directly impacted the water temperature at this passage. Further evidence of the impact of these catchment runoff events is shown in the salinity profiles collected before and after the catchment inflows showing large reduction in surface salinity concentrations during this period (Figure 94 B).

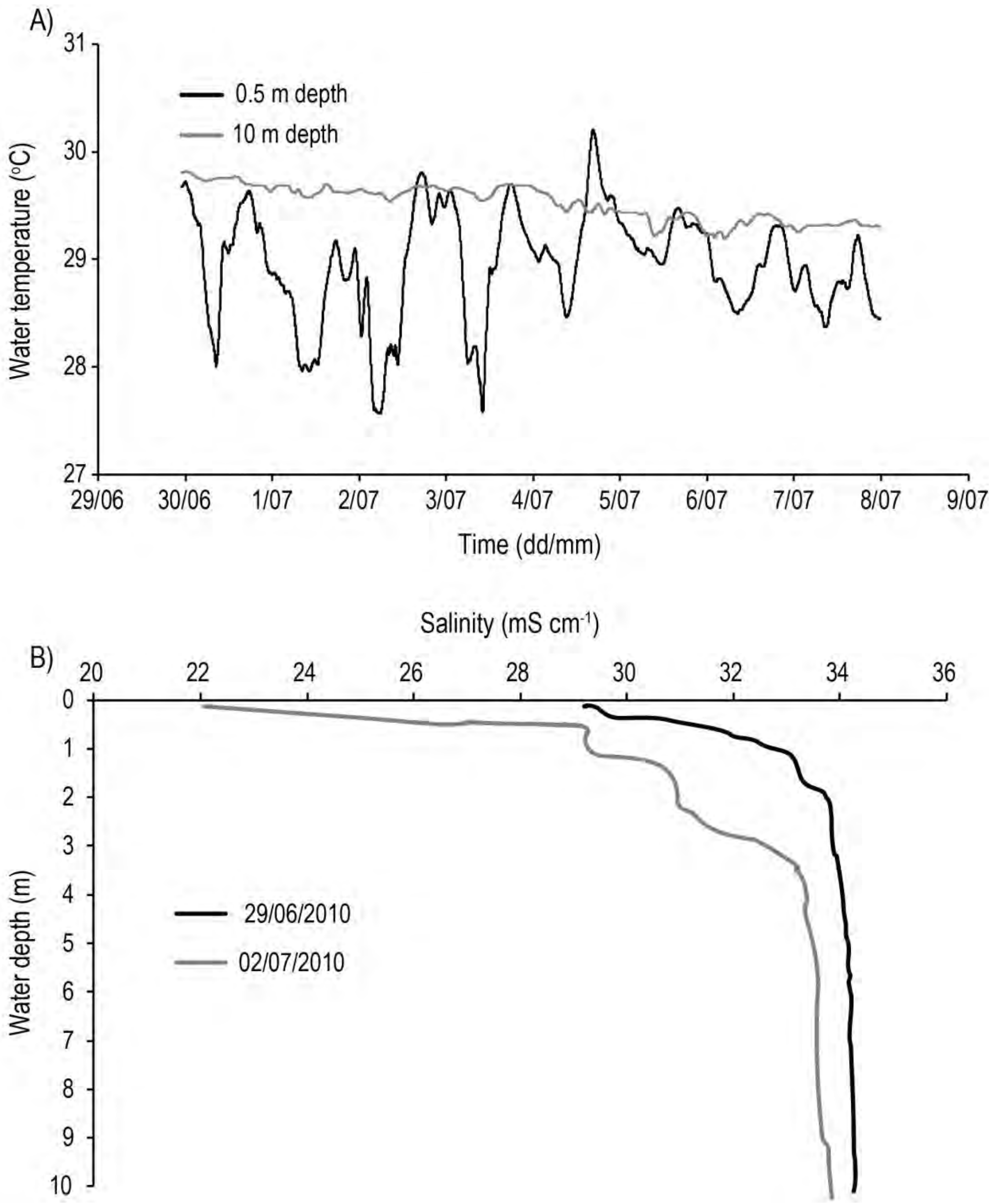

Figure 94 Dynamic changes in A) water temperature and B) salinity at passage site adjacent river mouth.

These dynamic changes in water temperature and salinity greatly impact the biotic community as these tend to have narrow tolerance ranges of both salinity and water temperature. In addition, both water temperature and salinity control dissolved oxygen saturation in water rapidly changing its relative availability. Finally, accompanying these cold, fresh catchment inflows is a generally higher nutrient availability and sediment load, stimulating phytoplankton communities and smothering benthic surfaces.

WATER QUALITY INDEX

A water quality index was developed using the methods established by Albert et al using selected water quality parameters (turbidity, chlorophyll, minimum dissolved oxygen). A water quality score was generated for each site and then interpolated between sites to better visualize the data (Figure 95). General trends clearly observed with water quality higher in Vonavona Lagoon relative to Roviana Lagoon. However, a strong gradient in water quality was observed between western and eastern areas of Vonavona Lagoon. Southern Roviana Lagoon had the poorest water quality compared with all other sites sampled. Roviana Lagoon has the potential for higher catchment inputs relative to Vonavona Lagoon due to its larger catchment area (504 km^2) compared with Vonavona Lagoon (35 km^2) but similar water surface area between systems (142 km^2 and 165 km^2). In addition, the southern region of Roviana Lagoon has very limited ocean exchange greatly restricting flushing of this section with relatively clean ocean waters.

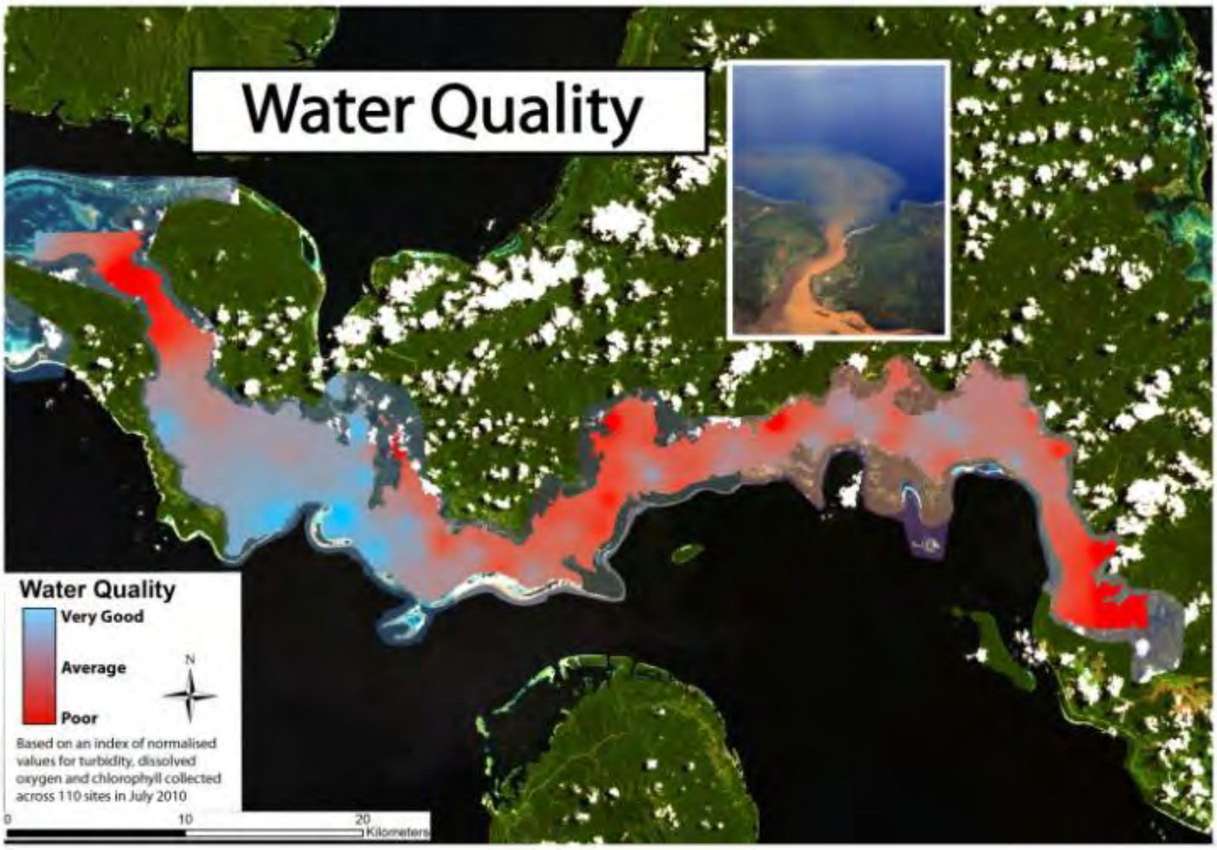

Figure 95 Water quality index developed from baseline water quality survey conducted in July 2010.

To better understand trends observed in the baseline water quality survey, a series of case studies in areas of interest were undertaken (Figure 96). These studies were not designed to be exhaustive investigations in their own right but rather to help support findings from connectivity and vulnerability assessments as well as provide before data prior to any major catchment developments. The overall aim is to allow more informed management decisions of catchment and marine land use changes and to better quantify the impact of such changes on the both lagoon systems.

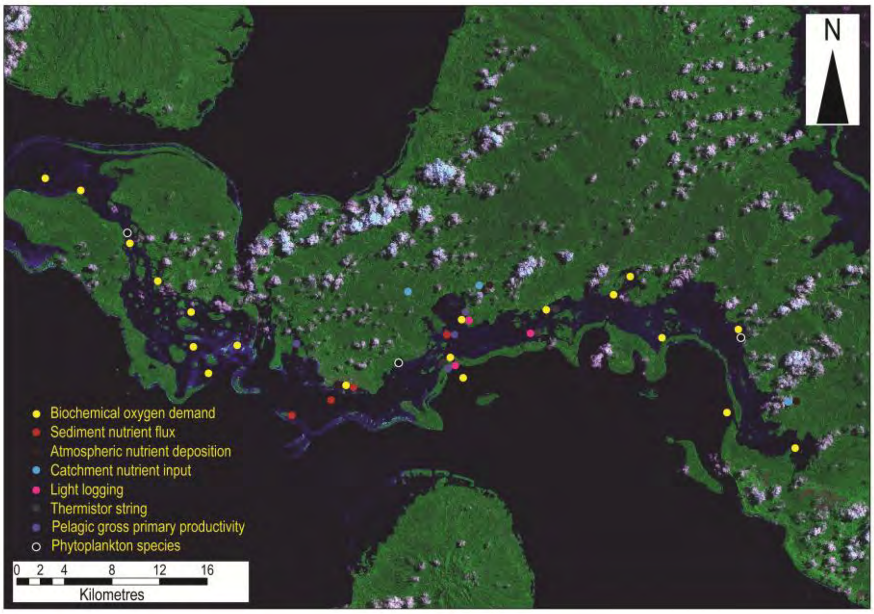

Figure 96 Sampling sites of focussed assessment studies during both July 2010 and January 2011 site visits.

PHYTOPLANKTON SPECIES

A recent massive fish kill in the adjacent Marovo Lagoon (Albert et al. 2012) prompted a rapid assessment of 3 sheltered bays within Roviana and Vonavona Lagoons (Figure 96) to assess the bloom potential of these systems. These surveys were conducted using 6 m vertical net tows with a 20 µm mesh phytoplankton net. The net and cod-end were washed with site water to yield a 40 mL sample, this was preserved with Lugol's solution for later microscopic identification. Phytoplankton species were identified using standard taxonomic keys. The toxic dinoflagellate *Pyrodinium bahamense var. compressum* was found at two sites in Roviana Lagoon however relative abundance was very low (<1%) in both cases. Samples were typically dominated by the dinoflagellate *Ceratium furca*, (Figure 97) whilst not a toxin producing species it can deplete dissolved oxygen during bloom events. These bloom events are generally triggered by excess nutrient availability and land use management of catchment areas surrounding these bays should include this in proposed developments in these sensitive areas.

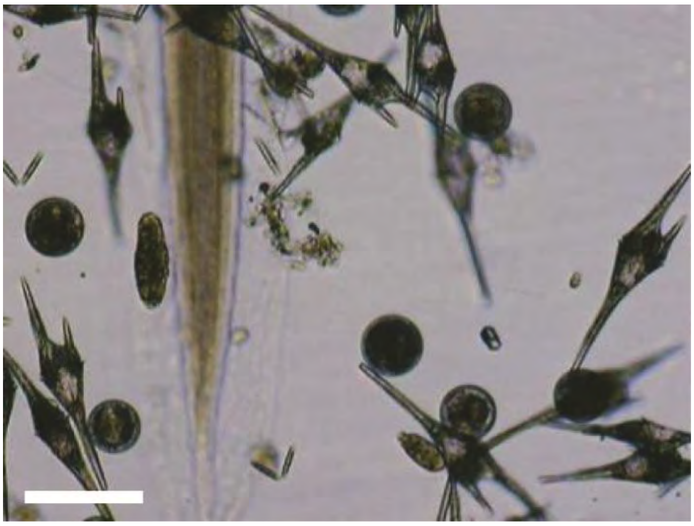

Figure 97 Light micrograph from typical inshore algal assemblage of Roviana Lagoon. Scale bar 40 µm.

PHYTOPLANKTON PRODUCTIVITY ASSAY

Phytoplankton are a diverse assemblage of oxygenic photosynthetic organisms commonly consisting of diatoms, cyanobacteria, chlorophytes and dinoflagellates inhabiting the light zone of the water column. Phytoplankton are generally the major primary producers in these shallow water systems providing an important food source to many organisms. In addition, during photosynthesis oxygen is produced increasing water column dissolved oxygen levels benefiting aerobic heterotrophs that require oxygen to drive their metabolism. However, blooms of phytoplankton can negatively impact aerobic heterotrophic activity either by toxin production or dissolved oxygen depletion. It is important to estimate phytoplankton primary productivity rates and establish baseline productivity levels. Clear 600 mL plastic bottles were carefully filled to ensure no bubbles remained and bottles were placed in a series of light availability pouches. These conditions ranged from total darkness to ambient light levels and pouches were tethered to a floating line *in situ* to maintain water temperature at ambient levels. Dissolved oxygen levels were monitored before and after a 6 h incubation that encompassed solar noon. Dissolved oxygen was measured using a micro-optode (Fibox 3, Presens, Regensburg, Germany) with a detection limit or 0.015 mg L^{-1}. Light loggers (Odyssey PAR Recorder, Christchurch, New Zealand) were placed under same field conditions and light levels recorded monitored every 5 min for the duration of the incubation. Chlorophyll samples were filtered at the end of each incubated and stored until processed in the lab. Productivity was expressed as gross primary productivity (GPP) and expressed in terms of oxygen production per unit chlorophyll per unit time (Figure 98). Samples were collected at 4 sites from river mouth to ocean passage. A peak in pelagic GPP was found at the inshore site relative to all other sites. The river mouth site had its highest GPP rates at low light intensities suggesting these communities are adapted to low light levels (Figure 98) possibly due to the shaded riparian zone found in these systems. The peak in GPP at the inshore is likely a consequence of increased incident light levels and ready nutrient supply from catchment inputs.

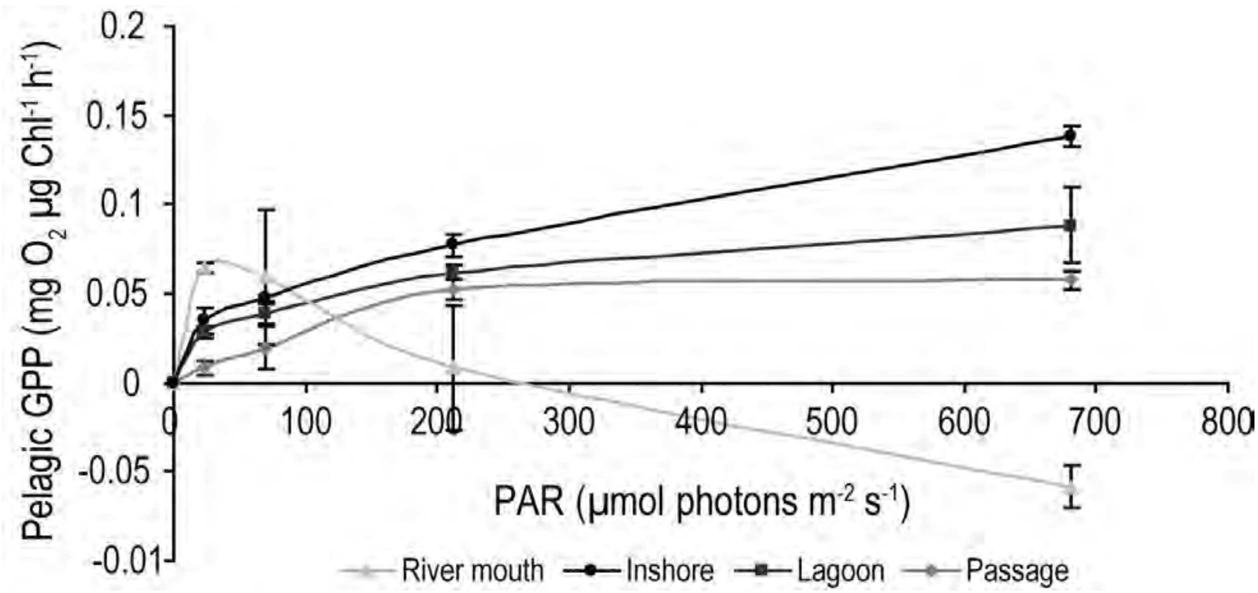

Figure 98 Gross primary productivity of phytoplankton across a range of photosynthetically active radiation intensities at four sites encompassing a transect from river mouth to ocean passage.

BENTHIC LIGHT

Benthic photosynthetic communities such as seagrass, coral and microalgae are dependent upon incoming photosynthetically active radiation (PAR) to perform photosynthesis during daylight hours. Photosynthesis is a critical source of energy to these communities and rates are generally dependent on the amount of light. Benthic PAR was logged using loggers (Odyssey PAR Recorder, Christchurch, New Zealand), deployed at three transect sites (Figure 96) Loggers were deployed underwater (2 m depth) at each site to monitor benthic light flux and these rates were referenced to surface light logged within 5 km of each site. Sample rate was every 10 min for 10 days. Periodic revisits to clean underwater loggers were performed every 3 days.

Little differences in benthic PAR was found between a river mouth and inshore lagoon site however an order of magnitude increase in benthic PAR was recorded at the passage site (Figure 99). The slightly lower benthic PAR at inshore relative to river mouth sites could be due to the increased pelagic GPP found at these sites (Figure 98) further reducing benthic light flux. Rates of benthic photosynthesis are likely to be greatly increased at the passage relative to the river mouth or inshore sites. It is generally accepted that photosynthetic communities are limited depths that receive more 1% of surface PAR and communities inhabiting the 2 m depth zone at both the river mouth and inshore sites were very close to this limit. In contrast, photosynthetic communities at the passage site will be able to inhabit zones deeper than 2 m due the greatly increased light availability found here.

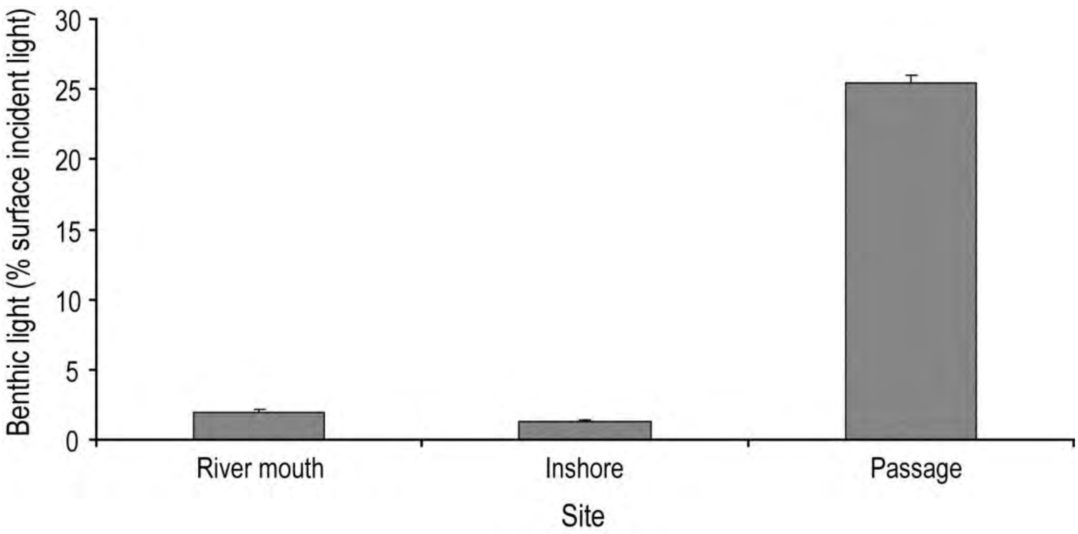

Figure 99 Benthic PAR relative to surface PAR from a river mouth, inshore and passage sites in Roviana Lagoon from July 2010.

However, benthic PAR varied considerably over short timescales at the passage site with a 10% drop in benthic PAR in a single day (Figure 100– 2nd to 3rd July). Catchment rainfall events appear to drive these dynamic changes in benthic PAR as there was strong discoloration within the freshwater lens observed during this period, followed by a recovery of benthic PAR after a period of low catchment rainfall (Figure 100).

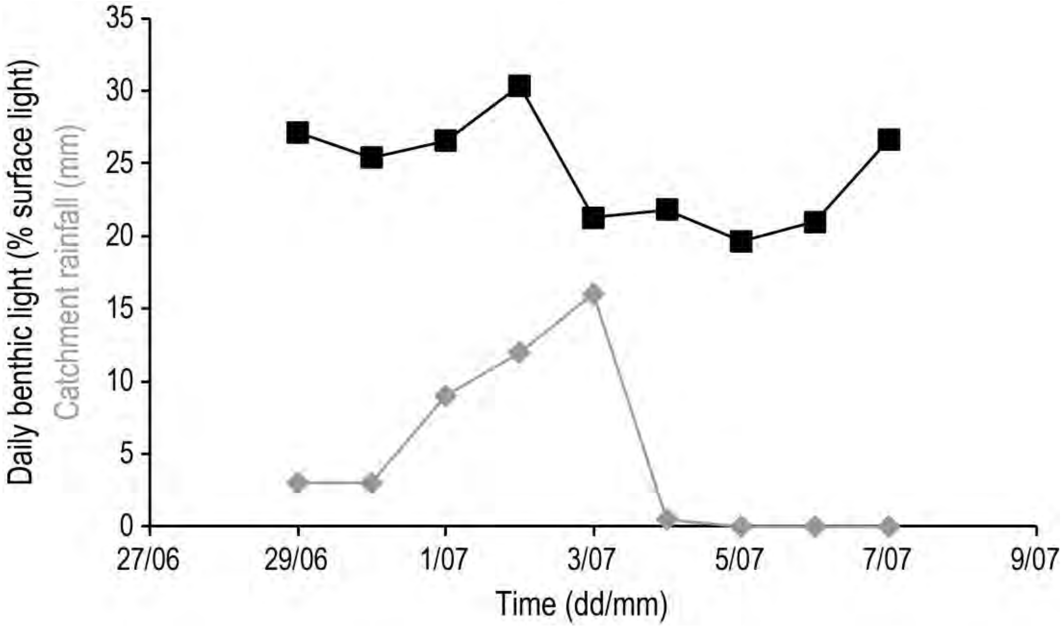

Figure 100 Close coupling between benthic PAR at passage site opposite a major river mouth and catchment rainfall. During periods of heavy catchment rainfall reduced benthic PAR was found.

Analysis of sediment grain size

Sediment grain size of the benthic zone is a critical component of any water body as it generally dictates the type of microbial community inhabiting this zone. The microbial community consists of bacteria and archea capable of living under a wide range of dissolved oxygen, redox, pH levels. Low dissolved oxygen environment in the deeper sediments are zones of inorganic nutrient generation from organic matter degradation. These can then diffuse into the overlying water column and cycled back into the organic pool. The rate at which this exchange occurs depends on the sediment particle size. Sandy sediments generally allow greater penetration of dissolved oxygen into the upper sediment zone decreasing the rate of inorganic nutrient release as much of it is processed within the upper sediment layers prior to release to the water column. In silty sediments dissolved oxygen penetration is greatly reduced allowing high concentration of porewater nutrients very close to the sediment surface and increasing diffusive nutrient flux rates. In addition, silty sediments have much slower settling rates after resuspension into the water column relative to sandy sediments. This can result in a greatly reduced benthic light flux during periods of sediment resuspension in silty sediment zones, decreased rates of photosynthesis under these conditions further reduces sediment dissolved oxygen penetration allowing increased nutrient flux rates. Sediment samples were collected from 83 sites across both lagoon systems using a gravity corer (Figure 101 A). Samples were wet sieved, dried and weighed and fractions classified as follows - silty sediments were less than 0.064 mm; sandy sediments between 0.0064 and 2 mm; and gravels were greater than 2 mm. Values for single sites were interpolated across all sites to better visualize data. Silty sediments generally dominated the benthic surfaces of both lagoons relative to sand and gravel (Figure 101 B – D). These data suggest the system is vulnerable to reduction is water column dissolved oxygen concentrations as this will likely increase sediment nutrient flux due to reduced sediment dissolved oxygen penetration. The increased sediment nutrient flux will likely stimulate phytoplankton communities further reducing benthic light flux and sediment dissolved oxygen penetration. This can result is large dead zone formation is dissolved oxygen content is completely removed from the lower water column.

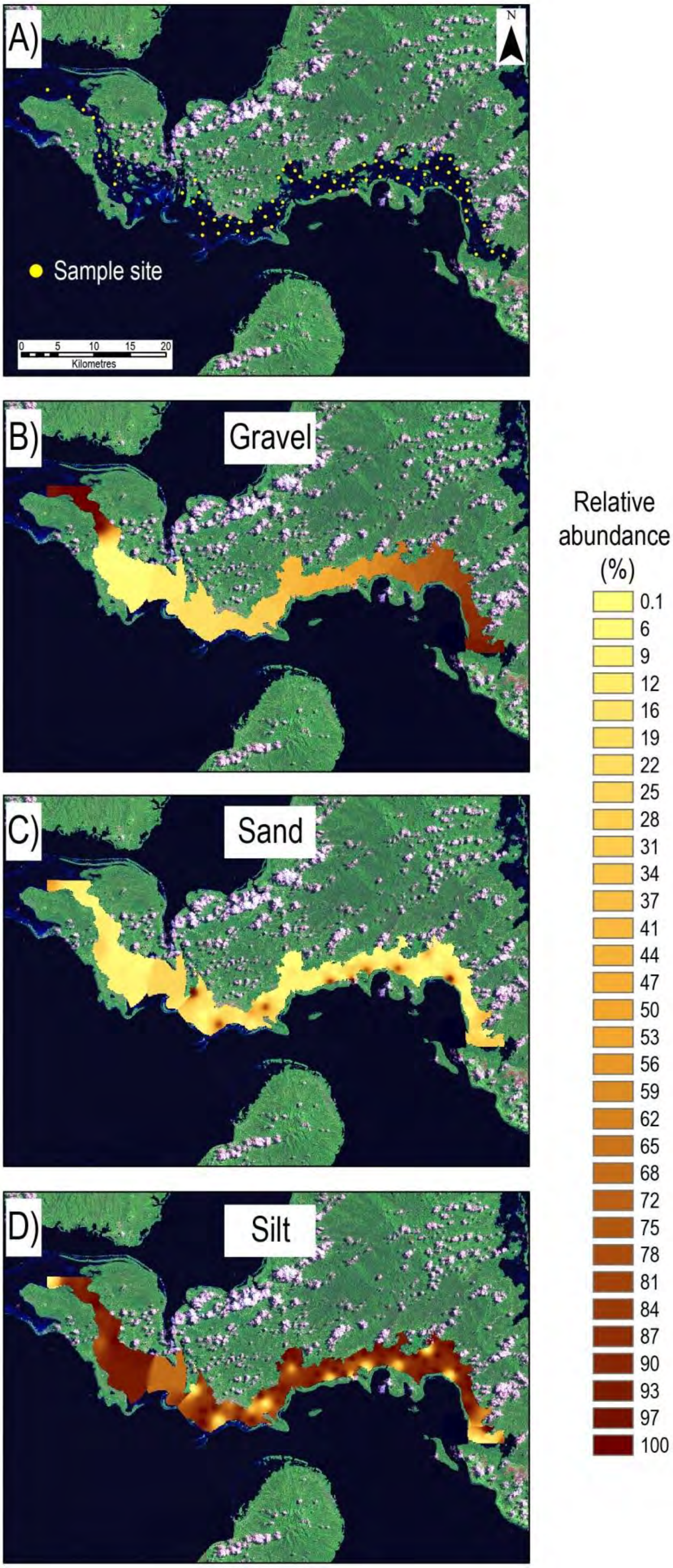

Figure 101 Sediment sampling program showing A) sites sampled and interpolated B) gravel, C) sand and D) silt fractions.

Biochemical oxygen demand

Biochemical oxygen demand (BOD) is a measure of the quantity of dissolved oxygen required by aerobic heterotrophs inhabiting a water body. These include multicellular organisms such as fish, coral and invertebrates as well as unicellular organisms such as protists and bacteria. It is commonly used as indicator of organic pollution and expressed as the reduction of dissolved oxygen after a 5 day incubation period. Values less than 1 mg L^{-1} indicate relatively pristine systems with low levels of organic pollution. BOD tests were conducted across sites located in both Roviana and Vonavona Lagoons, as well as offshore oceanic sites and freshwater sites in major river systems (Figure 8). 600 mL clear plastics bottles were carefully filled ensuring no air bubbles remained and sealed using parafilm. Bottles were placed in a black plastic bins to ensure dark conditions and were placed indoors where temperatures ranged from 28 to 30 ^{o}C. Dissolved oxygen levels were monitored before and after incubation using a micro-optode (Fibox 3, Presens, Regensburg, Germany) with a detection limit or 0.015 mg L^{-1}. Average BOD values were all less than 1 mg L^{-1}, indicating very low levels of organic pollution at all sites sampled (Table 32). In addition, these likely represent the upper range as BOD incubations generally occur at 20 ^{o}C, so the conditions used here were almost 10 ^{o}C higher than standard which would greatly accelerate rates of aerobic heterotrophy and therefore increase BOD. It is interesting to note that BOD from Roviana Lagoon sites was almost twice as high on average compared with Vonavona, a pattern similar to that of the water quality index.

Table 32 Biochemical oxygen demand from river, lagoon and offshore waters during July 2010 and January 2011 visits. Values given as averages ± standard error (if appropriate).

Area	Site	BOD (mg L^{-1})
River	Mare	0.3 ± 0.08
	Nusa Hope	0.2 ± 0.06
	Hura	0.1 ± 0.03
	Average	**0.2**
Roviana	R73	0.5
	R65	0.5
	R58	0.4
	R69	0.4
	R26	0.6
	R37	1.3
	R45	0.2
	R86	1.2
	R100	1.6
	Average	**0.74 ± 0.16**
Vonavona	R8	0.3
	R102	0.5
	R5	0.4
	R106	0.2
	R103	0.9
	R1	0.3
	R11	0.3
	R7	0.4
	Average	**0.41 ± 0.08**
Offshore	R38	0.5
	R97	0.4
	Average	**0.45**

Nutrient input from catchment

A conceptual understanding of nutrient input into a shallow lagoonal system is outlined in Figure 102. Catchment inflows are generally considered to carry the bulk of nutrient inputs with a variable contribution from benthic nutrient fluxes within the lagoon itself. Atmospheric input in the form of dry and wet deposition is usually not considered or dismissed as unimportant.

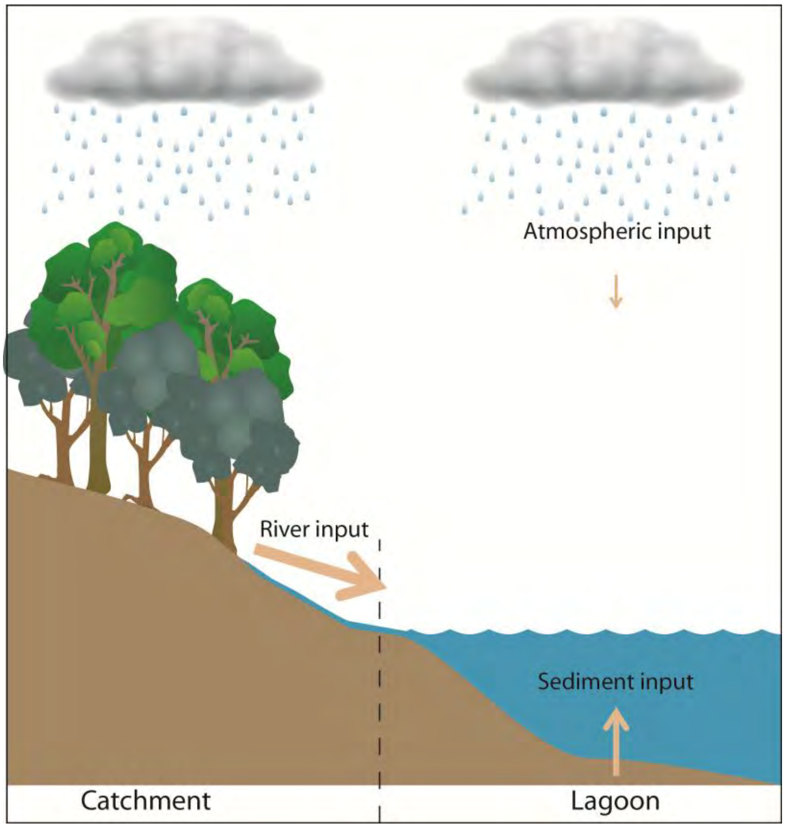

Figure 102 Conceptual model of nutrient loading to lagoon systems.

Atmospheric nutrient deposition was estimated using a plastic funnel (11 cm diameter) attached to a commercial nutrient passive sampler (Sorbisense, Tjele, Denmark). These passive samplers consist of a porous ion exchange resin bed and salt tracer, the resin bed traps nitrate and phosphate whilst the salt tracer estimates water volume through the resin bed. Samplers were established at four sites across the lagoon and placed in open areas within the catchment (Figure 103 A). From this data it is possible to estimate the average nutrient concentration in rainfall which can be extrapolated across the region using long term averages from Munda metrological station (3500 mm per annum). River inputs were estimated using the same nutrient passive samplers placed underwater above the stream bed (Figure 103 B). An initial deployment of 10 days was conducted in July 2010 and a long term (3 month) deployment followed this.

In situ sediment nutrient fluxes were derived using incubating chambers inserted into the sediment. This follows the bell jar methodology in Stutes et al. (2006) where dissolved inorganic nutrient levels were monitored in light and dark containers. Custom built cores were constructed using Perspex (light) and PVC (dark) piping and three replicates were used per site. Cores were carefully inserted into sediments ensuring that a 10 cm high water column remained above the sediment (Figure 103 C). One dark and one light core were used in each replicate. Water samples above the sediment zone were collected using a 50 mL syringe with replacement water entering via a side port of the chamber. After approx. 6 h the process was repeated. Dissolved inorganic nutrient samples were filtered (Figure 103 C), frozen and subsequently analysed colourmetrically using a flow injector analyser by Queensland Health, Forensic & Scientific Services.

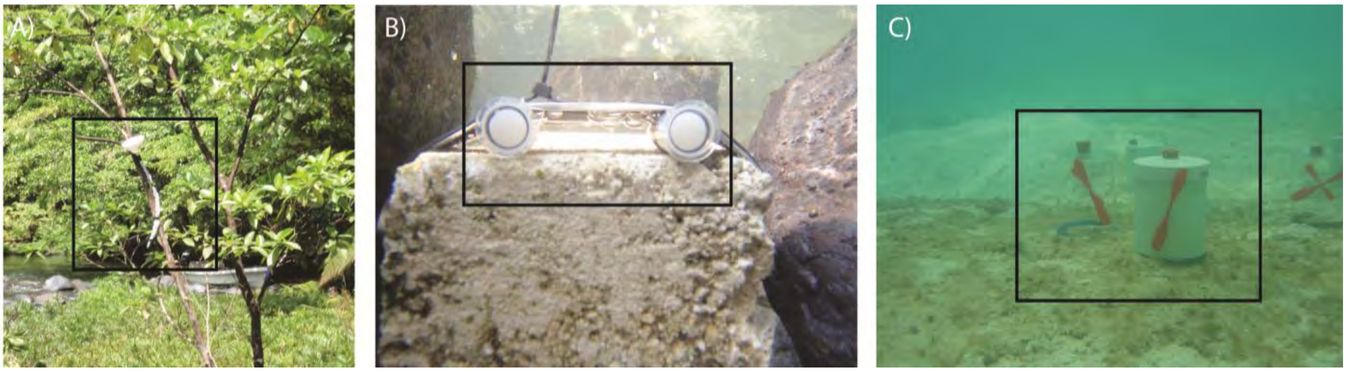

Figure 103 Nutrient sampling during January 2011 monitoring A) atmospheric deposition, B) catchment inflows and C) sediment inputs.

From these data it is possible to develop a preliminary nutrient loading budget for each lagoon. Phosphate was chosen to test this conceptual understanding as good recovery occurred in the passive nutrient samplers. A number of assumptions were required to develop this budget:

- River phosphate concentration was assumed to be similar between Roviana and Vonavona.
- Rainfall phosphate concentration was assumed to be similar between Roviana and Vonavona.
- Average sediment phosphate fluxes were assumed to be similar between Roviana and Vonavona.
- Annual rainfall at Munda was assumed to be similar across the region.

The preliminary budget revealed the conceptual understanding closely approximated Roviana Lagoon where river inputs were almost an order of magnitude higher than either atmospheric or sediment inputs (Table 33). However, this was not the case for Vonavona Lagoon where river input were very similar to atmospheric inputs and 3 times lower than sediment inputs. Total loading was greatly increased in Roviana Lagoon relative to Vonavona Lagoon primarily due to the higher river input from the much larger catchment area in Roviana Lagoon. It is interesting to note, Roviana Lagoon generally has higher phosphate loading rates and poorer water quality (Figure 95).

Table 33 Phosphate delivery rates and estimate annual loading to Roviana and Vonavona Lagoons.

Input source	Delivery rate	Roviana (tonnes yr^{-1})	Vonavona (tonnes yr^{-1})	Total (tonnes yr^{-1})
Rivers	0.22 ± 0.09 mg L^{-1}	194 ± 79	13 ± 6	207 (69%)
Rain	0.05 ± 0.01 mg L^{-1}	12 ± 2	14 ± 3	26 (9%)
Sediment	0.0006 ±0.002 mg m^{-2} d^{-1}	31 ± 120	36 ± 120	67 (22%)

CHAPTER 6

CONNECTIVITY

Andrew Olds

Libby Liggins

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Badin Gibbes

Key Messages

- High proportion of genetically unique fish individuals in Roviana
- Genetic uniqueness indicates limited gene flow/connectivity between Roviana and other parts of the Indo-Pacific
- Limited genetic overlap between Marovo Lagoon (100 km SE) and Roviana Lagoon, indicating a surprising lack of connectivity between these two systems
- For some fish species, there is more genetic similarity between individuals from Tonga and PNG than between individuals from Marovo and Roviana
- This relative isolations of Roviana increases vulnerability and makes local scale management of marine ecosystems critical
- Local-scale connectivity of fish shows the importance of connectivity between coral reef, seagrass and mangrove habitats
- Fish abundance on reefs near seagrass and mangrove habitats higher than isolated reefs
- Influence of connectivity particularly strong for the iconic Bumphead Parrotfish that is critical for maintain reef ecosystem health
- Passages important areas for spawning and require additional management actions
- Protection of key species such as Bumphead Parrotfish can have wider benefits for a range of other species
- Design of some MPAs in Roviana (based on traditional ecological knowledge) has been successful in preserving connectivity between habitats
- Existing reserves without connectivity between reef, seagrass and mangrove and new reserves should include a diversity of habitats

HYDRODYNAMIC FLOWS

WATER LEVEL FLUCTUATIONS

To address the absence of historical measured data on the tidal regime and subsequent water level variations within the lagoon a project was initiated to collect basic data on water level fluctuations within the lagoon. A network of 10 self-logging pressure transducers (In-Situ miniTROLL Professional) was deployed at key locations within the lagoon at various depths (1 to 8 m depth). These instruments recorded pressure at five minute intervals for a period of 9 days from 29th June to 7th July 2010. Barometric pressure during the same period was monitored at five minute intervals using a self-logging pressure transducer (InSitu BaroTROLL). The atmospheric pressure signal was removed from the submerged pressure transducer signal and the pressure signal normalised to the mean value recorded at each location before being converted into equivalent meters of water. This data was then analysed using the T_TIDE (Pawlowicz et al. 2002) software to provide basic information on harmonic components of the water level fluctuations. Briefly, tidal cycles were similar across all sites sampled with a tidal range of approximately 1.1 m. Flooding tides occurred over an approximate 13 h period whilst ebbing tides were slightly quicker at 11 h. Low tide occurred around 12:00 to 13:00 each day sampled (Figure 104).

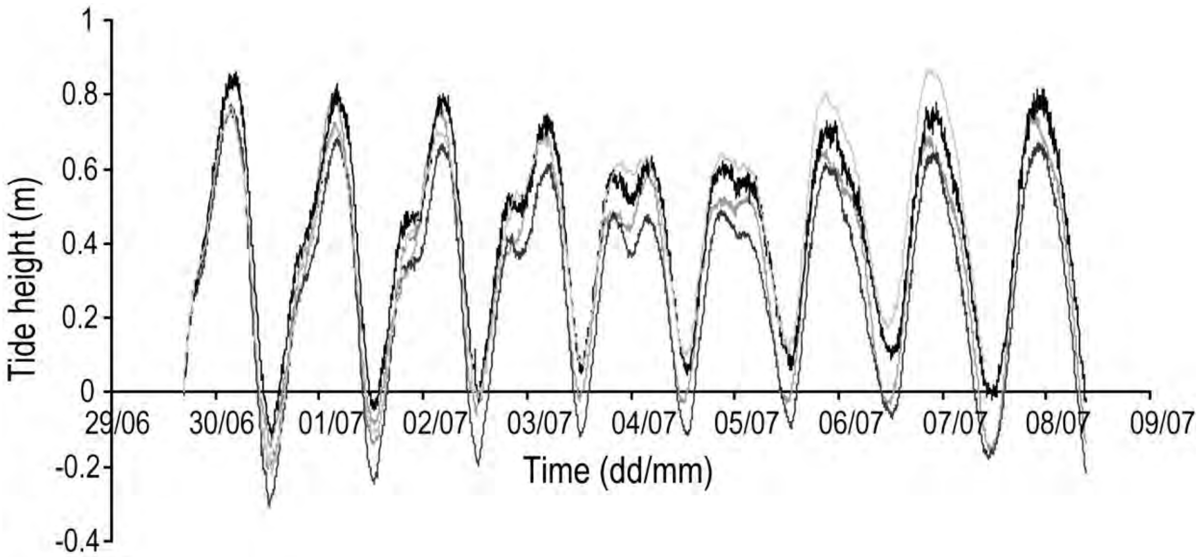

Figure 104 Tidal heights at 10 sites in Roviana logged over a 9 day period.

Current patterns

Little information exists on the movement of water through either lagoonal system and a series of long-term drifter and drogue deployments were conducted to overcome this knowledge gap. The drifters consisted of a 1 m length of PVC pipe (40 mm diameter) permanently sealed at one end (Figure 105 A). The permanently sealed end was weighted internally using dry beach sand to a height of 25 cm within the pipe to ensure that when deployed 90 cm (90 % of pipe length) was submerged. This minimised surface wind directly affecting the drifter movement. Before deployment a GPS logger (Holux M241) was fixed to the inside of top cap and set to log position and time every 2 seconds.

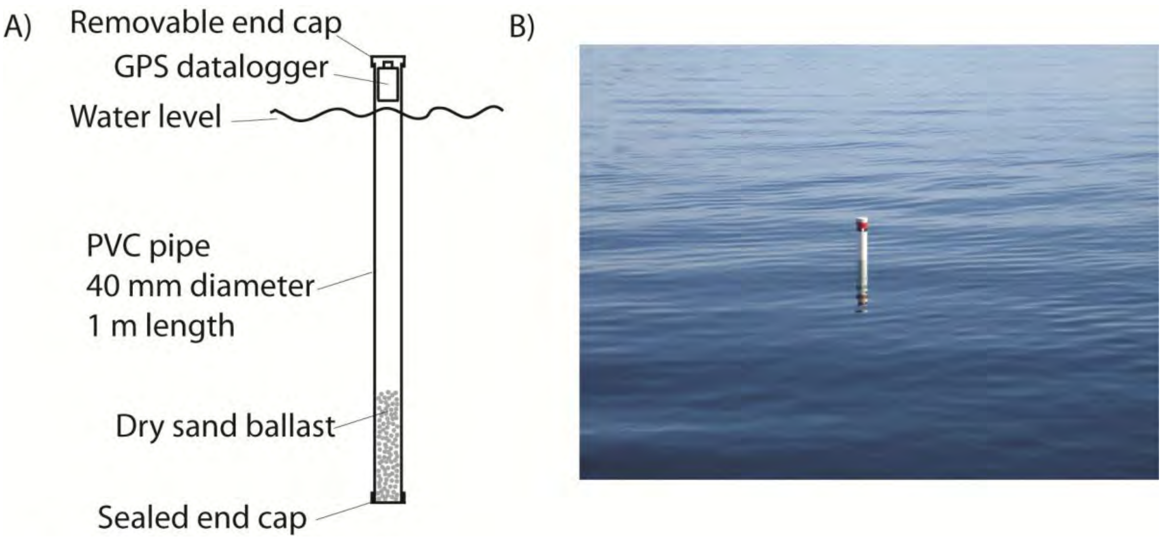

Figure 105 A) Design of drifter used to monitor water currents and B) profile of drifter during deployment.

A series of drifter deployments in areas of interest within both Vonavona and Roviana on two separate periods July 2010 and January 2011. Areas of interest included estuary mouths, inner lagoon, mid lagoon, ocean passages and within marine protected areas. Prior to deployment locals were recruited to monitors drifters during sampling. A brief workshop was held explaining the sampling strategy and advice was sought on local water circulation patterns and in selection of suitable deployment sites. Deployment times occurred early morning generally 7 to 9 am with retrieval scheduled between 3 to 5 pm. One local assistant was assigned to each drifter and followed it using a 2-3 m wooden canoe. A distance of at least 10 m was maintained around between canoes and the drifter unless the water depth became too shallow (causing drifter to contact the bottom) and the drifter would then be collected and redeployed in the nearest deep water channel (typically <50 m away) and the time at which this occurred noted. Drift tracks generally followed the tidal cycle moving seawards during ebb tides and landward during flood tides (Figure 106).

Figure 106 Surface current drifter track adjacent to Hura River mouth-central Roviana.

After each deployment the units would were collected and GPS loggers would be downloaded and reset for the next day's sampling. Position and time data for each track was then visualized in ArcMap (version 9.2) and the direction and speed calculated. The mean current speed was then calculated using all deployments for each area of interest. The predicted drift extent was estimated using the drift rate from the drift tracks and tidal phase duration from the pressure transducer data (Figure 107). These data suggest strong connectivity within the centre of the Roviana – Vonavona system (Munda region), with higher average drift rates and larger associated predicted drift extent. Marine protected areas within this region will likely service a larger region relative to their size compared with more distal areas.

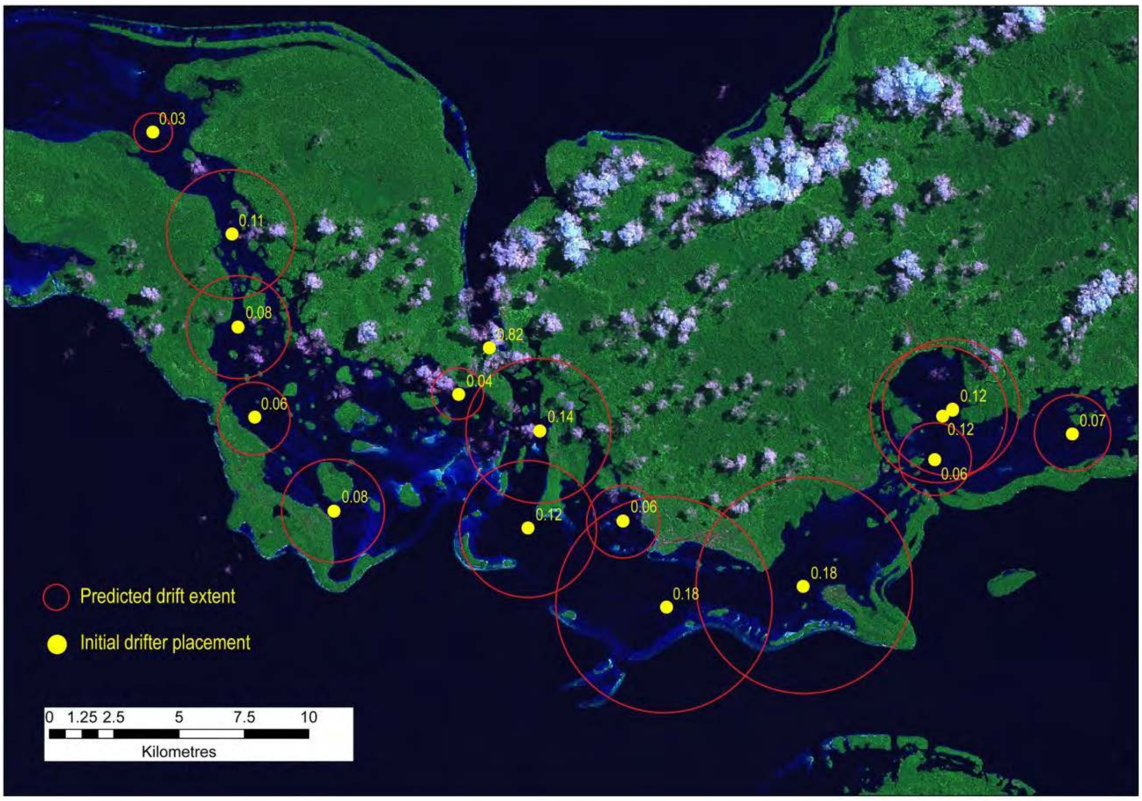

Figure 107 Initial drifter deployment site and average drift rate during ebbing tide. Units m s-1. Indication of predicted drift extent based on drifter track, note central site of Noro Passage has no drift extent as this is beyond the boundary of the figure.

HYDRODYNAMIC MODEL DEVELOPMENT

A core driver of hydrodynamics in shallow lagoon systems such as Roviana is bathymetry. As no nautical charts or bathymetric surveys have documented bathymetry of the Roviana and Vonavona lagoon, this program collected this baseline data. Bathymetry was surveyed using a single beam 200 Hz sounder linked to a GPS (Garmin Extrex) onboard 6 m fibreglass boats to enable high speed sounding over shallow waters (Figure 108).

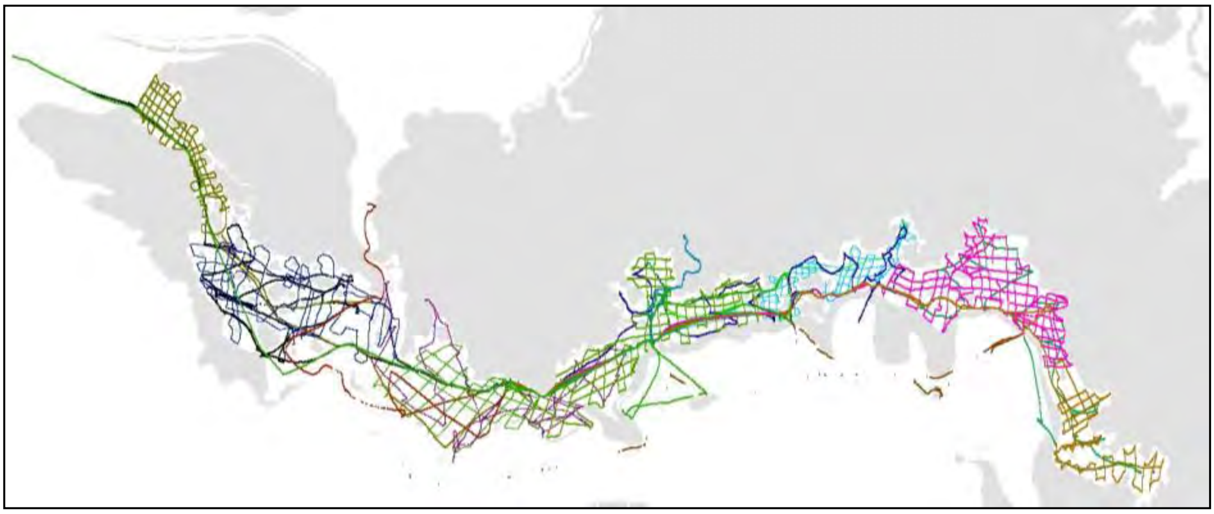

Figure 108 Tracks of single beam bathymetry collected in July 2010.

Bathymetric data from these surveys was combined with existing bathymetric data for offshore areas and topographic data to develop a series of digital elevation models (DEMs). These DEMs incorporate a coarse-scale whole of Solomon Islands DEM as well as more detailed Western Province and Roviana Lagoon DEMs.

A pilot hydrodynamic model has been established for the western province region. Whilst development of a fine-scale hydrodynamic model of Roviana during the project phase was not possible, work is continuing to source and refine appropriate input data (meteorological data, ocean current data and tide data) to support the next stages of development. The development plan includes the nesting of the Roviana Lagoon model within the Western Province and whole-of-Solomons model.

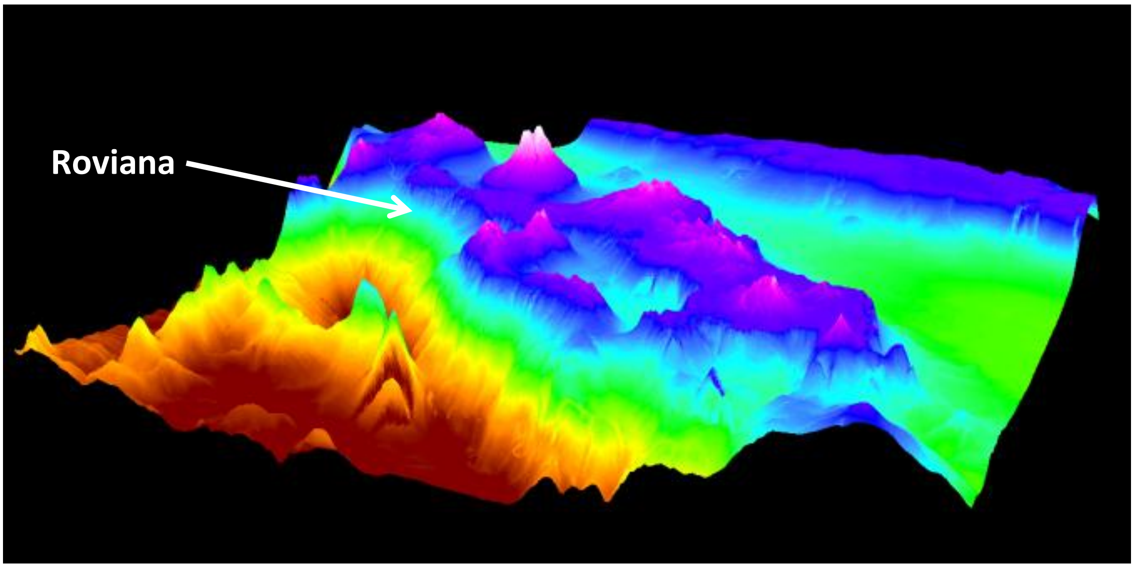

Figure 109 Digital Elevation Model (DEM) of Roviana region.

Seascape connectivity and marine reserves

Summary

Enhancing connectivity has emerged as a favoured option for conservation in the face of climate change because it provides the mechanism for reserves to enhance populations and ecosystem resilience across their borders. Indeed, connectivity between reefs and mangroves can enhance the performance of reserves in promoting fish abundance and improve the recovery of critical ecosystem functions in reserves. We examined the effects of connectivity among tropical reefs, seagrass and mangroves on the performance of marine reserves in Roviana and Vonavona lagoons in the northwestern Solomon Islands. These reserves were designed to both improve artisanal fishery productivity and conse the bumphead parrotfish (*Bolbometopon muricatum*). The large size, exploitation and cultural significance of this species makes it a flagship for conservation, the ecological functions these fish perform means they are keystone species on coral reefs, and their diverse habitat requirements infer that they may also be an important umbrella species for the conservation of local reef fish assemblages. Our findings demonstrate that connectivity can improve the performance of marine reserves in promoting the abundance of bumphead parrotfish, and suggest that this species is an important umbrella species for the local reef fish conservation. That is, the protection of heterogeneous seascapes with high habitat connectivity and diversity to conserve bumphead parrotfish has also inadvertently conserved many other fish species. In addition its influence on bumphead parrotfish abundance, connectivity among reef, seagrass and mangroves enhanced the effects of protection on the abundance of 17 harvested fish species. This has significant implications for local communities because the overwhelming majority of these species are harvested in local subsistence fisheries, and they contribute substantial protein to people's diets. These results support the assertion that habitat connectivity, diversity and heterogeneity can improve the performance of marine reserves and indicate that we may further improve coral reef resilience to climate change by managing both reefs and their adjacent habitats together as functional seascape units. This is important because many of these habitats (e.g. mangroves) appear to be threatened to a greater extent by coastal clearing and development than from climate change, and can benefit greatly from improved local management. We suggest that the performance and resilience of marine reserves in Roviana and Vonavona will be enhanced where they incorporate high connectivity among reefs, seagrass and mangroves and are positioned to facilitate the offshore movement of adult fish and the inshore recruitment of juveniles into lagoon nursery habitats.

Introduction

Connectivity and Seascape Ecology

Connectivity is a fundamental component of many ecological concepts and paradigms (Sheaves 2009). It is of primary importance to ecosystem functioning, to the distribution and abundance of all biota (Lindenmayer et al. 2008), and is assumed to confer ecosystems with resilience, as connected populations can recover from disturbance through the linking of populations, processes or food webs (e.g. Mumby and Hastings 2008). Consequently, enhancing connectivity has emerged as a favoured option for conservation in the face of climate change (Hodgson et al. 2009). The term has been applied widely across the field, but is most often employed to describe the linking of populations and habitats in different places through the movement of organisms or fluxes of nutrients and detritus (e.g. Heck et al. 2008, Nagelkerken 2009a). It can profoundly influence biological interactions, ecological processes and food web dynamics (e.g. Polis et al. 1997, Valentine and Heck 2005, Lundberg et al. 2008), and has important implications for the natural processes that control the growth and persistence of populations, and for the appropriate scales of their management (e.g. Sale et al. 2005). Given the existing impacts of habitat degradation and species exploitation, the impending effects of climate change, and the dearth of empirical evidence, a better understanding of the role for connectivity in conservation is required.

Connectivity is a function of habitat area, quality and spatial arrangement, and the dispersal capabilities of individual species (Hodgson et al. 2009). It can be conceived from a whole of landscape perspective, or visualised as linkages between particular habitats or populations. Landscape connectivity, or the physical connectedness of patches in a particular landscape (Lindenmayer and Fischer 2007), can be quantified using structural connectivity metrics, which describe the spatial arrangement of habitats from basal resource maps. Marine ecosystems are dynamic and spatially heterogeneous landscapes, or seascapes (Pittman et al. 2007), in which different habitats are connected to one another by biological, physical, and chemical processes. Marine fish, for example, utilise a range of these habitats during their lives, as juvenile nurseries (e.g. Nagelkerken 2009b), for foraging and sheltering (e.g. Valentine and Heck 2005), or for spawning and dispersal (e.g. Jones et al. 2009). Following the principles of landscape ecology (sensu Forman and Godron 1986), the characteristics of the seascape (e.g. habitat composition, arrangement and proximity) can, therefore, have a major influence on the composition of fish assemblages. The implications of this seascape connectivity for fish are best understood for the waters of the Caribbean (Grober-Dunsmore et al. 2009), where reef fish assemblages are affected by linkages with seagrass (e.g. Grober-Dunsmore et al. 2008) and mangrove (e.g. Mumby et al. 2004a) habitats. In contrast, there have been relatively few quantitative analyses in Pacific reef seascapes (Nagelkerken 2007), where studies have focused on fish assemblages in seagrass (e.g. Unsworth et al. 2008) and mangrove forests (e.g. Pittman et al. 2004).

Connectivity, Conservation and Marine Reserves

The degree to which marine populations are connected has important consequences for how they persist, how they respond to natural and anthropogenic disturbances, and how they can be managed (Sale et al. 2005, Jones et al. 2009). High connectivity is assumed to confer resilience, or the capacity to absorb recurrent natural perturbations and regenerate without slowly degrading or changing state (Hughes et al. 2010), as connected populations and habitats can recover from disturbance through the arrival of individuals or resources from other locations, or with the linkage of ecological processes over space and time (e.g. Mumby and Hastings 2008). However, in the present day ocean, the effects of overfishing, declining water quality, habitat loss and the impacts of climate change have resulted in broad-scale changes to the condition of marine ecosystems. The cumulative impacts of these stressors are reasonably well understood for coral reefs (e.g. Pandolfi et al. 2011), seagrass meadows (e.g. Waycott et al. 2009) and mangrove forests (e.g. Duke et al. 2007). The overhavesting of large mobile consumers (Estes et al. 2011), however, has also lowered the level of connectivity among populations, curtailed the transfer of energy among ecosystems, and may have reduced the overall resilience of these seascapes (Valentine and Heck 2005, Hughes et al. 2007, Knowlton and Jackson 2008).

Enhancing connectivity is now a focus for the management of marine reserves as it provides the mechanism for reserves to enhance populations outside their borders, and to improve the resilience of adjacent habitats to disturbance (e.g. McCook et al. 2009). Existing reserve networks, however, generally fail to incorporate connectivity into their management frameworks (Almany et al. 2009) and, with the exception of larval dispersal (e.g. Jones et al. 2009) and the spillover of fished species (e.g. Stobart et al. 2009), the implications of connectivity for marine conservation remain poorly studied. Recently, it has been demonstrated that connectivity between reefs and mangroves can enhance the ability of marine reserves to promote the abundance of exploited fish populations (Olds et al. 2012a). Connectivity may also have consequences for the maintenance of ecological processes inside reserves. For example, the role of herbivorous fish in removing algae and thereby promoting coral growth and reef resilience is now widely recognised. Mangroves and seagrass can be important nurseries and foraging areas for herbivorous reef fish and connectivity with mangroves can increase grazing on reefs nearby (Mumby and Hastings 2008, Adam et al. 2011). Exploited herbivore populations can also recover on protected reefs where they may subsequently reduce algal cover and enhance coral recruitment (e.g. Stockwell et al. 2009, Mumby and Harborne 2010). It is logical, therefore, to expect that these connectivity and reserve effects may operate synergistically to enhance the resilience of protected reefs near mangroves (refer Cumming 2011). It is uncommon, however, for the design of reserves to explicitly consider connectivity between reefs and adjacent habitats (Steneck et al. 2009), but recent findings (e.g. Olds et al. 2012b) suggest that ecosystem resilience can be improved by managing both reefs and their adjacent habitats together as functional seascape units.

Connectivity and Marine Reserves in Roviana and Vonavona lagoons

Roviana and Vonavona lagoons lie within the western province of the Solomon Islands and form part of the Coral Triangle ecoregion, which spans Indonesia, Malaysia, the Philippines, Papua New Guinea, Timor Leste and the Solomon Islands, and is recognized as the global centre of marine biodiversity with the highest priority for conservation (Roberts et al. 2002, Veron et al. 2009). The lagoons are formed by raised offshore barrier islands and support a diverse tropical reef seascape that incorporates mangroves, seagrass beds, sand channels, shallow fringing coral reefs, lagoon patch reefs and outer barrier reefs (Aswani and Sabetian 2010). The most direct threats to these marine resources arise from overfishing, sedimentation from logging and local population growth (Aswani et al. 2007). Subsistence fishing still dominates village life and marine resources continue to provide the bulk of the protein in people's diets (Aswani and Sabetian 2010). For this reason, a community-based marine conservation program was established in 1999 and Roviana and Vonavona lagoons now contain a network of 23 marine reserves (Aswani et al. 2007). These reserves were designed through the integration of indigenous ecological knowledge, existing sea tenure governance and marine and social science, with one of the primary objective to conserve bumphead parrotfish (*Bolbometopon muricatum*), which are vulnerable to over-exploitation by nocturnal spearfishing (Aswani and Hamilton 2004a). Bumphead parrotfish are large, mobile, coral predators with a broad range across the Indo-Pacific, they are considered to be a keystone species on coral reefs, where bio-erosion from their feeding activities can literally shape corals and coral reefs (Bellwood and Choat 2011). They rely on a variety of habitats during their lives, with larger adults dominating on outer barrier and passage reefs, smaller fish and sub-adults in lagoons, and small juveniles in shallow inner-lagoon nursery areas that are often contiguous with other lagoon habitats (e.g. mangroves and seagrass) (Aswani and Hamilton 2004a, Hamilton et al. 2009, Bellwood and Choat 2011). Consequently, bumphead parrotfish utilise a range of habitats across tropical reef seascapes and serve to connect these through a series of ontogenetic shifts with changing resource requirements. The large size, exploitation and cultural significance of this species makes them an important *flagship* species (an iconic symbol for local conservation) (Aswani and Hamilton 2004b), the ecological functions they perform means they are a *keystone* species (their actions impact on many other species) on coral reefs (Bellwood and Choat 2011), and their diverse habitat requirements suggest that they may also be an important *umbrella* species (their protection may also protect many other species) for local conservation (Simberloff 1998, Branton and Richardson 2010, Barua 2011, Verissimo et al. 2011). Indeed, many other fish species also move among these habitats over tidal, diel and ontogenetic cycles and indigenous knowledge of these patterns of habitat use has been utilised to harvest these fish for generations. The marine reserves in Roviana and Vonavona lagoons were, therefore, designed to protect this habitat diversity and connectivity across seascapes that support coral reefs, seagrass meadows and mangrove forests (Figure 110). Consequently, to examine the success of these reserves in promoting fish abundance it is necessary to explicitly incorporate information on fish behaviour and connectivity into the study design. From this perspective, we tested the following hypotheses: (1) that connectivity with seagrass and mangroves will influence the composition of reef fish assemblages, and (2) that connectivity between coral reefs, seagrass and mangroves will affect the ability of marine reserves to promote fish abundance and diversity, in Roviana and Vonavona lagoons in the northwestern Solomon Islands.

METHODS

SEASCAPE ANALYSIS

We surveyed the fish assemblages of coral reef, seagrass and mangroves at six locations in Roviana and Vonavona lagoons between April and June 2011 (Figure 111). Three of these were effective no-take marine reserves, adjacent to the villages of Kida, Nusa Hope and Olive, and we compared assemblages between these (established in 2002-2003, protected for eight years) and three unprotected control locations. At each location, we surveyed one site with close reef and seagrass, one with close reef and mangroves, and one with isolated reef. Ideally, we would also have surveyed isolated seagrass and mangroves at each location, but these habitats were not present in the reserves surveyed.

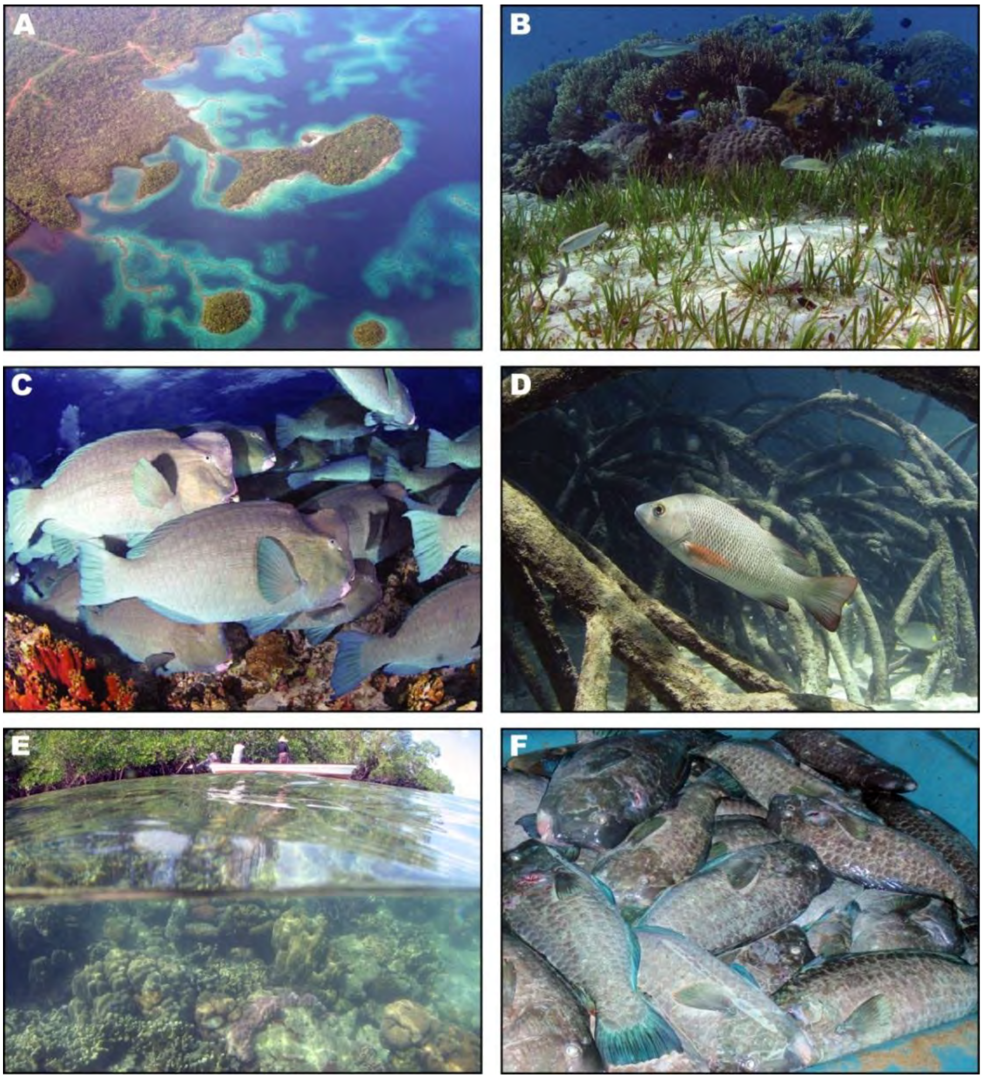

Figure 110 Roviana and Vonavona lagoons support diverse seascapes containing coral reefs, seagrass and mangroves (A). These habitats are distributed as an interconnected mosaic (B), are managed with a network of marine reserves established to conserve bumphead parrotfish (*Bolbometopon muricatum*) (C), and are linked by the tidal, diel and ontogenetic migrations of fish, such as mangrove jack (*Lutjanus argentimaculatus*) (D). Fish are harvested as they move among these habitats by line, net and spearfishers (E), where indigenous ecological knowledge of habitat use and migration patterns can produce large harvests (F) (photos: (*a,b,d,e*) A. Olds; (*c*) A. Plummer; (f) M. Jimuru).

Connectivity was quantified from benthic habitat maps for Roviana and Vonavona lagoons using ArcGIS (Chapters 3 and 4) as the edge-to-edge isolation distance between habitats. Importantly, seascape studies need be scaled to the mobility of the species of interest (Grober-Dunsmore et al. 2009). A common method for determining this spatial context is to scale studies by maximum distances travelled during routine daily movements (Pittman et al. 2007). Our choice of spatial scale was limited to that present in the existing marine reserves and sites classified as supporting 'close' habitats were, therefore, restricted to locations with a maximum separation of 500 m; sites classified as 'isolated' were restricted to a minimum separation of 1000 m. This scale encompassed daily home ranges of adult parrotfish (scaridae), rabbitfish (siganidae), snappers (lutjanidae), sweetlip (haemulidae) and wrasse (labridae), which are large components of fish assemblages in the coral reef seascapes of the western Pacific (e.g. Sheaves 1993, Chateau and Wantiez 2007, 2008, Meynecke et al. 2008, Fox and Bellwood 2011). Ideally, home ranges of other species would also be included when selecting a spatial context, but movement data are lacking for other fish in the region.

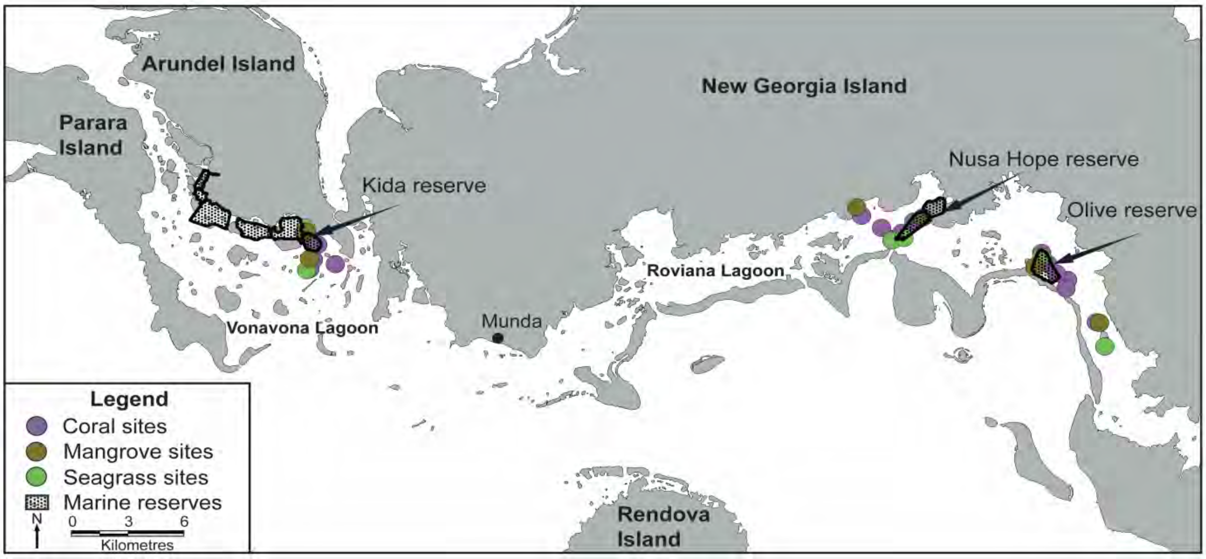

Figure 111 Survey sites in Roviana and Vonavona lagoons, Solomon Islands.

FISH SURVEYS

Fish were surveyed in coral reef, seagrass and mangrove habitats using underwater visual census (UVC) (following Olds et al. 2012a). UVC is a standard method for the survey of coral reef fish (Fulton et al. 2001). It is also appropriate for examining large mobile species in seagrass (Unsworth et al. 2009) and mangrove (Dorenbosch et al. 2009) habitats with sufficient water clarity. Five replicate 50 x 4 m transects were surveyed in each habitat at each site. Mangroves were surveyed during higher tides (when inundated and accessible to fish), and coral and seagrass habitats were surveyed when mangroves were dry and not accessible. Adjacent transects were at least 50 m apart. Each census consisted of a diver swimming parallel to the reef slope, seagrass edge or mangrove fringe and recording all fish > 5 cm total length (TL). Individual fish were identified to species and placed into 5 cm size categories. Seagrass and mangroves were sampled at depths of 0.5-1.5 m and reefs were surveyed along the reef slope at depths of 5-10 m.

We examined the interaction between reserve and habitat connectivity effects on the composition of fish assemblages, and the density of trophic groups (i.e. herbivores, piscivores, benthic invertivores), fish families and individual species. Herbivores are a crucial functional group on coral reef seascapes and underpin reef resilience by grazing on algae (Hughes et al. 2010); roving herbivore density was calculated from the families Acanthuridae, Ephippidae, Kyphosidae, Pomacanthidae, Scaridae and Siganidae (following Choat et al. 2002). The harvesting of these mobile herbivores makes up important components of the catch for subsistence and sale purposes in Roviana and Vonavona lagoons (Brewer et al. 2009, Aswani and Sabetian 2010). Piscivores are important in structuring marine food webs and influence trophic transfers among habitats (Valentine and Heck 2005); piscivore density was determined from species that commonly consume fish (following, Baker and Sheaves 2005, Dorenbosch et al. 2009). Roving benthic invertevores undertake tidal or diel migations to forage in habitats adjacent to coral reefs and can provide important subsidies to reef food webs when they return (Nagelkerken et al. 2008); benthic invertevore density was calculated from the families Haemulidae, Holocentridae, Labridae, Lethrinidae, Mullidae and Nemipteridae.

Data Analysis

Reserve and connectivity effects were evaluated using a modified Control-Impact design. Analysis examined the interactive effects of connectivity and ecosystem protection through comparison of the three reserves and three control locations. Replicates were grouped into five sites at each of the six locations, three of these were on coral reef (close to seagrass, close to mangroves, and isolated from both), and one in each of seagrass and mangroves located close to reef. Fish density data were log transformed to reduce heterogeneity of variances and analysed with analysis of variance (ANOVA). Post hoc Student–Newman–Keuls tests were used to differentiate significant means. Assemblage data was examined using permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001) applied to Bray-Curtis similarity matrices, calculated on fourth-root transformed data. *A posteriori* pair-wise tests were applied to significant factors following PERMANOVA. Three-factor analyses were conducted for reef fish variables, and two-factor analyses were performed for mangrove and seagrass fish variables. The factors were: protection (a fixed orthogonal factor), location (a random orthogonal factor) and connectivity (a fixed orthogonal factor used in reef analyses only). Patterns of similarity in the composition of fish assemblages were displayed visually using non-metric multidimensional scaling (nMDS) (Clarke 1993). The size of individual species with distributions on reefs that correlated with connectivity to mangroves or seagrass was compared between reefs and either adjacent habitat using T-tests.

Results

Reserve and Connectivity Effects on Fish Assemblages

Habitat connectivity mediated the effect of marine reserves on the composition of reef fish assemblages. Reserve reefs adjacent to seagrass and mangroves supported different assemblages to unprotected reefs, irrespective of location (near mangroves: $t = 3.94$, $p = 0.001$; near seagrass: $t = 4.16$, $p = 0.001$) (Figure 112). In contrast, the composition of fish assemblages did not differ between reserve and unprotected reefs that were isolated from both seagrass and mangroves ($t = 1.38$, $p > 0.05$). Reserve seagrass adjacent to reefs contained different assemblages to unprotected seagrass, irrespective of location ($F = 8.15$, $p = 0.001$), and assemblage composition varied among locations ($F = 9.14$, $p = 0.001$), but did not influence the effect of protection (Figure 112). Reserve mangroves adjacent to reefs supported different assemblages to unprotected mangroves, regardless of location ($F = 7.26$, $p = 0.001$) (Figure 112). Assemblage composition also varied among locations ($F = 8.05$, $p = 0.001$), but not between reserve mangroves at Kida and Olive ($t = 0.50$, $p = 0.884$).

Reserve and Connectivity Effects on Fish Densities

Connectivity improved the performance of marine reserves in promoting the abundance of three fish families (haemulidae, lutjanidae and siganidae) and 18 fish species (Figure 113, Table 34). The responses of these taxa were consistent across the three locations examined, nine species were affected by connectivity between coral reefs and seagrass, six by connectivity between reefs and mangroves, and three by connectivity among reefs, seagrass and mangroves (Table 34).

Protection of neighbouring reef and seagrass from fishing enhanced the abundance of three species (bumphead parrotfish, maori wrasse [*Cheilinus undulatus*] and thumbprint emperor [*Lethrinus harak*]) on adjacent reefs and seagrass, four species (paddletail snapper [*Lutjanus gibbosus*], manyspotted sweetlip [*Plectorhinchus chaetodonoides*], lined sweetlip [*Plectorhinchus lineatus*] and bluebarred parrotfish [*Scarus ghobban*]) on reefs near seagrass, and two species (grass emperor [*Lethrinus laticaudis*] and whitespotted rabbitfish [*Siganus canaliculatus*]) on seagrass near reefs (Fig. 4, Table 1). In contrast, it had a negative effect on the abundance of ornate emperor (*Lethrinus ornatus*) and dashdot goatfish (*Parapeneus barberinus*).

Protection of adjacent reef and mangroves enhanced the abundance of three species (mangrove jack [*Lutjanus argentimaculatus*], giant sweetlip [*Plectorhinchus albovittatus*] and brown sweetlip [*Plectorhinchus gibbosus*]) on close reefs and mangroves, blackspot snapper (*Lutjanus fulviflamma*) on reefs near mangroves, and two species (redfin emperor [*Lethrinus erythropterus*] and blacktail snapper [*Lutjanus fulvus*]) on mangroves near reefs (Figure 113, Table 1). It also had a negative effect on the abundance of monocle bream (*Scoliopsis* spp.).

Closure to fishing increased the abundance of anchor tuskfish (*Choerodon anchorago*), barred rabbitfish (*Siganus doliatus*) and lined rabbitfish (*Siganus lineatus*) in adjacent mangrove, reef and seagrass habitats (Figure 113, Table 34). It also enhanced the abundance of lined bristletooth (*Ctenochaetus striatus*) and white-ringed surgeonfish (*Acanthurus* spp.) on coral reefs, regardless of their proximity to seagrass and mangrove habitats (Figure 113, Table 34).

Seventeen of the species that were influenced by habitat connectivity were larger on reefs than in adjacent habitats (Table 35). Differences in the sizes of fish: between seagrass and reef (nine species), mangroves and reef (five species), and among all three habitats (three species), suggest that the importance of connectivity for these species may relate to changes in habitat usage and a migration to coral reefs with increasing size (Table 35).

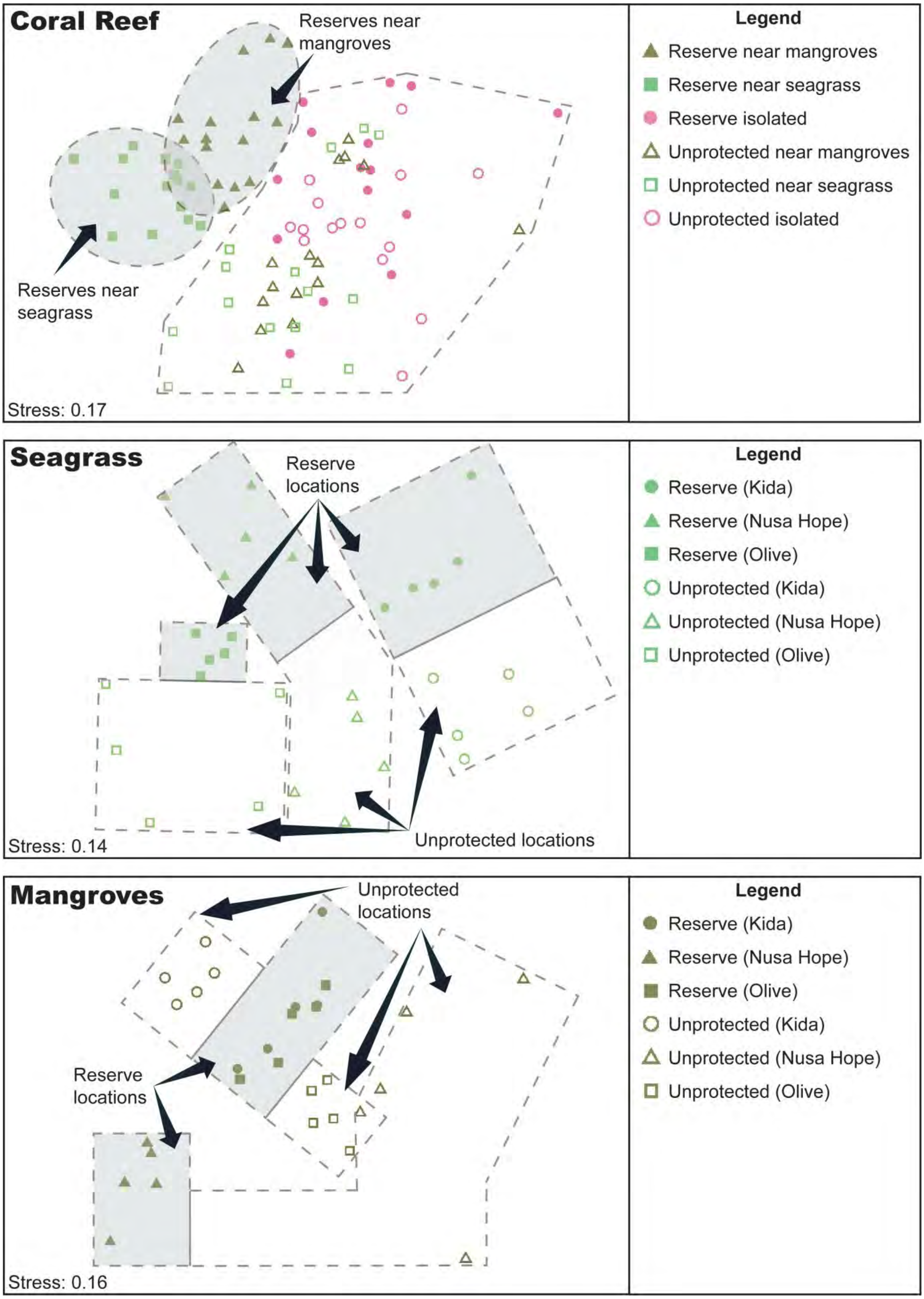

Figure 112 Multidimensional scaling (MDS) ordinations comparing relationships among: (1) fish assemblages on reserve and unprotected coral reefs at each level of connectivity with mangroves and seagrass, and fish assemblages in reserve and unprotected (2) seagrass, and (3) mangroves at each location.

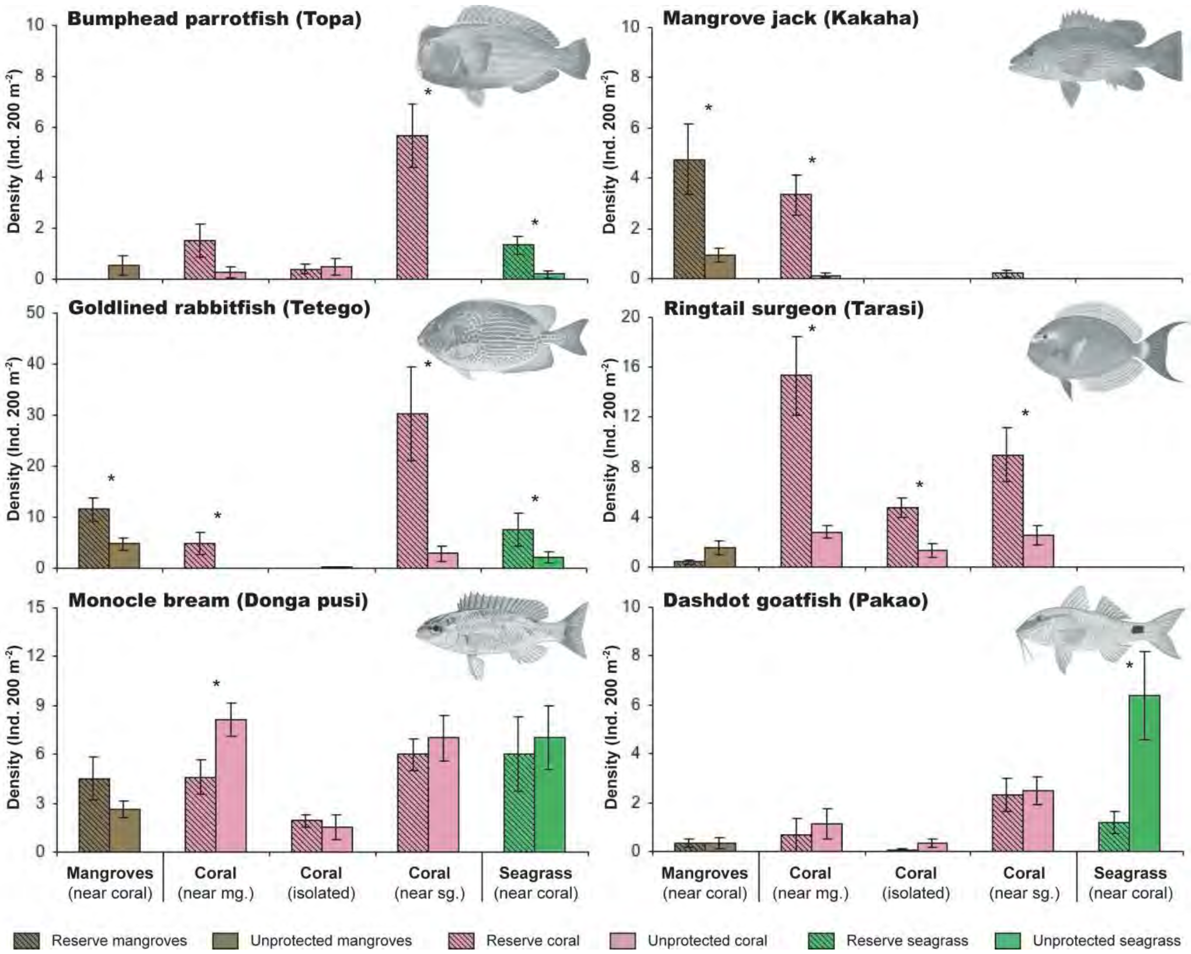

Figure 113 Density of selected fish species (mean ± SE) on reserve and unprotected mangrove, coral reef and seagrass habitats. * represent significant differences between reserve and unprotected locations (identified by SNK post hoc analyses). Bumphead parrotfish represent species with responses to protection that were enhanced by reef-seagrass connectivity. Mangrove jack signify species for which protection effects were mediated by reef-mangrove connectivity. Goldlined rabbitfish denote species with protection responses that were improved by both reef-mangrove and reef-seagrass connectivity. Ringtail surgeonfish epitomize species for which protection effects were not influenced by connectivity. Monocle bream and dashdot goatfish represent species that were more common in unprotected then reserve habitats (fish illustrations sourced from www.efishalbum.com).

Several taxa exhibited location specific responses to reserve protection and habitat connectivity. At Nusa Hope, reserve mangroves supported more pygmy snapper (*Lutjanus maxweberi*), rabbitfish (siganidae), parrotfish (scaridae) and roving herbivorous fish than unprotected mangroves. Reserve reefs also contained more snappers (lujanidae) and parrotfish (scaridae), and more roving herbivores and benthic invertevores when close to seagrass and mangroves. At Olive, reserve seagrass supported more orange-striped emperor (*Lethrinus obsoletus*), emperors (lethrinidae), parrotfish (scaridae), roving herbivores and benthic invertevores. Reserve mangroves contained more pygmy snapper and reserve reefs supported more onespot snappers (*Lutjanus monostigma*), emperors (lethrinidae) and parrotfish (scaridae) when close to seagrass, and more roving herbivores and benthic invertevores when close to seagrass and mangroves.

Table 34 Mean density of taxa in reserve (R) and unprotected (NR) mangroves, coral reef and seagrass. Only means that differed (ANOVA, $p < 0.05$) between reserve and unprotected locations for each habitat are reported. NM, coral near mangroves; I, isolated coral reef; NS, coral near seagrass; ns, non-significant.

Scientific Name	Rovianan name	English name	Mangrove		Coral (NM)		Coral (I)		Coral (NS)		Seagrass	
			R	NR	R	NR	R	NR	R	NR	R	NR
Seagrass influence												
Bolbometapon muricatum	Topa	Bumphead parrotfish	ns	ns	ns	ns	ns	ns	5.67	0.00	1.33	0.20
Cheilinus undulatus	Habili	Maori wrasse	ns	ns	ns	ns	ns	ns	2.40	0.07	1.33	0.33
Lethrinus harak	Osanga	Thumbprint emperor	ns	ns	ns	ns	ns	ns	3.07	0.47	11.20	3.00
Lethrinus laticaudis	Osanga	Grass emperor	ns	ns	ns	ns	ns	ns	ns	ns	1.60	0.47
Lethrinus ornatus	Osanga	Ornate emperor	ns	ns	ns	ns	ns	ns	ns	ns	0.00	2.33
Lutjanus gibbosus	Heheoku	Paddletail snapper	ns	ns	ns	ns	ns	ns	2.87	1.00	ns	ns
Parapeneus barberinus	Pakao	Dashdot goatfish	ns	ns	ns	ns	ns	ns	ns	ns	1.20	6.40
Plectorhinchus chaetodonoides	Pipirikoho	Manyspot sweetlip	ns	ns	ns	ns	ns	ns	4.13	0.00	ns	ns
Plectorhinchus lineatus	Pipirikoho	Lined sweetlip	ns	ns	ns	ns	ns	ns	5.00	0.07	ns	ns
Scarus ghobban	Bobogo	Bluebarred parrotfish	ns	ns	ns	ns	ns	ns	3.27	0.40	ns	ns
Siganus canaliculatus	Nidiri kuli	Whitespotted rabbitfish	ns	ns	ns	ns	ns	ns	ns	ns	57.47	28.20
Mangrove influence												
Lethrinus erythropterus	Ramusi	Redfin emperor	1.73	0.53	ns	ns	ns	ns	ns	ns	ns	ns
Lutjanus argentimaculatus	Kakaha	Mangrove snapper	4.73	0.93	3.33	0.13	ns	ns	ns	ns	ns	ns
Lutjanus fulviflamma	Kida kale	Blackspot snapper	ns	ns	2.07	0.13	ns	ns	ns	ns	ns	ns
Lutjanus fulvus	Odongo	Blacktail snapper	4.00	2.13	ns	ns	ns	ns	ns	ns	ns	ns
Plectorhinchus albovittatus	Pehu	Giant sweetlip	2.20	0.20	1.60	0.13	ns	ns	ns	ns	ns	ns
Plectorhinchus gibbosus	Pehu	Brown sweetlip	1.00	0.13	2.60	0.07	ns	ns	ns	ns	ns	ns
Scoliopsis spp.	Donga pusi	Coral breams	ns	ns	4.60	8.13	ns	ns	ns	ns	ns	ns
Lutjanidae		Snappers	19.33	10.80	ns	ns	ns	ns	ns	ns	ns	ns
Mangroves and seagrass influence												
Choerodon anchorago	Pakopako	Anchor tuskfish	3.00	1.13	ns	ns	ns	ns	2.60	0.73	4.33	2.07
Siganus doliatus	Mendo mendo	Barred rabbitfish	ns	ns	5.40	0.27	ns	ns	19.73	0.40	1.00	4.60
Siganus lineatus	Tetego	Lined rabbitfish	11.53	4.80	4.87	0.00	ns	ns	30.33	2.87	7.53	2.13
Haemulidae		Sweetlips	3.53	0.33	5.73	0.27	ns	ns	9.73	0.07	ns	ns
Siganidae		Rabbitfish	16.40	10.67	12.07	0.67	ns	ns	52.67	3.60	66.00	35.07
No seascape influence												
Acanthurus spp.	Tarasi	Whiteringed surgeon	ns	ns	15.33	2.80	4.73	1.33	9.00	2.53	ns	ns
Ctenochaetus striatus	Koere	Lined bristletooth	ns	ns	8.93	1.13	3.67	1.13	9.93	3.33	ns	ns

Table 35 Mean size of fish in mangroves, coral reef and seagrass habitats. Only means that differed (T Test, $p < 0.05$) between reef and mangrove or reef and seagrass habitats are reported. 'nc': no comparison of fish sizes was made between seagrass-reefs for species with densities influenced by mangroves or between mangroves-reefs for species with densities influenced by seagrass.

Scientific name	Roviana name	English name	Mangroves	Coral reef	Seagrass
Seagrass influence					
Bolbometapon muricatum	Topa	Bumphead parrotfish	nc	37.88	5.36
Cheilinus undulatus	Habili	Maori wrasse	nc	29.63	5.68
Lethrinus harak	Osanga	Thumbprint emperor	nc	24.83	12.27
Lethrinus laticaudis	Osanga	Grass emperor	nc	21.55	8.99
Lethrinus ornatus	Osanga	Ornate emperor	nc	19.00	8.78
Lutjanus gibbosus	Heheoku	Paddletail snapper	nc	27.70	9.97
Parapeneus barberinus	Pakao	Dashdot goatfish	nc	23.40	10.65
Plectorhinchus lineatus	Pipirikoho	Lined sweetlip	nc	59.25	7.40
Scarus ghobban	Bobogo	Bluebarred parrotfish	nc	27.27	10.55
Mangrove influence					
Lutjanus argentimaculatus	Kakaha	Mangrove snapper	28.82	48.75	nc
Lutjanus fulviflamma	Kida kale	Blackspot snapper	20.01	29.06	nc
Lutjanus fulvus	Odongo	Blacktail snapper	21.42	31.76	nc
Plectorhinchus albovittatus	Pehu	Giant sweetlip	40.71	74.33	nc
Plectorhinchus gibbosus	Pehu	Brown sweetlip	40.00	48.48	nc
Mangroves and seagrass influence					
Choerodon anchorago	Pakopako	Anchor tuskfish	17.31	23.73	10.90
Siganus doliatus	Mendo mendo	Barred rabbitfish	11.74	21.99	6.30
Siganus lineatus	Tetego	Lined rabbitfish	19.44	27.17	10.59

Discussion

The approach to conservation planning in Roviana and Vonavona lagoons incorporated local indigenous ecological knowledge, existing sea tenure and conservation science to design marine reserves with the primary objective of conserving exploited bumphead parrotfish (Aswani and Hamilton 2004a). Our results demonstrate that habitat connectivity between reefs and seagrass improved the performance of these reserves in promoting fish abundance including the iconic bumphead parrotfish. Given the large size, mobility and the diversity of habitats utilized by this species (Aswani and Hamilton 2004a, Hamilton et al. 2009, Bellwood and Choat 2011), the design of these reserves necessitated protection of habitat diversity and connectivity across heterogenous tropical seascapes that support reefs, seagrass and mangroves. Many other fish species are also exploited as they move among these habitats over tidal, diel and ontogenetic cycles, and in addition to effects on bumphead parrotfish abundance, habitat connectivity mediated the affect of protection on the composition of reef fish assemblages and the abundance of 17 fish species. Reef-seagrass connectivity improved the performance of reserves in promoting the abundance of an additional eight species, reef-mangrove connectivity enhanced reserve performance for six species and connectivity among all three habitats elevated reserve performance for another three species. These findings indicate that the approach adopted for marine conservation in Roviana and Vonavona lagoons has been successful, and suggest that bumphead parrotfish are an important umbrella species (sensu Simberloff 1998, Branton and Richardson 2010) for the conservation of local reef fish assemblages. That is, the protection of heterogeneous seascapes with high habitat connectivity and diversity to conserve bumphead parrotfish has also inadvertently conserved many other fish species. This has significant implications for local communities because the overwhelming majority of these species are harvested in local subsistence fisheries, and they contribute substantial protein to people's diets (Brewer et al. 2009, Aswani and Sabetian 2010). These results corroborate the findings of studies that have shown the potential for habitat connectivity, diversity and heterogeneity to improve the performance of marine reserves (Edwards et al. 2010, Huntington et al. 2010, Olds et al. 2012a). Furthermore, they support the idea that we may further improve coral reef resilience by managing both reefs and their adjacent habitats together as functional seascape units (Bellwood et al. 2011, Olds et al. 2012b). This is important because many of these habitats (e.g. mangroves) appear to be threatened to a greater extent by coastal clearing and development than climate change, and can benefit greatly from improved local management (Adam et al. 2011).

Two species that occurred in greater abundance in reserves where reef and seagrass were located in close proximity (i.e. bumphead parrotfish and maori wrasse) are considered threatened globally (Donaldson and Sadovy 2001, Donaldson and Dulvy 2004). These are the world's largest parrotfish and wrasse species, they are heavily harvested throughout their ranges, but quantitative studies that examine their use of habitats as juveniles and changes in habitat use through ontogeny are lacking (Dorenbosch et al. 2006, Bellwood and Choat 2011). We recorded small juveniles of both species in shallow water coral reef and seagrass habitats, juvenile bumphead parrotfish were also recorded in mangroves, but abundance was greatest in areas of contiguous seagrass and coral patches. Differences in the size of these fish (and 15 other species) among habitats suggest the importance of habitat connectivity may reflect migration to coral reefs with increasing fish size. That being said, many of these species (including members of the haemulidae, labridae, lethrinidae, lutjanidae, scaridae, serranidae and siganidae) are known to migrate tidally or diurnally between reefs and adjacent seagrass and mangroves (Heck et al. 2008, Grober-Dunsmore et al. 2009, Sheaves 2009). Indeed, the abundance of larger individuals from each of these families in seagrass and mangrove habitats indicates that they may also be important foraging areas for fish in Roviana and Vonavona lagoons. Never-the-less, the movement of these species between lagoon habitats may in turn be followed by the migration of larger adults to passage and outer barrier reefs to spawn, or with changing resource requirements (Aswani and Hamilton 2004b). Such migrations would take fish across the boundaries of existing marine reserves in the lagoon to areas where they could be captured by local fishers. The potential for this spillover highlights the importance of establishing lagoon reserves close to passages and river channels to both facilitate the offshore movement of adults, and to improve their potential for capturing the inshore recruitment of juveniles into nursery habitats (sensu Nagelkerken 2009b). Our results suggest that both functions will be enhanced where new reserves are established near passages in heterogeneous seascapes that include reefs, seagrass and mangroves. They also indicate that the performance of existing small reserves may be improved by extending their boundaries to increase habitat connectivity, diversity and heterogeneity. Aggregations of large adult fish on passage and outer barrier reefs are also vulnerable to exploitation, for this reason bans on the spearfishing of bumphead parrotfish have been introduced for passage habitats (Aswani and Hamilton 2004a) and reserves have been established to protect spawning aggregations of groupers and maori wrasse (Aswani and Hamilton 2004b). This provides little protection, however, for other fish species that aggregate on these reefs and additional offshore reserves may need to be established in the future to maintain the recruitment of juveniles into lagoon reserves.

Our findings indicate that the approach adopted for marine conservation in Roviana and Vonavona lagoons has been successful. They demonstrate that connectivity can improve the performance of marine reserves in promoting the abundance of iconic bumphead parrotfish (a local conservation priority), and suggest that the large size, mobility and the diversity of habitats utilized by this species make it an important umbrella species for the conservation of local reef fish assemblages. In addition to the influence on bumphead parrotfish abundance, connectivity among reef, seagrass and mangroves enhanced the effects of protection on the abundance of 17 harvested fish species. These results support the assertion that habitat connectivity, diversity and heterogeneity can improve the performance of marine reserves and indicate that we may further improve coral reef resilience by managing both reefs and their adjacent habitats together as functional seascape units. We suggest that the performance and resilience of marine reserves in Roviana and Vonavona will be enhanced where they incorporate high connectivity among reefs, seagrass and mangroves and are positioned to facilitate the offshore movement of adult fish and the inshore recruitment of juveniles into lagoon nursery habitats.

Figure 114 Typical seagrass, mangrove and seagrass habitat adjacent to small lagoon islands

Figure 115 High fish biomass within mangrove habitats of Roviana

GENETIC CONNECTIVITY

OVERVIEW

Genetic individuality and levels of genetic connectivity between Roviana and Marovo lagoons were investigated using four coral reef fish species. The genetic attributes of each lagoon, and patterns between the lagoons were also considered in the context of several other Indo-Pacific populations of the same species. The four fish were selected based on their differing life histories and ecology to provide representation for a variety of coral reef fish species.

The Convict surgeonfish (*Acanthurus triostegus*) is a common, shallow water tropical water fish that is sometimes taken for food. This surgeonfish is herbivorous and has pelagic eggs, a highly dispersive larval stage (pelagic larval duration up to 70 days) and a benthic juvenile and adult stage. The Checkerboard wrasse (*Halichoeres hortulanus*) is also sometimes fished for food. This wrasse has pelagic eggs and its larvae can disperse for up to 32 days before settling in the coral reef environment. The Domino damselfish (*Dascyllus trimaculatus*) is a planktivorous fish common in the aquarium fish trade. It lays benthic eggs, from which larvae hatch and disperse for a period up to 26 days. This damselfish will only settle on anemones or branching coral following which it resumes a site-attached, benthic life. The Neon damselfish (*Pomacentrus coelestis*) is also common in the aquarium fish trade. This damselfish often occupies the rubble areas among coral reef patches feeding on plankton. It lays benthic eggs and has larvae that disperse for up to 24 days before resuming a benthic lifestyle.

Tissue collections were undertaken in Roviana and Marovo lagoons from December 8-21, 2010. Sampling elsewhere in the Indo-Pacific has been undertaken intermittently over the last 4 years. The mitochondrial control region was amplified and sequenced for *P. coelestis* (348 nucleotide base pairs, bp), *D. trimaculatus* (375 bp) and *H. halichoeres* (366 bp), and the mitochondrial ATPase region was amplified and sequenced for *A. triostegus* (830 bp). Intra- and inter-population genetic patterns were analysed using classical population genetic diversity measures (polymorphic sites, *s*; number of haplotypes, *H*; haplotype diversity, *Hd*; number of unique haplotypes; and nucleotide diversity, *pi*; using DNAsp version 5, (Librado and Rozas 2009)) and measures of genetic differentiation (pairwise φ_{ST}, which takes into account differences in haplotype composition as well as the level of differentiation among haplotypes; and analyses of molecular variation were undertaken in Arlequin version 3.5, (Excoffier et al. 2005)). The haplotypic composition of the sampled locations was represented using PhyloGeoViz (version 2.4.4, (Tsai 2011)).

RESULTS

CONVICT SURGEONFISH

The Convict surgeonfish had relatively high levels of genetic diversity in both Marovo and Roviana lagoons (*Hd*, Table 36), but neither lagoon contained unique genetic variants (hereafter haplotypes; Figure 1a). Over the entire sampled range of the surgeonfish, 99.78% of the genetic variation reflected differences within sampling localities, rather than differences between locations. This indicates that there has been much historical gene flow among populations of the Convict surgeonfish in the Indo-Pacific and there is likely to be contemporary gene flow among these locations. However, there were differences in the genetic composition of Roviana and Marovo lagoons (proportion of haplotypes shared with other regions, Figure 1b), although these differences were not significant (pairwise φ_{ST}, Table 36).

Table 36 Convict surgeonfish-Sample sizes and genetic diversity measures for all sites included in the study (see Figures for sampling location key). Locations within the Solomon Islands are indicated in grey and genetic differentiation found between Roviana and Marovo lagoons is shown at the bottom right (significance was assessed following 10000 permutations).

Acanthurus triostegus Convict surgeon fish

	Total	ASH	FIJ	KAV	LIH	LIZ	MOT	NIN	TGA	TIM	TUV	SOL	ROV	MOR
No. samples	149	15	11	15	15	15	7	18	7	15	16	15	7	8
Polymorphic sites, *s*	48	8	15	21	15	22	10	18	14	18	22	18	16	10
Haplotypes, *H*	39	6	7	7	9	10	4	9	6	7	10	8	5	6
Haplotype diversity, *Hd*	0.8320	0.7048	0.8727	0.8191	0.8857	0.9143	0.8085	0.8366	0.9524	0.7714	0.8250	0.8667	0.9048	0.8929
Unique haplotypes	na	1	3	4	4	5	1	3	2	2	3	0	0	0
Nucleotide diversity, *pi*	0.0050	0.0022	0.0045	0.0052	0.0037	0.0069	0.0044	0.0046	0.0067	0.0057	0.0064	0.0047	0.0060	0.0039
Genetic differentiation between lagoons, paiwise φ_{ST}													0.0852 (*p*=0.9010)	

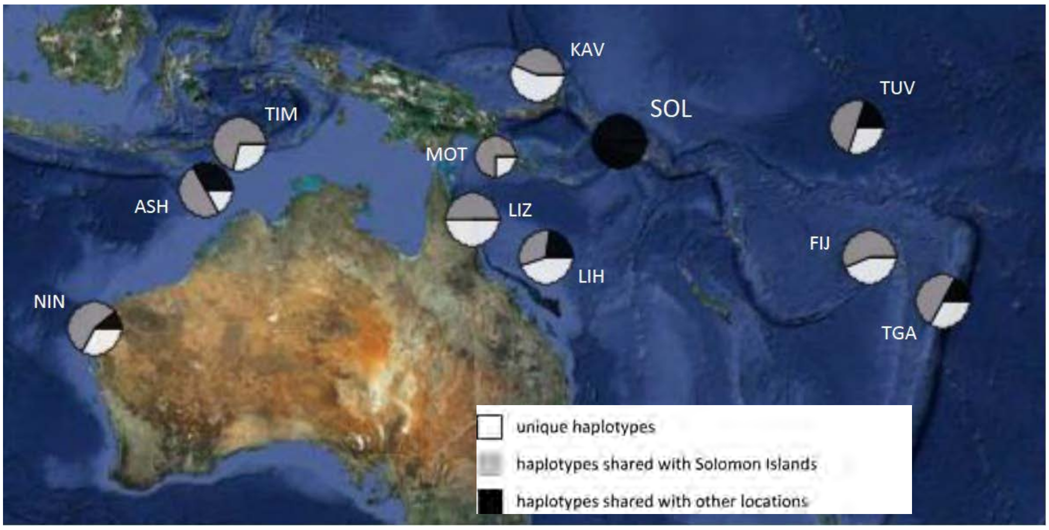

Figure 116 Genetic (haplotype) composition of Convict surgeonfish at sites across the Indo-Pacific. Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

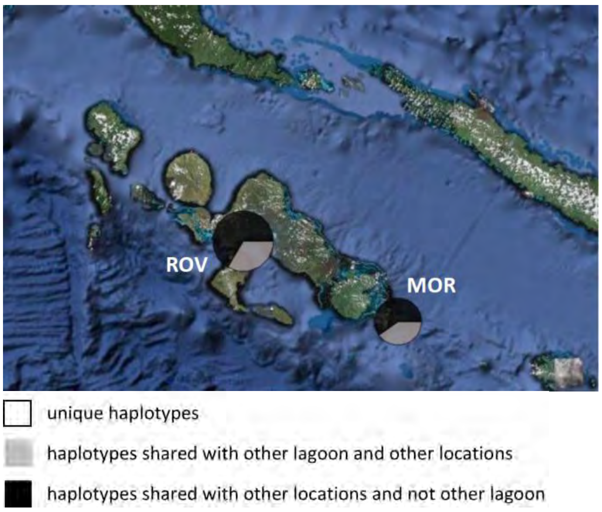

Figure 117 Genetic (haplotype) composition of Convict surgeonfish within the Solomon Islands (Roviana (ROV) and Marovo (MOR)). Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

SAMPLING LOCATION KEY

ASH	Ashmore Reef, WA
FIJ	Fiji
ENG	Wessel Islands, NT
HER	Heron Island, QLD
KAV	Kavieng, PNG
LIH	Lihou Reef
LIZ	Lizard Island, QLD
MOT	Motupore Island, PNG
NIN	Ningaloo Reef, WA
TGA	Tonga
TIM	Timor-Leste
TUV	Tuvalu
SOL	Solomon Islands
ROV	Roviana lagoon, Solomon Islands
MOR	Morovo lagoon, Solomon Islands

Domino Damselfish

Levels of genetic diversity were similar across the sampled range of the Domino damselfish (*pi*, and *Hd*, Table 37), however the genetic composition of each locality varied, with each having a high proportion of unique haplotypes (Figure 118; including both Roviana and Marovo lagoons, Figure 119). Both lagoons shared only a small proportion of their haplotypes and were significantly differentiated from each other (pairwise φ_{ST} = 0.2701, p = 0.0360, Table 37). The level of differentiation found between Domino damselfish populations in Roviana and Marovo lagoons was greater than the differences found between Tonga and Timor-Leste (pairwise φ_{ST} = 0.0807, p = 0.0180), Tonga and Kavieng (pairwise φ_{ST} = 0.12410, p = 0.0090) and Timor-Leste and Motupore Island (pairwise φ_{ST} = 0.06911, p = 0.0451), despite these locations being more geographically distant from each other. The greatest population differentiation found across the sampled range of the Domino damselfish was found between Marovo lagoon and Kavieng (pairwise φ_{ST} = 0.3034, p = 0.0360). These results indicate that there is likely to be little contemporary gene flow among populations of the Domino damselfish across the sampled Indo-Pacific range, and between populations that are geographically near, such as Roviana and Marovo lagoons in the Solomon Islands.

Table 37 Domino damselfish- Sample sizes and genetic diversity measures for all sites included in the study (see Figures for sampling location key). Locations within the Solomon Islands are indicated in grey and genetic differentiation found between Roviana and Marovo lagoons is shown at the bottom right (significance was assessed following 10000 permutations).

Dascyllus trimaculatus Domino damsel fish

	Total	ASH	FIJ	KAV	LIH	LIZ	MOT	NIN	TGA	TIM	SOL	ROV	MOR
No. samples	138	17	5	16	6	15	16	15	15	16	17	14	3
Polymorphic sites, *s*	82	29	10	31	13	15	21	22	19	28	24	20	7
Haplotypes, *H*	84	15	5	16	5	12	13	12	13	16	15	13	3
Haplotype diversity, *Hd*	0.9704	0.9853	1.0000	1.0000	0.9333	0.9619	0.9667	0.9429	0.9810	1.0000	0.9853	0.9890	1.0000
Unique haplotypes	na	10	1	8	3	5	7	9	8	8	9	8	1
Nucleotide diversity, *pi*	0.0117	0.0145	0.0107	0.0134	0.0136	0.0117	0.0121	0.0130	0.0146	0.0139	0.0129	0.0114	0.0125
Genetic differentiation between lagoons, paiwise φ_{ST}												0.2701 (p=0.0360)	

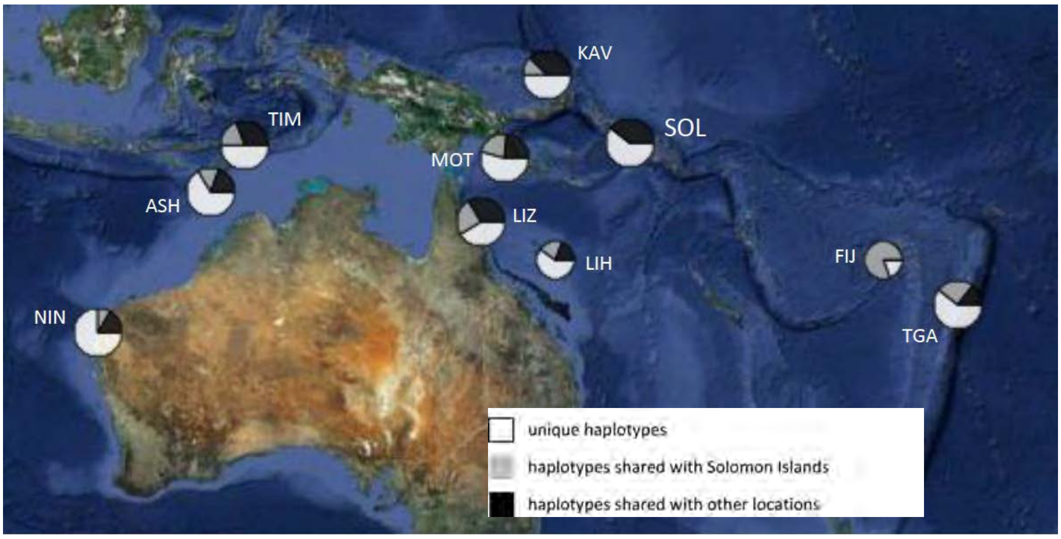

Figure 118 Genetic (haplotype) composition of Domino damselfish at sites across the Indo-Pacific. Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

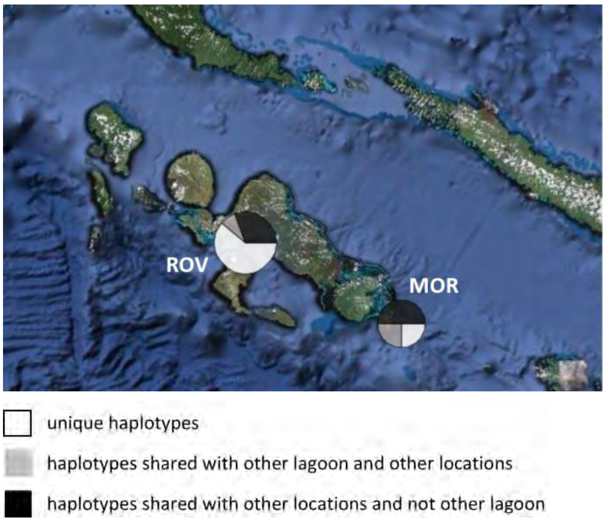

Figure 119 Genetic (haplotype) composition of Domino damselfish within the Solomon Islands (Roviana (ROV) and Marovo (MOR)). Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

Checkerboard Wrasse

The sampled Solomon Island populations of Checkerboard wrasse had relatively low levels of nucleotide diversity (*pi*), but high levels of haplotype diversity (*Hd*; Table 38), sometimes indicative of population size expansion (for example after a bottleneck or a selective sweep). The Marovo lagoon population did not share any haplotypes with locations outside of the Solomon Islands and was significantly differentiated from the Ashmore Reef population (pairwise φ_{ST} = 0.3152, p = 0.0090). The Roviana lagoon population was also significantly different from the Ashmore Reef population (pairwise φ_{ST} = 0.2647, p = 0.0090) as well as the Timor-Leste population of Checkerboard wrasse (pairwise φ_{ST} = 0.1747, p = 0.0360). While there was no significant difference between the populations of Roviana and Marovo lagoons (pairwise φ_{ST} = 0.0090, p = 0.5676, Table 38), Roviana lagoon's population of Checkerboard wrasse was more similar to the populations of Tonga (pairwise φ_{ST} = 0.0000, p = 0.5045), Fiji (pairwise φ_{ST} = 0.0000, p = 0.7658), Kavieng (pairwise φ_{ST} = 0.0000, p = 0.8198) and Lihou Reef (pairwise φ_{ST} = 0.0000, p = 0.5135), than to Marovo lagoon's checkerboard wrasse population. Similarly, Marovo lagoon's population was more similar to the populations of Kavieng (pairwise φ_{ST} = 0.0063, p = 0.3333), Lizard Island (pairwise φ_{ST} = 0.0000, p = 0.5405) and Timor-Leste (pairwise φ_{ST} = 0.0000, p = 0.3694), than to the population in Roviana lagoon. Although most of the genetic variation found across the sampled range of the Checkerboard wrasse could be contributed to intra–population differences (93.23%), there was still a significant amount that could be attributed to among population differences (6.77%). These genetic patterns indicate that there may be little contemporary gene flow among the sampled Checkerboard wrasse populations across the Indo-Pacific, however there is likely to be contemporary gene flow between the populations of Marovo and Roviana lagoons.

Table 38 Checkerboard wrasse-Sample sizes and genetic diversity measures for all sites included in the study (see Figures for sampling location key). Locations within the Solomon Islands are indicated in grey and genetic differentiation found between Roviana and Marovo lagoons is shown at the bottom right (significance was assessed following 10000 permutations).

Halichoeres hortulanus Checkerboard wrasse

	Total	ASH	FIJ	KAV	LIH	LIZ	MOT	TGA	TIM	SOL	ROV	MOR
No. samples	109	15	5	16	16	7	15	15	5	15	10	5
Polymorphic sites, *s*	62	21	12	40	22	16	17	31	16	22	22	8
Haplotypes, *H*	68	14	5	15	14	7	14	14	5	12	9	5
Haplotype diversity, *Hd*	0.9770	0.9905	1.0000	0.9917	0.9750	1.0000	0.9905	0.9905	1.0000	0.9619	0.9778	1.0000
Unique haplotypes	na	9	1	10	8	5	6	10	2	7	4	3
Nucleotide diversity, *pi*	0.0212	0.0186	0.0148	0.0233	0.0192	0.0187	0.0191	0.0173	0.0230	0.0159	0.0177	0.0115
Genetic differentiation between lagoons, paiwise φ_{ST}											0.0090 (p=0.5676)	

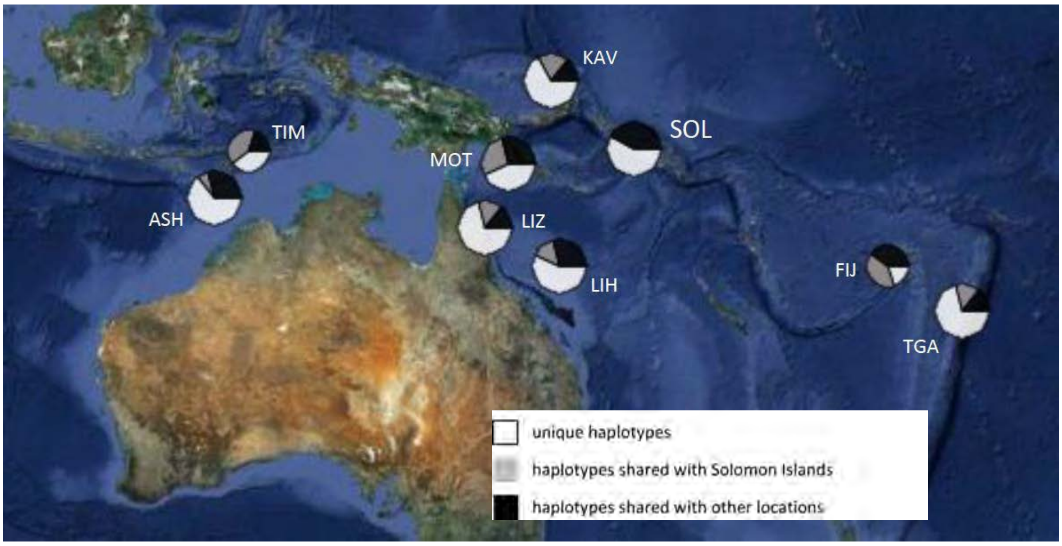

Figure 120 Genetic (haplotype) composition of Checkerboard wrasse at sites across the Indo-Pacific. Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

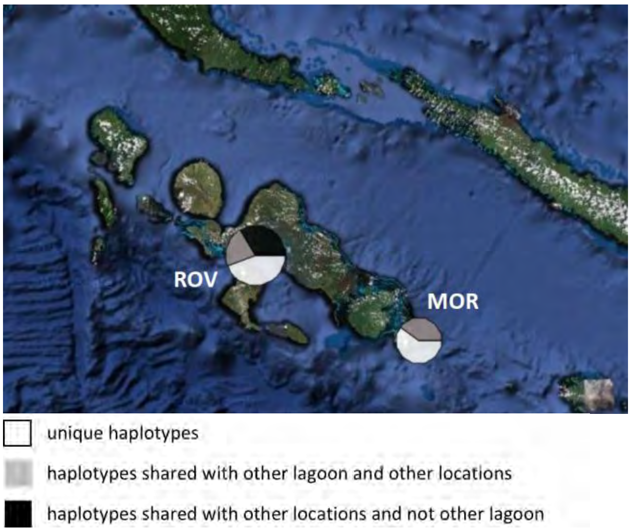

Figure 121 Genetic (haplotype) composition of Checkerboard wrasse within the Solomon Islands (Roviana (ROV) and Marovo (MOR)). Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

Neon damselfish

The Neon damselfish had relatively low levels of genetic diversity within the Solomon Islands relative to other sampled locations (*Hd* and *pi*, Table 39), although both lagoons still had a very high proportion of unique haplotypes (Figure 123). Roviana lagoon shared no haplotypes outside of the Solomon Islands, and the majority of haplotypes found within the Solomon Islands were shared with locations of eastern Australia and Papua New Guinea (Figure 122). Accordingly the Marovo lagoon population was significantly different from those of Ningaloo Reef (pairwise $\varphi_{ST} = 0.1137$, $p = 0$), Ashmore Reef (pairwise $\varphi_{ST} = 0.2983$, $p = 0$), Timor-Leste (pairwise $\varphi_{ST} = 0.1854$, $p = 0$) and the Wessels Islands (pairwise $\varphi_{ST} = 0.4629$, $p = 0$); and the Roviana lagoon population was significantly differentiated from the same locations (NIN pairwise $\varphi_{ST} = 0.1839$, ASH pairwise $\varphi_{ST} = 0.2983$, TIM pairwise $\varphi_{ST} = 0.2561$, ENG pairwise $\varphi_{ST} = 0.5685$, for all comparisons $p = 0$) aswell as Lihou Reef (pairwise $\varphi_{ST} = 0.1257$, $p = 0.0270$) and Motupore Island (pairwise $\varphi_{ST} = 0.0725$, $p = 0.0451$) although to a lesser extent. These genetic patterns indicate that there is little contemporary gene flow among the sampled Neon damselfish populations across the Indo-Pacific (16.82% of the genetic variation is found among populations); however there is likely to be contemporary gene flow between the populations of Marovo and Roviana lagoons as there is no significant difference in their genetic composition (pairwise φ_{ST}, Table 39).

Table 39 Neo damselfish-Sample sizes and genetic diversity measures for all sites included in the study (see Figures for sampling location key). Locations within the Solomon Islands are indicated in grey and genetic differentiation found between Roviana and Marovo lagoons is shown at the bottom right (significance was assessed following 10000 permutations).

Pomacentrus coelestis Neon damsel fish

	Total	ASH	KAV	LIH	LIZ	MOT	NIN	TIM	ENG	HER	SOL	ROV	MOR
No. samples	194	32	17	11	22	15	24	21	16	20	16	8	8
Polymorphic sites, *s*	89	28	21	12	21	18	30	39	19	20	15	5	12
Haplotypes, *H*	129	27	13	9	16	13	23	18	10	16	10	5	6
Haplotype diversity, *Hd*	0.9674	0.9839	0.9485	0.9636	0.9481	0.9714	0.9964	0.9714	0.8917	0.9474	0.8250	0.7857	0.8929
Unique haplotypes	na	22	9	5	13	10	18	14	8	11	8	4	4
Nucleotide diversity, *pi*	0.0145	0.0143	0.0104	0.0083	0.0133	0.0107	0.0140	0.0215	0.0091	0.0083	0.0060	0.0029	0.0090
Genetic differentiation between lagoons, paiwise φ_{ST}												0.0000 (*p*=0.6757)	

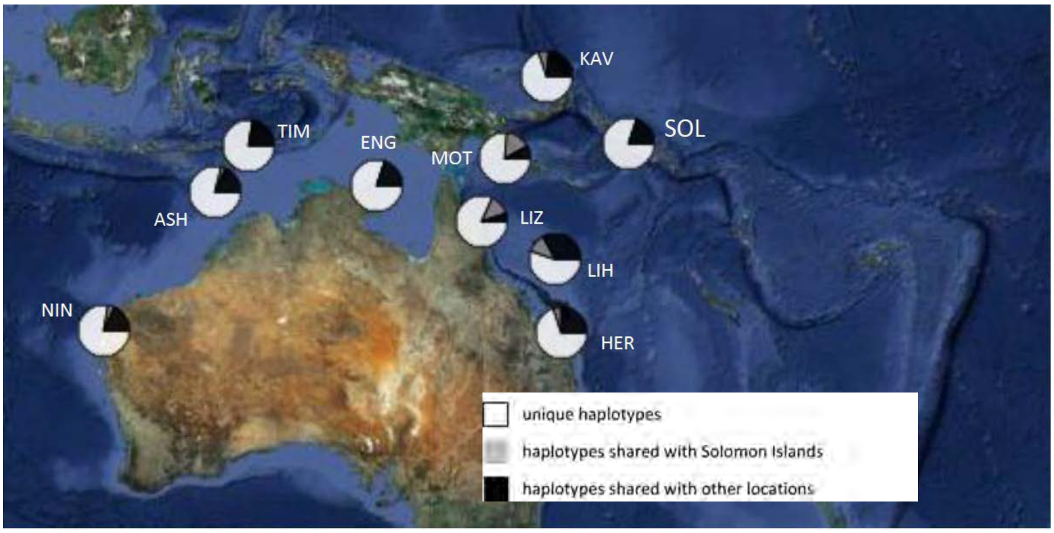

Figure 122 Genetic (haplotype) composition of Neon damselfish at sites across the Indo-Pacific. Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

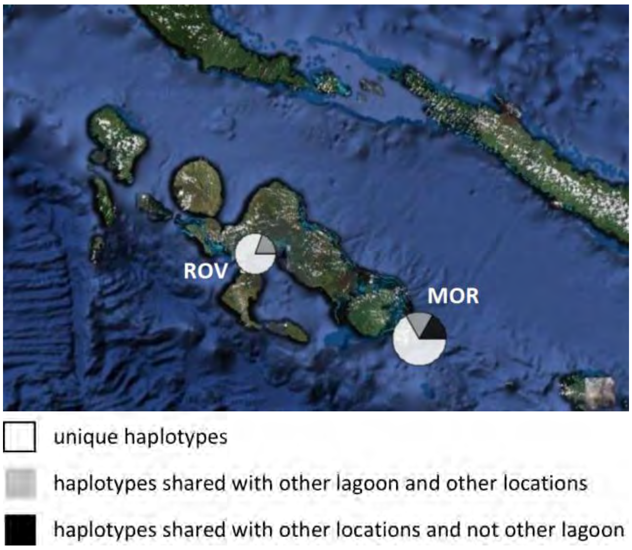

Figure 123 Genetic (haplotype) composition of Neon damselfish within the Solomon Islands (Roviana (ROV) and Marovo (MOR)). Size of the pie charts relate to the total number of genetic variants (haplotypes) found at that site; proportions within pie charts represent the genetic composition of that location (see legend).

Summary

In summary, although the genetic patterns found across Roviana and Marovo lagoons in the Solomon Islands and their relationship with other sampled sites in the Indo-Pacific varied across the four studied fish species, they do lend some consensus. Generally, levels of genetic diversity within the Solomon Islands and within each lagoon were similar to other sampled sites across the Indo-Pacific (except in the case of the Neon damselfish where levels were lower). There was a high incidence of unique haplotypes in the Solomon Islands (excepting the Convict surgeonfish) indicating there is little contemporary gene flow, and therefore little connectivity, among these sites and the wider Indo-Pacific. The presence of unique haplotypes (except in the Convict surgeonfish) in both Roviana and Marovo lagoons highlights the genetic individuality of each lagoon. Marovo and Roviana lagoons often differed in their genetic composition, indicating that there may be little genetic connectivity between the lagoons (i.e. a low proportion of shared haplotypes) and each lagoon may have different levels of connectivity with regions outside of the Solomon Islands (i.e. proportion of haplotypes shared with other regions and not the other lagoon).

CHAPTER 7

HORTICULTURE & AGROFORESTRY VULNERABILITY ASSESSMENT

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KEY MESSAGES

- Decreasing diversity of garden crops
- Crop diversity essential for climate change resilience
- Bushfoods are an important food source during disasters or food shortages
- Older generation has rich knowledge about bushfoods
- This bushfood knowledge is being lost and not passed onto next generation
- Perceived increase variability in climate has led to lower productivity through rotting of tubers in very wet periods and crop mortality during dry periods
- Young people no longer value garden knowledge
- Shortage of fertile land as a result of population growth and use of garden lands for commercial agroforestry plantations
- Lack of skills to improve soil fertility
- High use of destructive slash and burn methods which reduces soil fertility
- Increased reliance and preference for processed foods (e.g. tinned tuna, noodles, biscuits)
- Increase in pests and diseases having significant impact on garden productivity

DEFINITIONS

In this chapter, the terms used were adapted from various publications with meanings relevant to the Pacific, particularly the Solomon Islands context.

AGROFORESTRY – *as adapted from Pacific Food Security tool kit (FAO 2010b)) an extensive low input non – permanent agro forestry (shifting cultivation) intercropping deliberately combining selected crops and agriculture crop (predominately root crops) for short term productivity.*

COMMUNITY – *a group of individuals living/ glued together in a vicinity through inter marriages, religion, government, employment opportunities or socio-economic factors. A community is not necessarily from the same tribe or claimant of natural resources use or ownership in a particular area.* As adapt from Phil Bart (PhD), CEC website, *a community is the social organization of a settlement or association of people.*

EXPOSURE – *is used in literature to characterize the biophysical impacts of climate change on agroecological systems. Exposure encompasses the spatial and temporal dimensions of climate variability, such as droughts and heavy rains, the magnitude and duration of weather events, and long-term change in mean climate (temperature and precipitation),. As adapted from Asian Development Bank (2009).*

SENSITIVITY - *Sensitivity is defined by the IPCC as "the degree to which a system is affected, either adversely or beneficially, by climate variability or change" and refers to the ability of an agroecological system to withstand impacts without overt efforts to adapt. Sensitivity is a complex concept because the responsiveness of a system can be influenced by both intrinsic characteristics and degrees of external manipulation. For example, unprotected low-lying coastal areas may be more sensitive to rising sea levels and storm surges than those that have sea walls. Similarly, water-stressed areas that have no irrigation infrastructure will be more sensitive to drought compared to those that do have such systems in place. In Asia and the Pacific, many countries are sensitive to climate change and extreme weather events because of high water stress, high rates of land degradation, and the high dependency of their economies on agriculture. As adapted from Asian Development Bank (2009).*

SUPSUP GARDEN – *refers to a small, family managed food production garden within the village boundaries, usually near the home, or on the edge of the village.*

VULNERABILTY - *Vulnerability to climate change depends not only on exposure to climate events, but also on physical, environmental, socioeconomic, and political factors that influence how sensitive countries will be to a changing climate, as well as their ability to cope and to adapt. For adaptation and mitigation measures to be successful, an assessment of poor communities' current vulnerabilities, needs, and coping abilities is needed, including influential factors such as gender equality (ADB 2009).*

OVERVIEW

Rural communities of the Solomon Islands remain subsistence farmers and depend on gardens for daily survival. As has been observed in the Solomon Islands, there has been a slow shift from the traditional agro forestry systems to cash crop production (MECDM 2008) as the need for monetary benefit increases. This includes pressures on families to meet obligations such as school fees and other costs. Agro forestry, as an alternative income source, is one way of relieving economic pressure in the Solomon Islands. This research focused on looking at the use and adoption of gardens and agroforestry in the Roviana Vonavona region, and the social vulnerability to climate change impacts.

The traditional agro forestry system defined by Thaman et al. (2002) as a 'deliberate planting of trees around or within farming systems for short and longer term benefits', has not been observed in subsistence gardening in the Solomon Islands. The current practice observed around gardens or elsewhere focuses more on food crop production for immediate benefits. This is through the planting of crops, especially root crops or cultivars as defined by Pacific Food security Toolkit, (2010). In addition, the team observed that fruit trees in and around gardens and villages were both old and productivity low.

Results from the research demonstrate early impacts of climate change in the agro forestry sector. Of particular concern is the impact of extreme weather events (increase in rain intensity, increase hot days, storms etc) on natural resources. Rotten tubers and corms of crops resulted from flooding of low lying gardens, extreme sun periods reduces the production of crops especially staple crops. Or the unpredictable state of weather events contributes to reduce production from gardens and increase 'taem blo hangere' (Hungry periods), see *annex 5* for details on planting, harvesting and seasonal calendar.

Young people did not consider agriculture or farming practices as being important. Important skills in Agroforestry were either neglected or not transferred resulted in no practical knowledge and skills. Lacking skills and ability to worked the land could be disastrous in the future. There was also an opinion that there was no need to improve agroecosystem technology. Together, this makes the communities vulnerable to food and commodity security.

Land availability has been highlighted across all communities as an important issue. Availability of space for activities such as gardens, housing or for other important development such as cocoa or forestry plantation is limited. Associated with increase of population, land is of uttermost importance and requires meticulous management, planning and usage. Coastal terrestrial forests are extremely vulnerable to new development and quest for more land.

Though with many issues arising, Agro-forestry systems focused on utilizing limited land and basic resources for food production, goods and services through integration of trees with agricultural crops and animals is a useful adaptation process to help reduce community vulnerability.

SUMMARY OF RESEARCH FINDINGS

ISSUES ARISING FROM CLIMATE CHANGE

Community farmers have expressed many factors related to climatic conditions as having impacts on food and agro forestry systems.

1. There is currently a low diversity of root crops, vegetables and fruit trees across all communities of Roviana Vonavona. It was determined that there was a higher turnover of crop varieties, no proper stocking methodology
2. Jansen et al (2006) stated that diversifying crops and increase variety as traditionally practiced is an adaptive means to reduce risks and meet multiple family needs.
3. Land shortage was continuously mentioned as an important issue. Land shortage for planting, repeated use of garden areas and bad agricultural practices such as slash and burn farming method has contributed to higher soil erosion and degradation. Currently, there are no proper ways of improving soil management process or introducing new adaptation technology to improve soil nutrients. Enhancing soil nutrients through legumes and simple organic practice is an important practice that was trialed in two villages, Buni and Baraulu. Associated with increase population growth, gardening land is now used for new homes making less land available for gardens. Fallow periods decreases from fifteen to ten years (Woodley 2002, Jansen 2006, Ministry of Environment Conservation and Meteorology 2008) to two years as found in Baraulu and well documented in Vella Lavella as well.

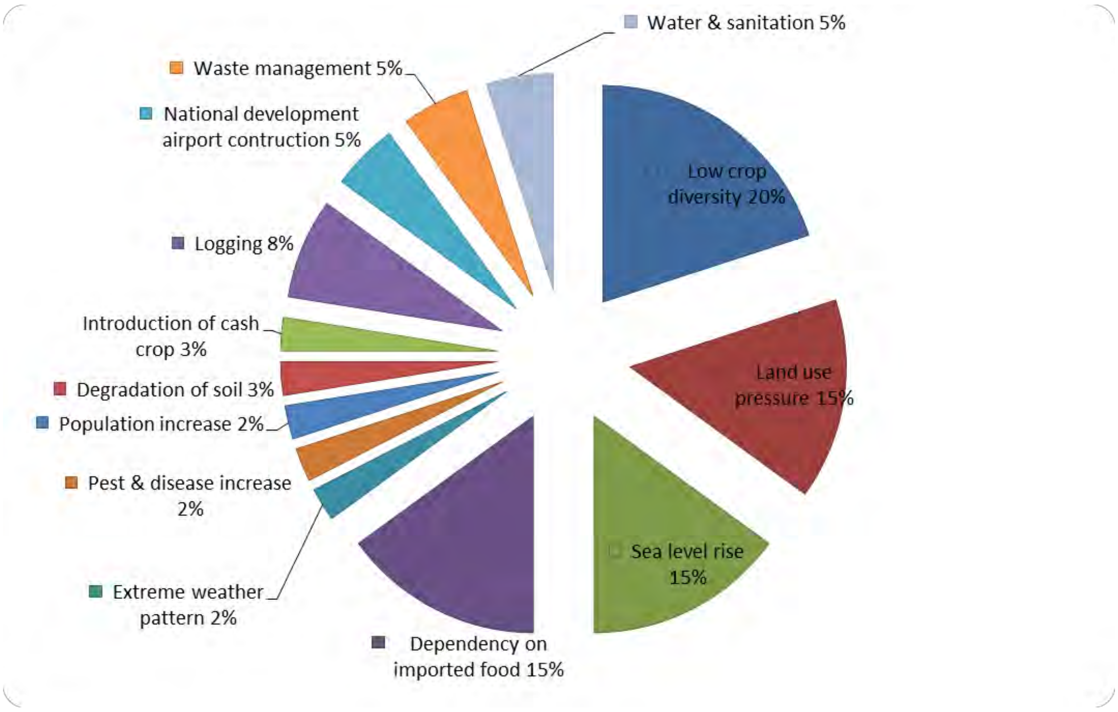

Figure 124 Roviana issues related to climate change vulnerability

4. Sea level rise has been identified as an important concern for coastal and barrier Islands communities. Coastal gardens have been noted as prone to sea level rise or salt winds with high waves. As mentioned during the research in Nusa Hope, cassava is sweeter after the tsunami in 2007, whilst elsewhere in the lagoon, gardens were flooded with saltwater and other infrastructure

damaged. Another scenario of such was the severe sea swells in December 2008 affecting other parts of the Solomon Islands such as the Ontong Java atolls. Such could be disastrous to low lying islands of Vonavona and Roviana.

5. As more people have access to money, families are becoming highly dependent on imported food. The main staple in families' diet is rice, taiyo and noodle. It was mentioned that imported food products are readily available and easier to prepare than subsistence food sources, thus more families prefer imported goods, see detailed in *annex 3* reasons for food source preferences and ranking. Jansen et al (2006) highlighted the changing diets as associated with social status, though nutritional were considered unhealthy.

6. Extreme weather patterns were mentioned during the research as being 'currently experienced'. Periods of long dry hot seasons and wet seasons have impacted the agro forestry systems in communities. Crops/cultivars are not able to cope with prolong dry and hot periods. This is in contrast to wet periods, when there is good growth but less productivity. At other times, food gardens were flooded. This has contributed to people becoming economically vulnerable and less food secure.

7. Pests and diseases on planted cultivars and crops are increasing and these were observed outside the normal seasons when they are usually present. Pest and diseases contributed to destruction of crops and growth, resulting in reduction of yield. Increase prevalence of pest and diseases exacerbate the impacts that extreme weather had on crop growth and production. Destruction of leafs, tubers and corms of crops resulted in families having less for consumption or income generation.

8. Population increase is a concern of communities across the Roviana Vonavona region. This was mentioned by the communities living on Barrier Islands. As there are more people, the villages were increasingly overcrowded. The need for more land to build homes and new gardens is having increased pressure on natural resources. Lack of proper sanitation is a separate issue identified and linked with population increase. This is an important issue considering increasing wet weather patterns and possibility of well water contamination.

9. Low soil fertility was mentioned to negatively affect farming. Reduced soil fertility has resulted from the slash and burn farming method. This method leaves soil exposed to sun and rain resulting in nutrient rich top soil being washed away during heavy rain. The burning of bush during land clearings has contributed to the destruction of the micro-organisms. This has reduced the fertility of soil and agricultural production. With the current trend of increase rain and sun intensity, top fertile soil is exposed to erosion; the ability of soil to retain moisture for good plant growth is reduced.

Other threat that has contributed to stress on the agro forestry sector is the introduction of commercial trees. This includes teak, oil palm, cocoa etc. These trees needed more land space, and increase pressure on land availability. Communities in the area of the study have agro teak plantations and are venturing into cocoa (cacao) farming. Whilst in Bulelavata, there is a trial in oil palm planting.

Unsustainable resources harvesting has been mentioned as a threat which may leave people vulnerable to climate change. Currently, there is intensive large scale logging on Barrier Island and some areas in the mainland of New Georgia. . Marine resources are commonly harvested by resource owners and non – resources owners increasing the pressure on marine resources.

If not properly planned, major national development such as large clearing for the Munda international airport construction and resettlement, can have aggravated consequences on local residence, such as financial burden such activities can have on the entire families relocated. Other development and sanitation related issues, such as no proper rubbish dumps, can contaminate water wells and pose health hazards to urban population as the environment faces increase climatic events in the near future.

FOOD SOURCES IN ROVIANA VONAVONA

Gardens, coastal, sea resources and small canteens or stores were mentioned during the research as main sources of food, *refer to annex 3*. Most of the food consumed by families is from garden production or collection from natural resources. An interesting shift in food consumption is the reliance on manufactured food products. It was mentioned that there are wild forest foods that sometimes people rely on, as more common food sources decline, but manufactured foods are now the preference and gathering wild sources is no longer practiced.

Table 40 Current Agroforestry cropping found in the Roviana Vonavona Region; ranking of food availability and uses were in annex3.

Currently Observed Food Crops	Currently Observed Vegetables	Current Observed Fruit trees
Cassava, kongkong taro, Banana currently preferred by most villages, Potato common amount most villagers as the stable crop	Chinese cabbage, lettuce slippery cabbage (Abelmoschus *manihot*), pumpkin, chilli paper, tomato ,beans were popular crops in gardens	oranges, ngali nuts, guava, cut nuts and other citrus fruits
taro, pana, yam Karovera, Voruku were traditional staple crops with reduced presence in gardens	Tatagala (Polyscias *fruticosa* and Polyscias *verticillata*), Pumpkin (Cucurbita *moschate*)	Coconut was commonly observed. Other important cash crops – coconut, cocoa, betel nut, sago palm and forestry tree species such as Teak, Eucalyptus and timber trees.
Voruku, Kakake,lokete, local /African-Vanuatu Yam climate adaptive root crops that were rarely planted in garden.	Kasume (fern), Fig Leaves-Sand paper Cabbage (Ficus *Copiosa* and Ficus *Wassa*) – wild leafy vegetables	Breadfruit was not commonly observed
Manufacturer foods currently popular in the villages	Rice, Taiyo, noodle, biscuits, coffee mix and other food stuff were ranked important for family use, availability and easy access.	

Main crop varieties in gardens were cassava, potato, banana, kongkong taro, taro, pana, yam, etc. Preferred cultivar or staple food was cassava, banana and kongkong taro. These cultivars were preferred due to it high yield production quality and ability to grow any soil type and condition. Vegetables identified were slippery cabbage, Chinese cabbage, beans, tomato, lettuce etc.

GENERAL CONDITIONS OF COASTAL TERRESTRIAL GARDENS & FOREST

The slash and burn farming methodology is continuously practiced across the study site. The process includes cutting down of forested areas, clearing of bushes by burning, hoeing, planting and harvesting. The general practice is simple and described as *'an extensive low input non – permanent agro forestry (shifting* *cultivation) intercropping deliberately combining selected crops and agriculture crop (predominately root crops) for short term productivity'* (FAO 2010b).

Farming technology is simple with basic tools such as axe, knifes, hoes or mattocks. Gardening information and cultivars is shared between farmers. It was evident that there is lack of understanding of pest and diseases as some planting materials /cultivars had diseases and pests present. Soil degradation, which results in low nutrient content, was evident in gardens in the research site. This included the erosion of nutrient rich top soil either by heavy rain or burning, resulting in poor growth of crops.

Gardens generally have low diversity of crops; some farmers have only one or two crops planted in gardens. Although participants mentioned that there are abundant variety of crops in gardens. Stocking of cultivars and good planting materials were found to be areas that needed addressing. Most farmers preferred to plant crops that can perform well in any weather condition or soil type.

General trend in agro forestry and coastal resources

The general trend in the research site is: current gardens and other resources were exposed to changes of climatic conditions such as extreme dry and wet conditions; increase prevalence of pest and diseases; land degradation; low nutrient content in soil resulting low yield production and reduced fallow period for gardening.

Yield from garden were continuously reduced and farmers tend to prefer planting crop varieties that increase yield production in any weather condition or soil type. Farming practices is mainly slash and burn method with focus in food production for immediate benefit, without any longer term considerations.

Families increase their reliance on imported food products as they are easy to prepare and access. Coastal forestry caters for log ponds or cash cropping plantations such as coconuts.

Coastal terrestrial played an important role in the Agroforestry and community wellbeing. Mangroves and coastal vegetation in particular provide "free" ecological services, with functions such as wind breakers, mitigate floods, cyclones and strong winds, tsunami (tidal waves), breeding ground and safe haven for fish and other marine resources, protect and stabilize coastlines.

Knowledge Gaps

It was identified during the research that there are serious issues with agro forestry. Information, knowledge, skills and technology are needed to develop capacity of farmers. There is a need for organizations to help improve the current knowledge and practice of farming. The following points below were observed to be important areas to develop capacity and manage resources sustainably.

- **Leverage knowledge through information, skills and technology**. Currently farming practices are partially traditional in practice. Community farmers currently continue to practice slash and burn farming techniques, using simple tools such as hoes, knives or axe. Adaptation farming technologies are important innovations that needed to be shared with communities for example. This includes the introduction of salt tolerant crops or improving soil nutrient content. It is important that training considers gender. Women play an important role in farming, though at times lack knowledge to improve their farming techniques.

- **Capacity development in pest and disease identification and eradication**. It was found in this study, that pest and diseases were present on cultivars or crop cuttings. Banana rash were found to be everywhere or beetle destruction of taro corms, leaf folders in potato and leafy cabbages.

However, there is little community knowledge of pest and diseases identification or ways to reduce or eradicate current pest and diseases.

- **Stocking of cultivars, gene and seed bank training** has been identified as skills needed to maintain cultivars or crop stocks. This training needs to be accessible within each family. It was found that crop turnover is very high especially with potato. There is a need for training on seed and gene bank development; this knowledge will help planning for the future through stocking planting material. Deliberate tree planting for economic and ecological benefits needs to be encouraged. Current fruit trees observed were old and productivity level is low.

- **Loss of traditional wild bush food knowledge and skills.** It was mentioned during the research that wild bush food exist and that they were sometimes used in hunger periods. The knowledge and skills to process wild bush food is slowly being lost, and even the tree species are starting to disappear. Documentation of such knowledge is very important for younger generations of the Roviana Vonavona region**.** It is important that terrestrial areas with wild bush food be conserved as a disaster preparedness mechanism.

OPPORTUNITIES /WAYS FORWARD

With the current status of agro forestry in the Roviana Vonavona region, it is imminent that adaptive mechanisms are put in place to better equip people with knowledge, skills and technologies to deal with change. Issues identified in this research were important areas of focus for any organization and the Roviana Conservation Foundation (RCF) to focus on working to improve or develop capacity of its members.

INCREASE CAPACITY DEVELOPMENT AT THE COMMUNITY LEVEL

STARTING FROM WHERE THE COMMUNITY ARE AT – Communities have an abundance of skills, knowledge and farming techniques which needed to be harnessed and improved. Any adaptation work should be localized, use what the people already know and improve (build on) the knowledge to fit into changing situations. There should be limited introduction of appropriate technology where there is imminent need or cheaper for rural usage.

COMMUNITY INCLUSIVE PARTICIPATION IN CLIMATE CHANGE ADAPTATION – It is appropriate to improve capacity of project beneficiaries through an inclusive participatory approach. Men, women and young people (or the family unit) is an important component in the agro forestry development. There should be equal participation and learning to empower each group of people in adapting to impacts of climate change.

INCREASE CAPACITY DEVELOPMENT WITH AN ORGANIZATIONAL FOCUS

CROSS SECTORIAL BRIDGING – Climate change is not a standalone issue that only requires a climatic approach. There are other issues associated which aggravate the impacts of climate change. During the research it was found that health and nutrition is an important issue which villagers are experiencing.

It is important that the Roviana Conservation Foundation (RCF) to develop partnerships with technical organizations within the country to deliver information and skills within the agro forestry sector. Food and nutrition are important aspect of indicators that inform decision makers about the status of community health.

Potential partners could be Government organizations such as, the Ministry of Health, Ministry of agriculture, Ministry of climate change environment and meteorology, climate change division. The Kastom

Gaden Association (KGA) could be an appropriate partner in developing appropriate farming techniques and technology to improve livelihood.

Introduction

This chapter focusses on understanding vulnerability of horticulture and agro forestry systems in Roviana to climate change. The key objectives of the research in detail are as follows;

- *Survey and document conditions of terrestrial coastal gardens and forests and document factors that are increasing vulnerability to climate change.*
- *Assess, and where possible map, threats (including trends) and areas that are particularly vulnerable or resilient to climate change (and why)*
- *Identify trends and identify food sources/species/cultivars considered most likely to be most at risk to climate change and suggest options for community response, including possible insights for future monitoring of climate change.*

Research coverage

The climate change research focused on the Roviana/Vonavona region of the Western Solomon with an approximate 17,000 residents (Solomon Islands Government 2009).

The research was conducted with representations from 8 communities (Baraulu, Bulelavata, Nusa Hope, Patmos, Ludumaho & Bibolo, Kindu, Dunde and Buni) across the Roviana/Vonavona lagoon. Participants in the research were selected by each community leaders of each community based on their daily experiences and leadership roles in the communities. Participation is inclusive of men, women and young people from communities within the Roviana Vonavona lagoon.

A participatory research process was conducted at Baraulu, (Kalikile resource management region), Dunde (Buki resources management region), Buni (Kiko resource management region), Figure 125.

Figure 125 Roviana lagoon participation areas. Highlighted were the Kiko Resource management area, Buki Resources Management zone and the Kalikile Resources Management Zone

RESEARCH METHODOLOGY

Rural Participatory Approach (PRA) tools were used by the team to collect information and stories from farmers, community leaders, men, women and youths from the villages visited.

Figure 126 Dunde Community participants during a seasonal planting calender exercise (right); Sirikolo and Brian Beti surveying coastal forests (left)

Tools to gather information includes, resource mapping exercises, source of food diagrams, crop diversity matrix and seasonal calendar, priority climate change risk matrix, focus group interviews and general observation. The process involved is participatory in nature whereby women and men discuss, agreed and detail information in mapping or matrix formats.

Gardens were also visited after consultation with community representatives and garden observations done. Observation process includes detail verification of crop variety and abundance, soil status, pest and diseases assessments in gardens etc.

Coastal terrestrial forest assessment method is through observation and site visits. The team draw transects to observe the composition of forestry, flora checklists and recording of coastal terrestrial, food species and possible impacts of climate change. The process includes a day of consultation with participants and a day of field observation in different areas of coastal terrestrial forest. Simple equipment as telescope, GPS, camera and note books were important instruments

The team spent two days in Roviana Lagoon, another two days in Munda and a day in Buni village. It is significant to note that the team was only able to visit 'evening' gardens which are nearby and not the gardens that are further inland due to the time constraints.

BACKGROUND

Climate change poses a broad and complex array of consequences for agro forestry [2] in the Pacific region. Having serious implications for all nations with many developing nations like the Pacific Island Countries

[2] Agro forestry definition in this report is adapted from Pacific Food Security tool kit (2010) as an extensive low input non – permanent agro forestry (shifting cultivation) intercropping deliberately combining selected crops and agriculture crop (predominately root crops) for short term productivity.

Territories (PICTs) are especially vulnerable because they are highly dependent on natural ecosystems for their livelihoods and as sources of food, income generation, water and shelter, (Pacific food security toolkit, 2010). Climate-induced changes in rainfall, temperature, soil and air moisture regimes will impact agricultural yields and the type of crops that can be grown in PICTs, (FAO 2010a).

At the global level, the International Panel Climate Change has predicted that in the future no country will be immune from the effects of climate change, further reinforcing the daily experiences of rural Solomon Islanders (IPCC 2007b). Climate variability, as well as extreme weather events, such as prolonged drought, heavy rains and heat waves, and the increased frequency and intensity of tropical cyclones, (Lal et al. 2009a) are some of the predicted happenings in the future and to some serious extent, sea level rise, eroding low laying atolls and fresh water Inundation (SPREP 2010) are threats currently and will be experienced by rural people of Solomon Islands.

The Solomon Islands government through the Ministry of Agriculture (MAL) and the National Adaptation Program of Action (NAPA) prioritized food security and agriculture as national issues (MECDM 2008, Wickham et al. 2009). With more than 80% of Solomon Islanders relying on subsistence agro forestry and natural food sources for food and income generation; climate change is becoming a major issue nationally.

Country Context

Solomon Islands forms an archipelago of approximately 990 islands with a total land area of 28,000 square km located in the Southwest Pacific about 1,900 km north east of Australia (Ministry of Environment Conservation and Meteorology 2008). Solomon Islands is demarcated into nine provincial governments and were represented by the large main Islands of Choiseul, Isabel, Malaita, Central Islands, Guadalcanal, Makira, Temotu and the group of Islands which consist the Western Province.

These mountainous islands are mainly of volcanic origin and are covered with dense rainforest. Extensive lagoon systems sheltering fish, shells, corals, and other marine life and terrestrial flora and fauna surround many of the islands, particularly in the Western Solomon (Aswani S 2004). Aswani (2006) describes the Roviana Vonavona lagoon consist of many offshore raised coral islands with accretion of limestone, volcanic detritus and organic debris. The Roviana and Vonavona lagoon though separated geographically has similar topography.

Weather and Climatic Conditions

Nationally climatic conditions of the country are high humidity with yearly average temperatures of 27 ^{o}C (80 ^{o}F) with significant extreme temperatures increases experienced more frequently (MECDM 2008); an average annual rainfall of 205 cm /120 inches (Ministry of Environment Conservation and Meteorology 2008).

In the Western Solomon region, average annual rainfall in the area ranges from 3,500 millimeters (mm) in low areas to more than 6,000 mm on the mountain peaks with most areas receiving 4,000 mm (Wall and Hansell 1974). In the South East of New Georgia (Gatokae, Vangunu and southeast part of New Georgia) rainfall is highest during the southeast trade wind (Gevasa) season, between May and October.

In recent years, weather patterns varied from experience expressed by rural community people. Climate projection for the Solomon Islands are in Table 41.

Table 41 Climate change projections for Solomon Islands

• Increase in air temp 0.5-1.5 degrees by 2030
• Increase in sea surface temperature of 1 degree by 2050
• Ocean acidification below threshold for healthy coral by 2060
• Sea level rise since 1996 has increased 8mm per year. There are global predictions of 0.5-1.4m by 2100
• Rainfall – small increase with more intense floods
• Fewer cyclones, but stronger ones

Population

Solomon Island population count in 2009 was 540,000 with 80.3% rural population an average annual growth rate of 2.3%, and an average 5.5 people per household (Solomon Islands Government 2009).

Generally speaking, the population of the Solomon Island is predominantly Melanesians (95%) with Polynesians, Micronesians and others were minorities. The population structure is predominately youths with 41% of the total population under 15 years of age. The current people to land occupation ratio is 17/km^2, (Solomon Islands Government 2009).

Roviana and Vonavona

Population

The majority of the Roviana/Vonavona people are currently living a subsistence lifestyle. The 2009 people's survey and census report is 17,043 people with about 15% of the total living around the urban centres of Munda and Noro. Most of the people lived on customary land and are resource owners. With the increase of population, there is pressure on harvesting and exploitation of terrestrial and inshore resources.

SOCIAL SERVICES

Culture & religion

The Roviana and Vonavona region are culturally stronger than other areas of the Solomon Islands with, traditional social networks and systems still in place. Community leaders participating through the research identified that traditional social networks are strong. They identified that in places closer to urban centres, community working together was a challenge and people cared more for immediate families. Religion was identified as a social asset which provides support through community leadership and networks. The Roviana and Vonavona regions were mostly Christian Fellowship Church (CFC) and United Church; there are other small pockets of other Christian churches as well.

Urban centers, services & Infrastructure

Munda and Noro are the main centres providing services such as retailing centre, government offices, airport, roads, wharfs, electricity, telephone connections, banks, shops, hospital (St. Helena Goldie Hospital), schools and mostly employment opportunities. Few of the total population were wage earners. Tourism is one of the growing industries within the Roviana Vonavona region.

Further away from urban centres, communities have access to aid posts, schools (both primary and secondary), social grouping and networks, other essential services such as banks were hardly mentioned during the consultation processes. Communities that visited or participated in the research identified that they have access to gravity water supply, though a few mentioned wells as their water sources as well.

Markets and income generation

Most markets are in urban centres and some logging camps or schools within the region. Income generation is primarily through market of garden produce, marine fish and shellfish, piggery, poultry and arts and crafts. Other income sources included cash crops (small holding farmers) consisting of tree planting especially teak and eucalyptus, cocoa, copra (coconut) etc. Patmos on the other hand identified rental from a BeMobile tower as one of their financial assets. Foreign companies have extensively logged most of the forest on New Georgia, with logging currently commencing on small barrier Islands of Roviana as well.

Rural transportation

Transportation from villages to the urban centre is mostly through Out Board Motor Engines (OBM) and wooden canoes from villages to villages. Shipping is accessible to most communities; further out from Munda and Noro, transportation is difficult, and accessibility is only through OBM.

Agriculture, health & nutrition

More and more families are dependent on imported goods, a shift from usual practice of reliance on gardening. With increased access to money, families consume rice, tinned tuna, noodles and other imported goods as staple food.

Information gathered at Patmos and Buni health posts highlighted impacts of this deteriorating healthy diet with increases in hypertension, diabetes and heart diseases among people between 45 - 70 years old. It was noted that around 15 people are currently diagnoses with hypertension and diabetes.

Having a sup sup garden alone will not guarantee families eating a balanced diet. However, promoting the nutritional values of these foods should contribute to making informed decisions.

Research Findings – Daily experiences of rural Roviana Vonavona people?

Agriculture

Gardening Practices & Status

Agricultural practices includes subsistence shifting cultivation (slash and burn), clearing of large areas of bush for cash cropping. The process of gardening practices includes, choosing patches of bush to brushed and cut down trees. The trees and buses are later burned and debris's cleared. Clearing, hoeing mounts and planting of crops, followed by weeding and waiting for harvest were main activities. The farming process is simple and there is lack of proper soil management and how to improve soil practices.

As practiced elsewhere in the Solomon Islands, there was no attention to improving soil through mulching or composting practices; the fallow periods are shorter up to 24 months compare to well documented practices of up to 10 - 15 years (Woodley 2002, Ministry of Environment Conservation and Meteorology 2008). Farmers continuously worked the same area for gardening in decades. This has contributed to low soil fertility, increase erosion of top soil and low soil moisture which is particularly important during dry conditions. As noted in the state of environment report (Ministry of Environment Conservation and Meteorology 2008), accessible soil were exposed to fertility and micronutrient deficiency, reducing yield production. Soil conservation practices and improving soil health through organic matter (mulching and compost) will help to improve soil and plant growth.

It was interesting to note that most middle age men and women do not spend enough time in agricultural activities; the older population spends most time cultivating the land. Women are mostly involved in large proportion of the work in the gardens, though sometimes have limited farming knowledge and skills.

Garden Crops

A significant issue to note is the narrow diversity of root crops and vegetables planted in some areas. There is a significant higher turnover of cultivars or crops with no significant stocking of cultivars or crops for future use. Gardens have limited cultivars or crop variety with cassava or potato dominating areas of gardens. It was noted that cultivars or crops were preserved (stocked) once there is higher production (yield in return), shorter period to harvesting, ability to withstand certain condition and taste factor, see Table 42 for frequency of planting crops in gardens.

Few important crops/cultivars that can better adapted to 'taem blo hangere' (hungry periods), were left unattended, and usually not planted frequently.

There is lack of recognition of destructive diseases, methods to reduce pest attacks or to improve yield.

Table 42 Annual food planting frequency, sometimes and rarely planted – Roviana Vonavona region.

Food crop 'frequently' planted (monthly)	Food crop 'sometimes' planted (once every six month)	Food crops 'rarely' planted (annually)
Potato	Karovera	Vuruku
Cassava	Tomato	Lokete
Banana	Peanut	Corn
Taro	Pana	Local yam
Bean		Kakake
Cabbage		African /Vanuatu yam
Slippery cabbage		
Pumpkin		
Chilli pepper		
Kakake, lokete and kalovera were identified as disaster preparedness crops that can produce yield in all weather conditions. Important food that were continuously overlooked		

Farming Technology

Farming technology still remains an important issue with simple tools such as a hoe, mattocks, axe and bush knives common among families. There is a higher proportion of involvement of older people in the garden activity. Thriving traditional farming practices and simple technologies were observed as common practice. Sometimes traditional farming practice may hinder learning and using improved and helpful gardening practices that can improve farming styles, methodology and eventually improved yield production.

Table 43 Annual crop yield production – monthly details of planting and harvesting periods, more details in annex 5 – Crop diversity and seasonal calendar.

Period of good yield production	Period of low yield production –' taem blo hangere'	Weather patterns
June –august were identified as good production of crops planted	January to march* and June July were identified as low food production periods	January to march was mostly wet weather (rain). June rain and sun, July to august is usually hot sun and windy times of the year
August to late October food production is within the median (not too good or too bad). Food production is in between good yield and low yield productions.		Sunny/rainy and strong windy periods
**- participants highlighted that social celebrations and holidays during the Christmas period may have contributed to low crop production in January to march period.*		

OTHER FARMING OPTIONS

The under-utilization of some areas like swampy grounds should be refocused as such areas are useful to plant giant taro, swamp taro (kakake/kakama) and other crops that can grow in the swampy areas such as sweet fern (Stenochlaena *Palustris*). Planting of wild growing vegetable such as Lege (Gnetum *gnemon*) and Kemanao-sand paper (Ficus *Copiosa* and Ficus *Wassa*) to increase production and availability were currently low and should be encouraged. During discussions, it was highlighted that venturing into new forested areas could help in improving soil and farming practices.

NATURAL ASSETS OF ROVIANA VONAVONA REGION

The Roviana Vonavona region is highly resourceful with marine, coastal, land and forestry assets. Resources owners or inhabitants of the region enjoy the use of natural resources either through subsistence farming (agro forestry) or through wild harvest of natural resources. Families within each community were both farmers and skilled fishermen. Although some families may concentrate mostly on either farming or fishing and other skilled jobs as a means of livelihood and income generation for example carving/weaving or paid jobs.

LAND USE

Topographical settings both on the mainland and islands have different characters and the soil on the barrier islands of Vonavona and Roviana lagoon are largely red clay, mixed with small rocks. The barrier islands were raised coral reefs with limestone and thin top layer of fertile soil. Gardening was done on barrier islands or in coastal areas of the main island of New Georgia. There was no inland farming, most forest inland were either logged or still in tack. Although some part of the inland of South New Georgia and Munda have good soil structures which are potentially good for agricultural activities.

In Roviana lagoon, especially on the barrier Islands the fallow period is decreasing to less than twenty–four months. It was noticed that soil fertility is declining. Baraulu and Vonavona farmers are heavily practicing shifting cultivation and so it is noticeable that there are areas that are mostly covered by small bushes or shrubs. The mainland of New Georgia is still intact with thick bushes although there is a presence of logging in many parts of the mainland.

LAND QUALITY

It is important to note that these areas were once a battle field during the Second World War and most of the top soil was removed to make roads and landing areas for warships and planes. Thus, there is a lot of coral and limestone especially in the Munda area which would require land management skills to regenerate the soil.

International companies logged the main land of New Georgia with intensive road systems breaking through land blocks and gardens. Within the Roviana Vonavona lagoon, logging has been intensively carried out. In some cases, land degradation and soil erosion has been visibly observed destroying fertile top soil. It was also observed in the lagoon areas of Roviana that sedimentation in the lagoon exists from logging practices, threatening coastal forests and marine ecosystems.

FOREST COVER

COASTAL FOREST STATUS- COASTAL STRAND OR BEACH FOREST

The coastal vegetation or beach flora in the two lagoons is very similar in structure and composition as they are next to each other and closely connected. Specific variations of this forest type were noted to be occurring in different habitats and locations. Typical sites with these examples are: along mouths of rivers and streams, disturbed fallow areas along coast lines, wetlands and areas that are invaded and dominated by certain species of plants.

Most mangrove sites are still intact and undisturbed. However, rapid population and competing social and economic needs from the communities is a great concern. There is progressive depletion of mangrove areas caused by new settlement and expansion of existing villages. Clearance for plantation and gardens, log points or log landing sites for logging activities, Fuel (petrol) sheds and associated wharves are causing disturbances to coastal forest systems.

Mangroves important role in both lagoons sustained and support the livelihoods of many generations. Coastal forest especially mangroves are vulnerable to man-made and natural destruction. The 2007 April tsunami exhibits the extent to which natural processes impacted natural ecosystems. The mangrove ecosystem with particularly the Bruguiera spp. and Rhizophora spp. within the areas between Kindu, Banga Island and Noro in New Georgia were yet to fully recover.

PLANT DISTRIBUTION

The following plants are commonly distributed (***annex 6*** details flora checklist) along the coasts and shorelines of the numerous islets within the lagoons : *Barringtonia asiatica, Cocos nucifera, Cerbera manghas, Tournefortia argentea, Premna corymbosa, Vitex trifolia, Timonius timon, Guettarda speciosa, Cordia subcordata, Casuarina equisetifolia, Calophyllum inophyllum, Wollastonia biflora, Thespesia populnea, Terminalia catappa, Scaevola taccada, Pandanus spp., Neisosperma oppositifolium, Morinda citrifolia, Inocarpus fagifer, Hibiscus tiliaceus, Hernandia nymphaeifolia*.

Other herbaceous coastal flora that co-existed includes *Vigna marina* (beach bean), *Centella asiatica* (Indian pennywort or asiatic pennywort), *Cassytha filiformis* (cassytha), *Tacca leontopetaloides* (polynesian arrowroot), *Crinum asiaticum* (Crinum or spider lily) and *Ipomoea pes-caprae* (beach morning glory).

The rapid population growth exerted pressure on land and coastal forest resources. This appears to be widespread in the lagoons. Coastal vegetation was cut to give way for new settlements, coconut plantations, gardens, log landing sites. These were major reasons for the habitual destruction of the beach forests throughout the two lagoons.

The conservation efforts of the Roviana Conservation Foundation (RCF) in establishing Protected Areas in selected sites reduces further stripping of coastal forested areas. Based on the general reconnaissance carried out, the status of the coastal forests in both lagoons are highly vulnerable to natural and ecological changes, social and economic development activities, cultural related demands and other competing needs by community members to sustain their livelihoods.

Apart from the above economical uses, mangroves and coastal vegetation provide “free” ecological services, in that they act as wind breakers, mitigate floods, cyclones and strong winds, tsunami (tidal waves), breeding ground and safe haven for fish and other marine resources, protect and stabilize coastlines.

Cash trees

Communities were involved in tree planting (teak, eucalyptus etc) with Bulelavata trialed oil palm as a community project. Betel nut is a common crop across all communities, as it is a cultural delicacy and an income earning crop. The shift from subsistence farming to small holders' cash cropping has resulted in the use of the best garden sites to plant teak, coconut, cocoa, betel nut or palm oil.

Inland of the New Georgia group of Islands were covered with forest either virgin or grow backs after logging. Smaller barriers Islands were exposed after years of farming on the land.


Figure 127 Typical coastal forest within Roviana Vonavona lagoon (left); exposed island of Nusa Roviana from gardening activities (right).

Dominant cropping and crop diversity identification

Agro forestry systems in the research region vary from community to community though fruit trees and crops planted in garden are same. During the research, information gathered showed that important cropping for disaster periods were neglected or overlooked. Focus is more on crops that can easily planted or have more yield production in shorter period of time.

There are typical examples of different patterns, designs and purposes of traditional and modern agro-forestry being implemented in all communities. Food security and family welfare was prioritized in most villages as observed during the field trips. Combination of root and vegetable crops were common with a few fruit and nut trees.

Arboriculture has been adopted and passed over to succeeding generations. Fruit and nut trees are common in villages and plantations as well. Soil fertility was claim to resulted in very low crop yields in some villages, poor food production and less garden food on the table.

Agroforestry Root Crops

THE STAPLES

Cropping assets within the Roviana vonavona region vary from place to place, depending on farmers and family interest and constraints of farming different crops. Table 2 of *annex 2 – Crops PRG Data* details a variety of crops/cultivars currently planted by the families within the region. Information collected indicates a low diversity of crop varieties across villages.

Figure 128 Typical sweet potato garden in Roviana

SWEET POTATO (*IPOMOEA BATATAS*)

Sweet potato is one of the main staple root crops that is widely planted in many of the villages and families across the lagoon areas and is consumed daily, most year round. Sweet potato is a productive and a resilient crop, growing in a wide range of soil type and condition. It is planted in mounds, which is formed with a hoe.

Cuttings and planting method varies considerably from villages to village and even farmers as well. There is a very high turnover of cuttings with farmers (women in particular) actively sharing, collecting new varieties and discarding old ones that could not produce higher yield. Fast and high-yielding three to four-month varieties of sweet potato are very popular but are usually complemented with some slower-maturing and longer lasting varieties.

POTATO VARIETY were preferred due to various reasons such as good growth and high yield during dry weather, performance in different weather conditions, shorter period to production or last longer in gardens .

Potato variety differs from place to place and sharing of the cuttings between farmers is common. Commonly planted variety of potato were Bakua, Bilua, 3 month, Qula, Amelia, Hako boni, Barasipo, Maruana, Opele and Tupele. Opele can performed well in both wet and dry session, Qula variety last for longer period of time without going bad while Maruana grows well on sandy soil.

As elsewhere in the Solomon Islands challenges remain in stocking of different potato varieties. Common varieties lost in from farmers in Roviana Vonavona region includes Paradise, Sugar, Jimei, Koripopu, Hakoboni, Nibi, Kausumae, Lebiasi and Boboe. Orange flesh sweet potato is not commonly grown even though it has high nutritional content.

POTATO PRODUCTION - Current production of sweet potato is declining. Good harvest of sweet potato and other staple crop were usually around September to February, whilst from April to July farmers usually experience low yield production resulting in food shortage (hunger periods). Baraulu women have expressed that hunger periods can sometimes extend to December. This may be an indication of changes in season and weather events with climate change.

Threats to production includes pest and disease attacks, narrow diversity of sweet potato varieties, low labour input, other social community obligations and the constantly unpredictable weather pattern . In Buni, Baraulu and Munda villages, common pest are leaf folder, where caterpillars do the damage causing farmers challenges to control.

In some areas, cassava and karavera are a popular choice than sweet potato.

CASSAVA (MANIHOT ESCULENTA)

Cassava has become widely planted in Roviana, Vonavona and Munda area which slowly replaces sweet potato and other important staple crops. This crop is also reported by a Nusa Hope informer that after the tsunami, it has become sweet, soft and grows well. This has also contributed to its increase status in the garden.

Cassava has been classified as a drought tolerance crop which easily adapted to any soil and weather condition. Cassava is also used to extend cropping period after one or two crops of sweet potato or in longer fallow areas as the third crop after taro, yam or sweet potato.

Figure 129 Mature cassava plants

CASSAVA VARIETY **-** Six common varieties observed grown in most villages includes Green top, Turukai, one boil, Kari, Rice cassava and under pant. Cassava stores well in the ground, for longer periods, than most other root crops.

CASSAVA PRODUCTION - Consumption of cassava increases and one of the recipe includes local pudding were consumed once a week by families. Cassava pudding is for sale in almost all rural markets throughout the year.

TARO (*COLOCASIA ESCULENTA*)

Traditionally, taro *(*colocasia *esculenta)* was the main staple, which eventually was replaced by sweet potato and cassava following a prolonged decline in taro yields caused by pest and disease problems (McKinnon 1973) as well as soil nutrient depletion. In some parts of Roviana taro is categorized as rare in most gardens, and a few farmers are planting taro in a relatively small quantity. With the difficulty of tending taro in gardens, it has gone unnoticed and slowly disappearing.

TARO VARIETY

In Vonavona some of the farmers continue to maintain local taro varieties and during the consultation have identified 17 different varieties of taro. In Buni alone, a woman farmer maintained local variety such as Taloluri, Qoliti, Kusuleke, Oreqo, Ene (maguge), Ruta, Malaita, Isabel, Rennell, Reef islands, Quale and Lauru.

THREATS

PEST AND DISEASES

Taro beetles and taro mite are commonly found in most of the taro gardens that were visited. Adult beetles damage the taro plants by burrowing into the underground part of their host. Plants remain alive, but grow poorly. Holes bored in the corms of taro make them unfit for market and where damage is considerable they are not even fit for home use.

LACKING SKILLS

Most farmers lack knowledge of planting and tending for taro. Farmers continue to practice traditional method of taro planting in many farming system, reducing productivity due to shortening fallow periods. Specialized knowledge to grow and tended for taro is needed.

KONGKONG TARO (*XANTHOSOMA*)

Xanthosoma (Kong Kong taro) is now becoming an important staple crop in some areas as colocasia taro is now too difficult to grow. Kongkong taro is less affect by taro beetle (although it is susceptible) and is not affected by same viruses that affect Colocasia. Kongkong can be grown easily in the garden or beside homes.

Xanthosoma is a crop that supports families during food shortage or hunger periods. In Buni Xanthosoma is slowly replacing sweet potato and cassava to some extent. Farmers around Vonavona claimed that kongkong taro grows well in any condition on the islands.

BANANA.

Banana is typically mixed in gardens, either planted within root crop plots or on plot boundaries depending on the system practiced. Banana was widely planted around villages and sometimes in coconut plantations. This crop is commonly harvested during hunger period and for selling at markets. During a planting exercise activity, it was found that most of the farmers are planting fewer bananas.

BANANA VARIETIES

In Baraulu there is a total of 31 local varieties grown by different farmers on different sites compared to some areas of Munda and Vonavona. Some of the banana varieties have high c beta- caroteniod especially the hakuaturu or vuaturu (Fei), although farmers are not aware of the nutritional content of such varieties.

Threats

The traditional belief is that this type of banana is not encouraged to be eaten. There is a wide spread of disease such as banana rash on many banana observe. The ability not to plant banana is a threat itself that needs refocusing. Banana can sometimes substitute other sources of food from the garden, therefore it is important.

Yam (*Dioscorea* species) and Pana

Pana and yam used to be the main staple diet in the areas. In recent times they are not planted as much as they used to be. The reason for such decline is from the different weather patterns and extreme weather that can disrupt their growth. The ability of farmers or families to grow yam or pana as other food sources for home uses is another factor to consider. The skills and knowledge slowly erodes as many external factors such as weather pattern interfered, the decline of quality of soil.

Its introduction would encourage the children to eat it and include in their diet. These root crops would increase production which women and men could choose from to prepare for their children.

Kakake/Swamp Taro (*Cyrtosperma Chamissonis*)

In Munda one of the farmers said that in olden days the old people regard Kakake or Kakama as a drought/windy season food or known as genani- peza. There are only two varieties which are commonly grown by farmers. However, it was mentioned that people do not consume them. It is important that Kakake should now be promoted for its nutritional and seasonal values for drought and climate change.

Voruku Elephant ear taro (Alocasia taro)

Although voruku was one of the major staple crop during times of food storage, it was found that only Buni maintain the crop. Roviana lagoon and Munda villages are still planting them, but in small quantity. It is important to reintroduce the plant in the gardens and encourage people to plant them and include them in their diet.

AGRO FORESTRY VEGETABLE CROPS

Leafy vegetables.

Slippery Cabbage (*Abelmoschus manihot*), is a major and most important daily green. Given its high nutritional status and easily grown, it is important to encourage its status in the daily diets. It is typically grown in mixed food garden intercropped with sweet potato or other staples, in garden blocks on its own, or planted amongst other vegetables.

However, Slippery cabbage is increasingly attacked by pests, including a devastating shoot borer and flea hopper beetle. The combination of these two pests has seen a significant decline in its cultivation across the country. Both pests appear to have outbreaks at different times of year, in both wet and dry seasons. This issue is serious in some coastal farming systems where it is a dominant crop, and critical for income and nutrition involvement.

Pest outbreaks have led to increasing use of pesticides. This is of concern given the low literacy and lack of safety procedures for farmers and passed on to consumers. In the areas of focus, an interesting traditional cooking recipe known as 'masimasi'- slippery kabis baked with layers of ngali nut – which is good income earner in local markets and to passing ships.There are other variations of cooking methods available.

Fern (Kasume), is a very important leafy green particularly at times when slippery kabis is not available. While it is used in time of shortage of other greens, it is still generally considered to be a good food with good eating qualities. The most common fern species is collected on river banks and swampy areas. Increased logging activity in the area destroyed growing areas of the kasume. Kasume should be encouraged to be planted, ensuring It is widely available, especially with increasing household use.

TATAGALA (*POLYSCIAS FRUTICOSA* AND *POLYSCIAS VERTICILLATA*), is usually planted as a boarder plant and observed to be currently highly resistant to pests and insects. However, with increased population it is being removed from most villages. Tatagala should be encouraged as another important source of greens for the family use. It can be planted in garden boarders and coconut plantations.

LEGE (*GNETUM GNEMON*), is a plant that can be eaten by both its fruits and leaves. Families should be encouraged to plant lege in gardens as well as coconut plantations, and introducing it into family diet. It is also important to note that lege is resistant to existing pests and diseases currently experienced.

FIG LEAVES-SAND PAPER CABBAGE (*FICUS COPIOSA* AND *FICUS WASSA*)**,** although eaten in the past is not widely available due to the high clearing of land for gardens and other activities. As such it should be encouraged to be planted again so the families could introduce it in the daily diet. It could be planted in the coconut plantation as well as boarders in the garden and or village areas.

PUMPKIN (*CUCURBITA MOSCHATE*)**,** can grow very well in any soil within the region, however sometimes it is left to grow by chance and not planted. Research information on pumpkin proved high carotene (orange coloured) content; therefore it should be planted as another source of nutritional plant. Pumpkin as widely practiced is consumed both fruits and the leaves which should be prepared as greens for family use.

AGRO FORESTRY FRUIT TREES

Fruit and nut trees, such as oranges, ngali nuts, guava, cut nuts and other citrus fruits should be encouraged to be planted. Fruit trees were either planted mixed in vegetables gardens especially ngali nuts and bread fruits, whilst most fruit trees were planted in between houses or bordering villages. Its should be noted that a few fruit trees were prone to diseases, for example oranges exposed to algal at Baraulu; and most fruit trees were either old and need replanting.

It is important that farmer have fruits trees available or planted and harvested all throughout the year. Fruits availability in abundance can increase children's intake of vitamin and minerals in their daily diet.

Figure 130 Picture of mixture of fruit trees background with cassava garden foreground.

Issues and Ability to Adapt in the Agroforestry Sector

During the research, there were issues identified which are associated with climatic change and other external factors which catalysed the impacts of climate change, ***annex 3** detailed issues*. This section details the priority issues identified during the research exercise, exposure and sensitivity and suggestion on the ability to cope and adapt. Participants during a priority listing exercise identified various issues which were related to climate change or will be impacted once climate change increases its impacted on people, see Figure 131,

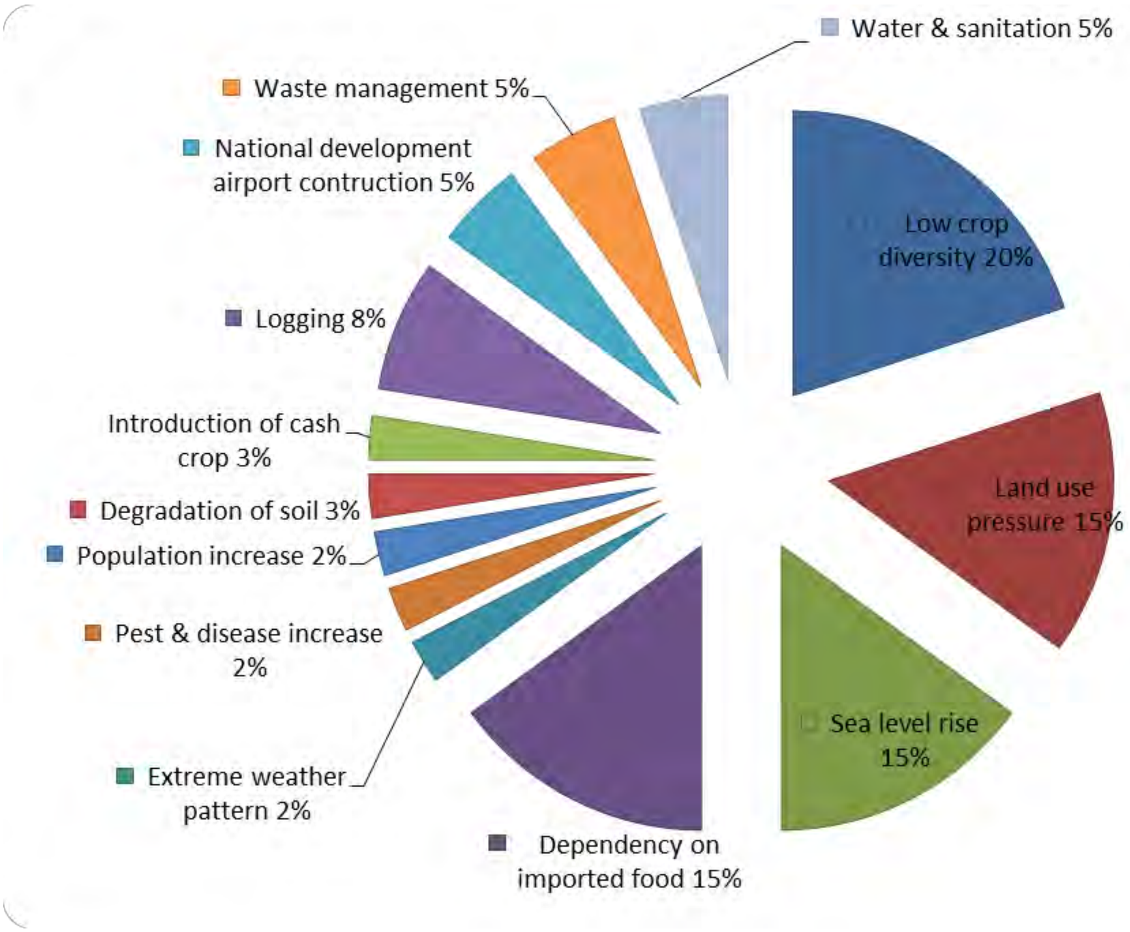

Figure 131 Roviana issues related to climate change vulnerability

Priority issues identified by participants clearly highlighted in Figure 131 were, low crop diversity, land use pressure, sea level rise and development that degrade soil composition. Below is an analysis of issues related to the Agroforestry sector that are currently experienced and can be exacerbated by climate change impacts and suggestions of how well communities can adapt to such situation.

Table 44 Vulnerability assessment of crop variety and diversification

Crop variety and diversification	
Vulnerability criterion	Research findings
Exposure	Few varieties of crops being planted in gardens. Lots of crop/cultivars varieties were highlighted during discussions whilst during field observations, only one or two of the varieties were grown by farmers. Families or farmers lack to diversify different crop varieties in their gardens. Farming systems exposed to few varieties of crops having a higher correlation to periods of hunger.
Sensitivity	Fewer crop diversification and lack of planning to plant according to different weather/seasonal changes result in low production of local food. Different cultivars did better in different soil types. Planting a few dominant varieties of food decrease yield return as some of the soil has been tiled for many years. Quality soil nutrient content is poor and reduces productivity of crops in gardens.
ABILITY TO ADAPT	Stocking crop diversity and variety should be improved. More crop varieties introduce with improved qualities so as to be certain that farmers have a wide variety of cropping to choose from. This will contribute to increase in yield production, good performance in different weather conditions and to fair well against the pests and diseases. The ability to identify the right type of crops according to seasonality and soil type should improve 'planning to plant', thus having more variety of crops and cultivars for higher yield production.

Table 45 Vulnerability assessment of soil degradation and fertility deficiency

BOX Two: - Soil degradation and fertility deficiency	
Vulnerability criterion	Research Findings
Exposure	Soil degradation is an increasing problem for all the farmers which were clearly highlighted during the research. Farmers used the same piece of land for many years. Soil is exposed to higher erosion in rainy seasons, lacks the capacity to contain moisture in extreme heat temperature and general fertility of soil reduced. There is no proper management of available land space to increase production and usability of land for many years to come. Current farming practices were not helpful in maintaining soil quality ,fertility and properly management of space for an increasing population.
Sensitivity	Population increase stress on land space as more people demand to build shelters reducing the availability of gardening areas. Existing garden areas were used for building new homes. Cash crops like cocoa, teak, oil palm, betel nut, coconut etc. have taken land area for gardening. The need for financial security has resulted in people shifting towards more cash crops. This requires more land space, thus leaving subsistence agriculture expanding to new land or using the same land areas with poor fertility and soil quality. There are families who are committed to gardening but the problem on soil fertility is a contributing factor for not interested in doing agriculture activity especially on gardening. Farmers are still extensively practicing slash and burn in their gardens, such practices do damages to the garden soil and all living micro- organisms that helps the fertility of soil is destroyed.
Ability to Adapt	The introduction of mucuna bean or velvet bean was found at Baraulu. A primary teacher there was involved in the bulking of mucuna bean however the distribution of seeds was not successfully done, as expected. Introduction of legumes as a natural nitrogen fixation process in soil and educational trainings on the importance of such to farmers in these areas. Encourage and introduce alternative natural soil nutrient enrichment plants to improve soil nutrient content. Opportunity to increase Agroforestry fruit trees as a means to support natural systems of soil nutrient enrichment. Increase simple agro forestry techniques that increase production of yield in limited space. Basic soil management skills such as composting techniques, mulching, worm farming, introducing of legumes in the garden, using of livestock manure and using alley cropping methods are important skills that should be introduced through trainings. With these skill and knowledge these should enable farmers to rebuild their soil and farm block of land for years without destroy new forest sites. Organic farming practice should be introduced to farmers of Roviana and Vonavona including areas around Munda.

Table 46 Vulnerability assessment of increase dependency on imported goods

Increase dependency on imported goods -Shifting 'food taste' from agricultural production to manufactured goods	
Vulnerability Criterion	Research Findings
Exposure	Increase reliance on manufactured store products reduces interest in farming and working in gardens to produce food. More young people not interested or lack the basic skills in involving in the agriculture sector. Gardening and farming is more a middle aged chore as younger people choose not to be involved.
Sensitivity	Families are exposed to more daily consumption of imported food an alarming change of diet as people becoming reliant on imported foods. Across all villages consulted, imported goods have been highly rated compared to farmed crops; ***annex 2.*** Preference to imported food as it has a better taste, readily available and easy to cook. Most of the meals consisted of high carbohydrate sources from the store such as white rice, flour, canned meat and noodle. Families are poorly served with fresh vegetables in their daily diet. Young people not able to farm, lacking skills and knowledge to becoming self-reliant and resilient. There has been a change in attitudes towards farmed produce. There was a preference towards imported goods; this has increased sensitivity of large proportion of the population. Access to financial benefits from large scale logging companies, or extraction of natural resources for monetary benefits.
Ability to Adapt	More promotion of local food and health benefits. Knowledge and skills dissemination to women, young boys and girls, men is an appropriate way to empower people in the region on nutrition and agriculture practices. Focus on working through existing village networks like the women's groups or through developing agro forestry models which provides practical learning experiences to all men, women and young people. More focus should be on women and girls helping to empower them, educational promotion and involvement of young and mature men to become equal partners in agriculture, nutrition and forestry management.

Table 47 Vulnerability assessment of increased pests and diseases

Increased prevalence of Pests & Diseases in Food Gardens	
VULNERABILITY CRITERION	RESEARCH FINDINGS
Exposure	Gardens were found prone to increase pest and diseases attacks. Pest and diseases contributes to low yield production and low quality of tubers, fruits or vegetables. It was highlighted that pest were seasonal, either appearing during dry or wet seasons. Common pest are leaf folder, caterpillars, melon fly, grasshoppers, rats, frogs, grasshoppers, beetles and birds. This causes farmers challenges to control. Farmers were exposed to poor yield and quality of food production as pest and disease attack food gardens. Some examples in Buni and other parts of the assessed areas indicate that birds destroy their garden. In Baraulu, it was highlighted that long nose rats swim across to barrier island destroying staples crops in gardens, tubers of potato. Red mouth bird and frog in Munda and Vonavona. Beetle is also present in Munda in the nearby gardens but not the inland gardens. Nisotras is presently visible and is a common pest that damaged slippery cabbage and banana scabs is also found. In Buni, the villagers are complaining on leaf rollers which is severely affecting their sweet potatoes Fungus were evident on the leaves, trunks, stalks, stems and tubers of the root crops, trunk of banana and fruit trees such as pawpaw and orange. The unpredictable weather patterns could provide favourable conditions for pest and diseases to flourish, increasing the likelihood of families having less food for income and family needs.
Sensitivity	Increase habitat destruction by large scale logging or disturbance of habitats through increase seasonal changes may have contributed to higher movement of pests. Rats, birds, wild pigs etc. were a few animals which contributed to destruction of gardens. Beetles and other small insects contribute to destruction of food production. Presences of fungus on plants and planting cultivars.
Stress Factors	The continuous operation of logging activity in the area is a threat to agriculture, destroying fertile land for food production, increase soil erosion and overall destroying delicate food chains within the forest ecosystems. It was inferred that animals were displaced and turned to food gardens as a source of food supply, stressing food production for humans.
Ability to Adapt	Educating and introduction of **disease free seeds and cuttings to farmers**. Farmers understanding of plant diseases reduces spreading of infected cultivars between families. Root crop varieties that are susceptible to disease should be discouraged to be cultivated instead provide varieties, which are diseases free and produce high yields according to the available soil type. Pest and disease is becoming a major threat in food production reducing household food production. Gardens visited in Baraulu and Munda showed that planting material used are contaminated with pest and disease. In Buni banana scab is common on banana fruits. Lack of knowledge on pest and disease resulted in such often unattended increasing the spread of pest and disease. Pest and diseases training needs to strengthen local farmers of Roviana Vonavona. For example, Alomae or bobone training needs to be carried out to taro farmers of, Munda,

	Roviana and Vonavona lagoon. **Plant protection training** is an important tool to improve skills in reduction of pest and diseases, whilst increasing production and resilience of farmers. Equipping farmers with Plant Protection skills enables them to understand, describe symptoms, cause, and can able to control emerging diseases or pests.

Table 48 Vulnerability assessment of adaptive capacity of Roviana people

Increase adaptive capacity of community women, men and young in the Roviana areas.	
Vulnerability Criterion	Research findings
EXPOSURE	Women, youths and men lack correct and proper information to improve understanding, knowledge and skills to mitigate or adapt to adverse effects of climate change. Rural people especially women and youths of Roviana Vonavona lack a clear understanding and well informed scenario of climate change impacts.
SENSITIVITY	During discussions with women, it was highlighted there is limited information shared or focus on women development and farming. It is important that support for women groups and networks to enable women farmers to advocate issues affecting their livelihood at different levels. Some women and men have expressed their need to get information to assist in their gardens. Currently the National Government translation of policy to action at the rural level is not adequate. In the NAPA, agriculture or food security is one of the many priorities which the government focuses on.
STRESSORS	Women play a significant leading role and more time in subsistence agriculture and village livelihood activities, compared to men. Some women lack improved agriculture technique or access to new disease free cultivars.
ABILITY TO ADAPT	Facilitate the process of advocacy, awareness and skills development on the issues of climate change, agriculture and livelihood sustainability using existing networks, community or church groupings. There is existing women, youths and other peer groups for example, farmers' networks or rural training graduates. Such structures are important elements to work with, strengthened and empower to advocate climate change, impacts and model adaptation methodologies. Strengthen networks; involve more partners from different sectors such as Non-Government Organizations (NGO), private or government agencies. Planning and implementation of activities

	needs to be people centred. Educational awareness and practical development modelling are positive adaptive measures. Women are placed in the front seat through empowerment and educating them with skills, knowledge, improved tools, technologies and even planting materials or cultivars that could improve their livelihoods.

Table 49 Vulnerability assessment of domestication of bush foods and agro-forestry trees

Better Management, domestication of wild bush food and increase planting of agro forestry fruit trees.	
Vulnerability Criterion	Research findings
EXPOSURE	Local knowledge on wild bush plants and agro forestry trees on terrestrial coastal and mountainous areas is slowly eroding. More and more young people don't know the process and access to wild food or involve in planting of Agroforestry food trees. During the research, food source matrix shows fewer foods from the bush mentioned compare to domesticated crops and imported food.
SENSITIVITY	Local knowledge eroding through lack of sharing by old folks, traditional education system inability to deliver. This may be to changes in the modern education systems. There is no documentation of bush food knowledge to increase resilience. Farmers are not fully participating in promoting forest food though it was highlighted during the discussion that when families experience food shortage they go out into the forest to gather lokete (wild yam), kane and kemanua. Shifting of food preference to manufactured goods instead of increasing bush food production and promotion.
STRESSORS	**Logging** is one of the most significant threats to subsistence and livelihood in the area assessed. It's known that the areas researched *is one of the* areas in the Solomon Islands where the logging has been in operation since the 1970s and still continue now. The older folks who used to eating wild bush food are no longer practice processing of wild bush food, and are not introducing it to young people or into the family diet.

ABILITY TO ADAPT	Farmers are encouraged to engage in planting forest food as well as emergency food such as Kakake (swamp taro), wild yam and also the bush leafy vegetables. There are various seasonal stable wild fruit trees or agro forestry trees which can substitute farmed crops during hunger periods. More awareness and promotion on the nutritional value of forest food is critically important for the young generation. Replanting of forest food is not commonly done although this increases community food security replanting is important; ensuring that such forest food is available. Farmers need to put more emphasis on replanting of such crops as it has proven that farmers used this food during food shortage. The seasonal planting calendar done in Roviana and Munda showed this situation. Communities should monitor, conduct inventory assessments and understand different wild food trees or crops and draw up management plans to protect terrestrial forest with wild food trees or crops. **Conservation and management of natural forest resources should practice with focus more on local benefits.** It is important that documentation of forest food is done for the young generation before many of the forest foods are lost.

FUTURE MONITORING COMPONENTS

Climate change data in country is scattered and stored with Non –Governmental Organization (NGO) or organizations who are working in the sector; there is no centralized storage of country related information to inform planning.

The Roviana Conservation Foundation (RCF) can take the lead in monitoring local agro forestry systems inclusive of crops to inform its future and any national climate change programs. Also, to become well verse with trends and threats that climate change will pose for the communities of Roviana and Vonavona.

Process or design of monitoring in communities is entirely an activity which RCF should develop. Some areas of importance were highlighted and the process should be an inclusive, participatory approach. Monitoring of agro forestry systems should be done annual for appropriate data collection; also considering the logistic challenges and costs. Such sessions could be designed to become more of a reflection of yearly experiences within the agro forestry sector.

Agro forest Staple food Crops

Suggested activities

- Continue collect information and monitoring on cropping & cultivars; current stress, threats; current adaptation practices.
- Asses crop productivity, types of crops that better adapt to changing weathers. Weather patterns, sea level intrusion etc.
- Identify resilient cropping, cuttings and varieties and productivity.

Suggested methodologies includes observations, inclusive focus group discussions , simple questionnaires which helps to collect information related to climate change, agro forestry. Set up databases to input information for future work, developing scenarios etc.

Locations of activities depend on RCF preferences to selected communities. Communities should be identified on different settings such as location (barrier islands versus mainland communities or low laying islands. This is important for triangulation of findings during the monitoring period.

Coastal terrestrial Forest systems (Agro forestry systems, tress and methods).

Suggested activities

- Detail inventory of types of agro forestry systems (local food trees available), stress/sensitivity to climate change,
- Current status of local agro forestry practices, knowledge, challenges with agroforestry.
- Identify cultivars that do better in different weather conditions

Methods use for such activities observations, inclusive focus group discussions or do field work to research such sectors of the agro forestry sector. Setting up models of Agroforestry could help in monitoring of changes that took place and improve the ability to compare with rural farmers.

Locations of such initiatives should be done by the RCF depending on its identified sites and active participants of its existing programs.

Other Monitoring activities

Develop relationship with the health sector to assess food, nutrition and health. The increase in reliance on imported food stuffs and its impact on health and development of the agro forestry sector needs to be monitored.

Potential Partners and Supporters

Various organizations and government ministries are currently working or shifting their focus to adaptation and mitigation of likely climate change impacts. There are organizations who are currently working within the sector on short term adaptation and mitigation measures, while others are working on longer term implications. Some organizations which the Roviana Conservation Foundation (RCF) should consult and work in partnership with include;

Non-Governmental Organizations –

1. Kastom Garden Association (KGA) – technical organization on food security, organic farming techniques and best farming technology.

2. Live and Learn Environmental Education (LLEE) – Strength on information dissemination. Currently have a climate change focused program on food security. Technical specialist in information dissemination

Governmental Ministries

1. Ministry of Environment, Conservation, Climate Change and Disaster Management (MECDM), Conservation & climate change division.
2. Ministry of agriculture regional PACC project under the Ministry of agriculture has been working on adaptation and food security strategies,
3. Ministry of Health – RCF to work with such institutions collecting data on health and nutrition.

Regional/International institutions

1. SPREP - The regional environmental organization, South Pacific Regional Environmental Program (SPREP) sets up an information database useful for climate change information disseminations.

2. UNDP Climate change programs – can provide funding and other related support to CBOs through its Global Environment Facility (GEF) program. RCF can work with such international organizations to advance climate change adaptation technique and intensive educational programs to improve understanding.

Recommendations & Future Actions

Communities of Roviana Vonavona lagoon are currently experiencing the effect of changing climate. During the research, it was identified that with increasing changes in climates related variables, the agro forestry sector is at the fore front of being impacted. There is little communities can do to change climatic conditions and it impacts, but there is still opportunity for people to develop their learning ability, to become more capable and adapt to changes.

Below are some discussions on alternative actions to help trained and develop the ability to adapt and reduce impacts of climate change on local agro forestry and people's livelihood.

Community Actions/Initiatives

Gender inclusive climate change planning and development

Women's role in the household is immensely important (Shankar, 2004) in provision of food. Women and young people should be well aware of the facts about climate change and risk to agriculture and farming systems. Getting women to participate more and improve their knowledge and skills of issues affecting their lives.

- EMPOWERMENT OF YOUTH, MEN AND WOMEN.

  Knowledge and skills dissemination to women, young boys and girls, men is an appropriate way to empower people in the region. Women especially are important partners in the agro forestry development and should be placed in the front seat.

  The process would involve working through existing village networks like the women's groups or through developing agro forestry models which provides practical learning experiences to all men, women and young people. More focus should be on women and girls helping to empower them, educational promotion and involvement of young and mature men to become equal partners in agriculture and forestry management.

As such, women should be integrated and given leadership roles within other existing community committee, accessing information and be able to make informed decision in any development actions that affects their lives.

Some areas of need highlighted include population, land management, seed saving, social and health problems. With their involvement they should help improve not only their own livelihood but also the lives of their family and overall wellbeing of Solomon Islands. .

No regret planning – COMMUNITY CONSULTATIONS AND PLANNING FOR THE FUTURE.

- Develop young farmers' agriculture campaign or promotion. Revive interest in agro forestry and farming. Traditional agro forestry system which inclusive of tree planting could play a vital role in protecting gardens and improve ecological conditions.
- Community infrastructure planning, Island and coastal dwelling population should look at options for progressive relocation. This would pay off in the long run versus drastic disaster relocations. As population increases, there is a need for space, so planning for the future is very important.
- Community coastal terrestrial forest management and conservation initiatives to protect coastal villages, food gardens and agro forestry systems from winds and salt sprays or sea level rise.
- Research traditional agro forestry systems, conducting inventories, documenting traditional knowledge, threats and ways forward to improve agro forestry systems as adaptation methods.
- More detailed research into linkage between climate change, health and nutrition. This is a component that is yet to be research in detail within the country. There will be serious issues with health and nutrition, dependency on manufactured food stuff; increases accessibility to readily available cheap food compared to the work load in farming and agriculture.
- Climate change adaptation and mitigation measures should not be isolated as climatic issue but requires a holistic approach. During the research it was identified that there are current stresses on natural resources, farming techniques, health, education, environment& resources management etc. Climatic changes issues will exacerbate existing issues in places causing damages to people's livelihoods.

INCREASE CAPACITY DEVELOPMENT

Capacity development through information dissemination, skills and knowledge development should focus on all sectors within the community and nationally. Increase capacity of rural dwellers to know, analysed and discern climate change impacts and future scenarios. Increase adaptive knowledge and skills to individuals to become more resilient to changing climate conditions and associate effects.

Currently farmers have little understanding of best agriculture practices, pest and diseases and ways to adapt to changes in weather patterns. Issues arising which requires thorough education and practical solutions are weather changes and food crops planning and productivity, soil fertility, erosion, improve protection of plants against pest and diseases.

DEVELOPING THE LOCAL AGRO FORESTRY SYSTEMS

Current practices have shied away from the traditional agro forestry practices where fruit trees, nuts and food crops were grown together. It is important that such important traditional practices be reviewed to inform best adaptation actions for the future. Work with communities to develop planting calendars, improve information on weather changes etc.

Support Existing Structures & Farmers Networks

In most communities visited, there are governance structures in place which always provide time and space for members to deliberate and share stories or information. Within the Roviana Vonavona region, it was identified that there are existing women, youths and other peer groups for example, farmers' networks or rural training graduates. Such structures are important elements which need to be considered, strengthened and empower to advocate climate change, it impacted and also provide model adaptation methodologies.

Starting from where the community are at

Community women, men and young people have decades of experiences that could be tap on as a source of adaptive strategies. Such experience and knowledge should be document and the information used to develop cultural fit adaptive strategies.

Community inclusive participation in climate change adaptation

Adaptation planning and actions are more effective with community inclusive participation and leadership. Planning and mapping of future action strategies should have the voice of men, women and young people of the Roviana Vonavona lagoon.

Organisational Responses – Specific to the Roviana Conservation Foundation (RCF)

The outcome of this research is very important for the Roviana Conservation Foundation (RCF) as a planning tool indicating areas of importance within the forestry and agriculture sector. Apart from its (research) usefulness for planning purposes, the data collect reflects the daily experiences of women, young people and men of the Roviana/Vonavona lagoon regarding the challenges with livelihood and ongoing changes resulted from climate change.

Cross Sectorial bridging

Climate change is not a standalone issue that requires a climatic approach to address. There are issues associated which aggravate the impacts of climate change. During the research it was found that health and nutrition is an important issue which villagers are experiencing. Food and nutrition are important factors to consider and should be use as indicators that inform decision makers about the status of community health and climate change impacts.

It is important that the Roviana Conservation Foundation (RCF) develop partnerships with technical organizations within the country to share information and skills within the agro forestry sector. High level decision makers such as the government, donor partners are well informed about rural people's aspirations and vulnerabilities.

Potential partners could be Government organizations such as, the Ministry of Health, Ministry of agriculture, Ministry of climate change environment and meteorology, climate change division. The Kastom Gaden Association (KGA) could be an appropriate partner in developing appropriate farming techniques and technology to improve livelihood.

Documentation and Innovation

The Roviana Conservation Foundation (RCF) is in a good position to continue collecting data/information on local agro forestry system for future planning. Such information is important to inform planning or developing appropriate local technologies for the benefit of communities. Take courage in the local traditional knowledge as a fit strategy to adapt for future changes. Traditional systems of agro forestry be reviewed, documented and developed to become more efficient for food production, improve livelihoods and ecosystem services. Such traditional knowledge is important and has been tested through times.

Set up a database with relevant information focusing on climate change and its impact on the Agroforestry sector and rural community people. RCF can work in collaboration with government agencies, non-governmental organizations or donor partners to successfully carry such monitoring activity.

Natural resource management

Proper management of natural resources especially coastal to terrestrial ecosystems should be prioritized. Coastal terrestrial forest plays a significant role as wind breakers, reduced salt content breeze or reduce saltwater intrusion to low laying coastal gardens. It is important to venture into terrestrial management of natural resources with **more focus on conserving areas of importance to food security**. Management of forestry should be inclusive of areas that have significant wild bush food trees, replanting of important food trees to increase local benefits.

Advocacy at all levels (community, provincial and national level)

The Roviana Conservation Foundation to continue to work with rural people in sharing information with the rural community people. Climate change awareness is an important aspect to inform people to be prepared and take appropriate adaptive actions.

Roviana Conservation Foundation (RCF) to share experiences and information from rural people with the National Government to focus more on adaptive measure now than later. RCF should take a pro-active stance to advocate for government recognition of rural people vulnerability and put into actions its policies. That the National Adaptation Plan of Action (NAPA) be community oriented and reaches the community level.

Access to information

Information accessibility on improved farming methods and technologies has been highlighted as lacking and important for villagers. There is a need for such information to be disseminated by the Ministry of Agriculture and Lands (MAL) or Kastom Garden Association (KGA) and other agencies. The national government through MAL, PACC Solomon Islands has priorities agriculture and food security as a development goal, such opportunities could be used to empower women, young people and men.

Organization such as Kastom Gaden Association (KGA) offers information and practical skills where farmers can be taught. An example is farmers are trained skills to produce their own quality seeds save them for later use or improving soil content.

Concluding Remarks

Communities in the Roviana Vonavona lagoon are already experiencing the effects of climate change. Consistent warming and wet weather trends, more frequent and intense extreme weather events have been observed and experience by Roviana Vonavona rural dwellers. There is a serious concern due to limited information on climate change facts to community individuals. Improving and reviving best practices to the agriculture sector especially with Agroforestry will help to build resilient communities, ecosystems and also improve the sensitivity of already stress food sources.

Increase lack of access to financial opportunities, essential services, coupled with lack of information on climate change, Agroforestry and stress to the natural environment are challenges that could undermine any adaptation strategies in country. Other important factor worth considering is the increase dependency on foreign or manufactured goods and negligence of the traditional agro forestry practices; Communities' dependency on the natural (wild) harvest of resources, few commodities such as copra, cocoa, betel nut etc for income generation is a concern as well; income generating base of families is quiet narrow. There will be more pressure on the government budgets, financial institutions for support in the longer term as impacts of climate change increases.

It is appropriate for adaptation measures to be localized. The Roviana Conservation Foundation (RCF) to be a leading figure in addressing climate change impacts in the Agroforestry sector in association with its resources management work. That the RCF vigorously work with partners, research and informed communities of current climate change information, improved adaptive measures to locally practice with less difficulty and culturally fit. Leveraging existing knowledge, skills and practices through research and information sharing is an important form of capacity development that add value to what is already practiced or exist in country.

Overall in the Roviana Vona vona lagoon, there exists the capacity for people to adapt to climate change given the right environment and opportunities. Reviving and strengthening the Agroforestry sector will bring benefits to food security, ecosystem services people's resilience and the natural processes. There are climatic related and external factors which people will live with, but aligning ones capabilities and learning to fit within the changes of events will strengthen the ability to cope and adapt.

ANNEX 1 - SUMMARY OF RECOMMENDATIONS

Detail recommendation for activities that could facilitate building a resilient agro forestry system. Leveraging existing knowledge in agro forestry and improving tolerant crop variety reduces introduction of new species. Enhancing ingenious food knowledge through improved technologies and local innovations can contribute to stronger adaptive capacity.

Management of natural resources, promoting agro forestry to improve conservation initiatives could improve local adaptive capacity. Educational promotion and awareness of existing climate change, its impact on agro forestry and farming systems.

Health and nutrition are important factors increasing population vulnerability, as more men, women and young people turned to imported goods as substitutes to local grown food.

SAFE GUARDING FOOD PRODUCTION - BETTER AGRICULTURAL PRACTICES & TECHNOLOGY	
Crop Diversity	Recommended Actions
Sweet Potato	Bulking of sweet potato and distribute to farmers. Bulking of improved sweet potato can be sourced from KGA. The high turnover of cultivars is a challenge to food security. Develop knowledge and skills in bulking of potato.
CASSAVA	Collection and bulking of varieties
TARO	Collection of lost all local taro varieties
PANA & YAM	Collect varieties and bulking of pana from central province Good of yams for bulking are the Kinabeo and African yam
BANANA	Promote more variety of bananas, establishing gene banks, promoting more nutritious orange flesh banana. Banana grow in any soil type and weather
VORUKU	Collect Voruku planting material from Vella la Vella for bulking and redistribution to farmers
KAKAKE	Promotion of swamp taro (kakake). There should be more activities in planting of the staple
Increase knowledge & skills in plant protection	Improved plant protection trainings for farmers; improved plant protection trainers for trainers

INTRODUCING &PROMOTING ADAPTATION TECHNOLOGIES **Low lying Farming techniques**	
Issue	**Action**
Increase knowledge on improved soil management	Introduction of soil management training for trainers' soil improvement technology for farmers. Farmers during the research process highlight across villages the status of soil low in nutrient content for different variety of food crops.
Introduce adaptive & CC tolerant crops sourcing and technologies	Technologies and innovations have been developed across the region and international arena. It would be beneficial for experts from organizations like SPREP or SIG –MAL to develop appropriate adaptation technologies and farming technique, sharing the skills and knowledge.
FOREST FOOD PLANNING, PROMOTION & MANAGEMENT - *Promoting bush and emergency food*	
Management & reviving fruit tree agro forestry	Develop forest food inventories and develop management plans to protect bush foods. Established fruit tree nurseries both domesticate and wild fruit trees which are capable of withstanding changes in weather or storms.
Integrating coastal and terrestrial agro forestry & forestry management	MPA programs to integrate agriculture and terrestrial management initiative using existing governance systems/structures.
LEVERAGING INDIGENOUS KNOWLEDGE AND SKILLS - skills and knowledge dissemination.	
Youth in agriculture	Identify community champions and provide attachment training for youths with Vanga and Abaca Rural Training Centres. Introduce skills training in agriculture areas including small livestock's and vegetable training for youths
Developing vegetable seed banks	Provide seed saving attachments programs with active farmers in farmers schools. Seed banks development requires trainings and skills transfer. Farmers gain practical experience in exchange programs or having skills, practical farmers to teach them.
Establishing Farmers marketing network	Established an exchange program with women of Roviana with Kolei women's farmers market network Establish farmers network
Farmers exchange programs	Conduct exchange farmers with Vanga Rural Training Centre,KGA farmer field schools
HEALTH AND NUTRITION	
Healthy lifestyle, population and nutrition promotion	Improve back yard gardening and village trainers to access vegetables and nutrition greens. Provide small grants to health workers to carry out community awareness programs Liase with st Helena Goldie hospital

ANNEX 2 – COMMUNITY ASSETS

Villages/Assets	Infrastructure/physical Assets	Financial Assets	Natural Assets	Social Assets	Human Asset
Villages/Assets	Infrastructure/physical Assets	Financial Assets	Natural Assets	Social Assets	Human Asset
Baraulu (Kalikile)	OBM, wooden Canoe (transportation), school, water supply, aid post, church	cocoa planting, market garden produce and marine products (fish, shells) Copra, handicrafts, pigs chickens	land, garden	women's group, church, sport groups	primary school, RTC, strong social networks
Bulelavata (kalikile)	OBM, canoe, land, hydro, water supply, school	Copra, marketing (marine & gardens products)	Flat fertile land, nut trees	women's groups, church, community well organized	primary, secondary school, RTC, graduates, small population, strong social network
Buni (Kiko)	OBM, Canoe, Shipping accessibility, clinic, women's centre, community hall, church	Cocoa, teak (reforestation),market goods sea & garden),wages at Noro, copra, hand crafts, livestock (pig & chicken)	Land, forest and swamp available	Women's group, social/sports groups, church, good community leadership	Primary/secondary/RTC school, women resources centre, family networks
Dunde (Buki)	OBM, Canoe, transport accessibility (ship, plane) hospital, banks (urban centre),clinic, electricity, phone, wharf, church, community hall	Cocoa, marketing (cooked food, marine & garden produce),copra, hand crafts, livestock (chicken/pig)	Land and forest available	Women's group, youth sports group, church, family focus affairs (hard to gather community people)	Primary, secondary & RTC schools, play field, strong family ties
Kindu (Kiko)	OBM, Canoe, ship, plane,	Cocoa, teak, market marine & garden	Land (food source – gardens) available,	Women's group, youth sports group, church,	Primary, RTC, graduates, family social

	bank, hospitals, schools, primary/community high schools, hospital, women's centre, phones, roads, community hall, church	produce –cooked food, copra, arts & crafts, livestock (pig/chicken),wages	marine food services, logging	family focus affairs (hard to gather community people)	networks
Ludumaho/Bibolo (Kiko)	Banks, plane, ship, OBM, shops, schools, hospital, water supply, road, phone, Noro, shops	Fish bait ground, market –cooked food, garden and marine, betel nut, wages, copra, arts & crafts	Garden (low yield),gravel & hilly (mountainous) land	Primary, secondary, RTC schools, strong family ties	Women's group, sports group, church, no strong community support
Nusa Hope (Kalikile)	OBM, canoe (transport accessible),school, water supply, aid post	Cocoa, marketing – garden/marine products, copra, handicrafts, livestock	Fertile land	Women's groups, youths/sports/church groups established	Primary, secondary, RTC, strong community networks
PATMOS (Kalikile)	OBM, canoe, school, hospital, water supply, women centre, meeting hall, road, phone, Noro, shops	Shell (pongu podu), fish, shells, arts & craft, pig. chicken, B mobile tower rent	garden, land, gravel hill land	women's group, church, sport groups, good community leaders	primary school, RTC, strong social networks, women centre

Annex 3 – Issues and vulnerabilities

Villages/Issues, Vulnerability	Community issues and vulnerabilities highlighted affecting the Roviana Vonavona region	
	Community Priority Issues	**Vulnerability Issues with Agro forestry identified**
Baraulu (Kalikile)	• Low crop diversity in gardens • Poor yield of sweet potato • Pest and disease are the major problem in their garden. • Soil infertility lacking knowledge and skills how to regenerate soil. • Organic farming practices and techniques are not well adopted. • Cash crop like cocoa, coconut and teak planting are taking place inside the garden sites. • No information on correct agricultural practices. • Land use management skills- composting, mulching and crop rotation are limited. • Rats and frogs destroy garden crops. • Women are over worked. • Youth and young couples are not taking up responsibilities on food production. • Lack of agricultural information and advices. • Lack of proper sanitation. • Experience short term hunger period. • Move to main land to access reserve land. • Increase population and teenage pregnancy. • Increase abuse of legal and illegal drugs among young people.	• Shortage of land for planting • Sea level rise • Low diversity of root crops and vegetables, including fruit trees. • Highly depended on imported food as their source. • Extreme weather patterns - long dry seasons and very heavy rain falls.
Bulelavata (kalikile)	• Low crop diversity in garden. • Poor yield of sweet potato. • Pest and disease is only starting but need to be controlled. • Organic farming practices and techniques are not well adopted. • Cash crop like oil palm and teak planting are taking planted inside garden sites. • No information on agricultural issues. • Land use management-composting, mulching and crop rotation are limited. • Women are over worked. • Youth are not participating in garden activities as much. • Lack of agricultural information and advices. • Lack of proper sanitation. • Experience short term hunger period. • Tend to eat introduced foods. • Increase population and teenage pregnancy. • Change of weather patterns.	• Semi-intensive cash cropping - palm oil and teak planting in garden areas. • Prevalence and increase of pest and diseases on plants just starting. • Low diversity of root crops and vegetables including fruit trees.

Buni (Kiko)	• Low crop diversity in gardens. • Poor yield of sweet potato. • Pest and disease are the major problem in their garden. • Soil infertility lacking knowledge and skills how to fix back soil. • Organic farming practices and techniques are not well adopted. • Cash crop like cocoa and teak planting is taking planted inside garden sites. • No information on agricultures issues. • Land use management information lacking. • Rats and birds destroy garden crops. • Women are over worked. • Youths are not fully participating in garden activity. • Lack of agricultural information and advices. • Lack of proper sanitation. • Experience short term hunger period. • Use well for most water needs. • Wells are becoming salty. • Increase population. • Increase teenage pregnancy. • Increase abuse of legal and illegal drugs.	• Shortage of land for planting on the island. • Sea level rise. • Low diversity of root crops and vegetables including fruit trees. • Highly depended on imported food as their source. • No proper water supply except for wells.
Dunde (Buki)	• Low crop diversity in gardens. • Poor yield of sweet potato. • Pest and disease are the major problem in their garden. • Soil infertility lacking ways how to regenerate soil. • Organic farming practices and techniques are not well adopted. • Cash crop like cocoa and teak planting is taking place inside garden sites. • Not using the information from nearby agriculture office. • Land use management skills are not available. • Birds and insects destroy garden crops. • Women are over worked. • Youths not fully participating in garden activities. • Lack of agricultural information and advices. • Not enough proper sanitation. • Experience short term hunger period. • Increase population. • Agriculture officers need to reach out to community. • Increase population and teenage pregnancy. • Increase abuse of legal and illegal drugs. • Marine products scarce due to large population.	Shortage of land nearby for planting other garden area is inland. Sea level rise on houses near the sea. Low diversity of root crops and vegetables, including fruit trees. Highly depended on imported food as their source. Logging is inland. Lack of a proper water supply.
Kindu (Kiko)	• Low crop diversity in gardens. • Poor yield of sweet potato. • Pest and disease are the major problem in their garden. • Soil infertility lacking knowledge and skills to	• Garden land is further inland and use nearby garden areas repeatedly. • Sea level rise on houses near the sea.

	regenerate soil. • Organic farming practices and techniques are not well adopted. • Cash crop like cocoa and teak planting is taking planted inside garden sites. • No information on agricultures issues. • Land use management crop rotation, composting and mulching is limited. • Rats and birds destroy garden crops. • Women are over worked. • Youth and young couples are not fully participating I garden activities. • Lack of agricultural information and advices. • Lack of proper sanitation. • Experience short term hunger period. • Increase abuse of Home brew and other legal drugs. • Teenage pregnancy is high. • Increase population. • Leaders lack of leadership skills to handle social problems. • Increase abuse of legal and illegal drug.	• Logging is taking place inland. • Low diversity of root crops and vegetables, including fruit trees. • Highly depended on imported food as their source.
Ludumaho/Bibolo	• Low crop diversity in gardens. • Poor yield of sweet potato. • Pest and disease are the major problem in their garden. • Soil infertility lacking knowledge and skills how to regenerate soil. • Organic farming practices and techniques are not well adopted. • No information on agricultures issues. • Land use management knowledge and skills lacking. • Birds destroy garden crops. • Lack of agricultural information and advices. • Not enough proper sanitation. • Experience short term hunger period. • Use wage to buy food from shops. • Less community support and leaders have a dominating. • Increase population and teenage pregnancy.	• Fertile land is further inland. • Logging is taking place inland. • Sea level rise on Lodumaho which is near the sea. • Low diversity of root crops and vegetables including fruit trees. • Highly depended on imported food as their source. • Bibolo village is inland but too close to the main road. • Surrounding villages harvesting marine products from us. • Large clearing on the airport nearby. • Fishing boats harvesting bait fish. • No proper rubbish dump.
Nusa Hope	• Low crop diversity in gardens. • Poor yield of sweet potato. • Pest and disease are the major problem in their garden. • Soil infertility lacking knowledge and skills how to regenerate soil. • Organic farming practices and techniques are not well adopted. • Cash crop like cocoa and coconut, teak planting is taking place inside garden sites. • Land use management is lacking.	• Shortage of land for planting • Sea level rise. • Low diversity of root crops and vegetables, including fruit trees. • Highly depended on imported food as their source. • Village is overcrowded and no proper sanitation.

	• Rats and frogs destroy garden crops. • Women are over worked. • Youth. • Very dry and wet seasons experienced. • Lack of agricultural information and advices • Lack of proper sanitation. • Experience short term hunger period. • Move to new village site in the main land. • Increase population and teen age pregnancy. • Lack of land on the island for expansion and or plant fruit trees. • Lack of playing ground except the sea. • Increase abuse of legal and illegal drugs among youths.	
PATMOS	• Low crop diversity in gardens. • Poor yield of sweet potato. • Pest and disease are the major problem in their garden. • Soil infertility lacking how to fix back soil. • Organic farming practices and techniques are not well adopted. • Cash crop like cocoa and teak planting is taking planted inside garden sites. • No information on agricultures issues. • Land use management knowledge o composting, mulching and crop rotation. • Rats and frogs destroy garden crops. • Women are over worked. • Increase population and teenage pregnancy. • Lack of agricultural information and advices. • Lack of proper sanitation. • Experience short term hunger period. • Change of weather patterns.	• Shortage of land for planting • Sea level rise • Low diversity of root crops and vegetables including fruit trees. • Highly depended on imported food as their source

ANNEX 4:-STATUS OF FOOD SOURCES, CROP DIVERSITY AND ABUNDANCE IN THE BUKI REGION[3].

Food Sources of the Buki region

DUNDE, BUKI REGION			
Sources of food	Type of food	scores	Reason for score
Garden	Kumara/Sweet Potato	5	Popular staple in communities and have been used in kitchens
	Cassava	5	
	Karuvera	3	
	Slippery Cabbage	3	Important staples but were not planted as should be in the gardens
	Pana	2	
	Taro	2	
	Carver	2	
	Yam	1	
Sea/Reef	Fish	5	
	Mie	1	
	Glum	1	
	Ununusu	1	
Mangrove (Pet'petu)	Vua Petu	2	
	Kapehe	1	
	Riki	1	
	Deo	1	
Store	Rice	5	Important food stuff in families diets.
	Flour	5	
	Noodle	5	
	Taiyo	5	

[3] The Buku region is inclusive of Dunde, Egholo of Rendova, Kindu, and Lambete

Food abundance in BUKI Resources Management region.
The table details different food crops and the commonality of those crops.

Food crop	Name of varieties	Status: VC – Very common: C – Common: R –Rare: L - Lost	Growing condition: Dry/hot weather, longlivity, PD resistant
Kumara/Sweet Potato	Ena Rimata	C	Grows properly in all weathers, dry and wet soil. Good production in dry seasons. Planting to harvest periods in 3-6 months.
	Bakua luzu	VC	
	Hako boni	C	
	Nibi	L	
	Kausu mae	L	
Cassava/Tapioka	Green Top	C	Grows properly in all types of soils and in dry weather condition. Average growth to harvest period 3-6 months
	PNG	VC	
	Yellow	C	
Yam	Yam tonge	VC	Rarely planted, average planting to harvest period is 6 months
BANANA	Hakua tari	C	Grow well in any condition and soil types. Average planting to harvest period is 6 – 12 months, common 6 monthly varieties in farmers gardens
	Hakua Fiji	C	
	Richard Hakua	C	
	Hakua Book	C	
	Hakua Pedi	C	
PANA	Pepol Pana	C	Grow well in dry weather. Average planting to harvest period is 6months
	White Pan	C	

Food sources of EGHOLO, Rendova

EGHOLO, BUKI REGION			
Sources of food	Type of food	scores	Reason for score
Garden	Cassava	5	Grow in any season and any soil type
	Yam	5	Seasonal, grow well in any time of the year
	Pana	5	Seasonal
	Banana	3	Grow well in any season and soil type but production is less due to pests
	Pineapple	5	Seasonal –during months of Nov – Dec
	Taro	2	Pests destroy taro tubers (ground bettle)
	Karuvera	3	Depends on type of soil that is planted in
	Kumara/Sweet Potato	3	Grow well during dry seasons and depend very much on soil type

	Slippery Cabbage	3	Pests destroy cabbage (leave roll, bettles etc)
Sea/Reef	Fish	5	Depends on good time to catch,too many fishermen and fish is hard to catch as well.
Mangrove (Pet'petu??)/Mud	Ghorehe	5	Not seasonal
	Rime	5	No season
	Mangrove fruit (Petu)	3	Has season
Store	Rice	4	
	Flour	4	Store goods depend on money, but have played an important diet in family food production
	Noodle	4	
	sugar	4	
	Salt	4	
	Taiyo	4	

Food abundance in BUKI (Egholo) Resources Management region.
The table details different food crops and the commonality of those crops.

Food crop	Name of varieties (Roviana Names)	Status: VC – Very common: C – Common: R –Rare: L – Lost	Growing condition: Dry/hot weather, longlivity, PD resistant
Kumara/Sweet Potato	Maruana	C	Grows properly in all weathers Grows well in dry and wet soil Mature in 3 months.
	Bakua luzu – 3mnth	C	
	Hako boni – 3 mnth	C	
	sugar	L	
	Paradise	L	
	Jimei	L	
	Reef	L	
	Kori Popu	L	
	Under Pan	C	
	Yellow tombe	R	
Taro	Goliti	VC	All varieties grow well in both dry and wet weather, Malaita in dry weather condition
	Jijiri	C	
	Malaita	L	
	Voruku	C	
BANANA	Sugar	VC	Grow well in any condition and soil types. Particularly good growth and production in dry weather condition
	Hakua Viti – 6 month	C	
	Richard Hakua -6month	C	
	Dai Tuna	VC	
	Sikili	VC	

BUKI RESOURCES MANAGEMENT (KINDU) FOOD SOURCES

Source of Food	Type of Food	Score (1-5)	Reason for score given
Gaden	Kasava	5	Good yield
	Pawpaw	5	Well accepted market
	Banana	5	Good growth & yield
	Bean	4	Market
	Bush Cabbage	3	Insect attack
	Peanut	3	High Demand but planted frequent
	Shallot	3	High demands but poor growth
	Potatoe	3	Decline yield ,Insect, Infertile ,over use of soil
	Tomatoes	3	Seasonal crop market
	Pana	2	Long Term Crop (6 mnth)
	Pumpkin	2	Seasonal
	Yam	2	Long term
	Egg plant	2	Market not accepted
	Karuvera	2	Not grow well
	Taro	2	Not grow well
Forest	Kane /Lokote	2	Not many
	Leqe	2	Not Commonly harvested
	Muduku	2	Scarce
	Pig	3	Occasionally hunting
Swamp	Gohere	3	Few farmer – plant
	Talo ene	3	Few farmer – plant
	Water grass	3	Market
	Kosikosiri	2	Market
Mangrove	Deo	5	Normal Diet
	Riki	5	Scarce
	Ropi	3	Growing favourite
	Dive	4	Papo/extinct
	Kuravaho	1	Papo/extint
	Mud Crab	1	market

Buki (KINDU) Crop variety and Abundance

Food crop	**Name of Varieties known by group**	**Status: Very Common – VC: Common –C: Rare-R,LOST – L**	**Growing condition dry/wet condition Stay long time PD resistant**
Potatoe	Bakua	C	Dry
	Bilua	C	Both Dry & ery
	Qula	C	Attack by birds
	Lebiasi	L	Dry
	Nibi	L	Stay long
	Boboe	L	PD Occasion
	Engarimata (red)	C	PD Occasion
	Engarimata(white)	C	PD Occasion
Pana	Rakihi/ragomo	C	Dry
	Leqata	R	Stay long
	Hokara	C	Dry & Wet
Banana	Ugi	R	Not stay long
	Pedi	C	Wet /dry
	Galekana	C	Staylong
	Vuaturu	R	Beetle attack
	Pithara	C	Wet/dry
Kasava	Green Top	C	Wet /dry
	Curry	C	PD resistance, Wet/dry
	One boil	C	Wet/dry, Not stay long

Risk identified, BUKI Region

Risk Identified	Priority (L,M,H)	Which areas are affected	Priority action to manage these risks.
Soil Degradation through slash and burn, over use of same areas and erosion of top soil	H	Immediate areas of gardening behind village	To move inland Organic Farming
Continuous rain increase flooding of gardens	M	Low Ground	Proper Drainage Move to high ground
Prevalence of pests(insects) in gardens, destructive to farm crops	M	Garden areas	Plant merry gold Apply ashes Plant marijuana

Food sources of Lambete, Buki Region

Source of Food	Type of Food	Score 1-5	Reason for score given
Market	Potato	5	Main food
	Cassava	5	Main food
	Swamp taro	5	Main food
	Banana	5	Main food
	Yam	1	Season food
	Taro	1	Season food
Vegetable	Slippery cabbage	2	Depend on farmers Vegetables.
	Tomatoes	1	
	Saladier	1	
	Sweet pepper	1	
	Taro leaf	1	
Store	Rice	5	Main food
	Taiyo	5	Main Protein
	Noodles	5	Main food
	Biscuits	5	
	Mince meat	1	Expensive
	Chicken meat	1	Expensive
	Sweet biscuits	1	Expensive not good for health
	Sugar, milo	1	
	Flour	1	
Fishery	Fish	5	Main Protein

Crop abundance for Lambete of the Buki Resources Management Region.

Food crop	Name of Varieties known by group	Status: Very Common –VC: Common –C: Rare- R,LOST – L	Growing condition dry/wet condition Stay long time PD resistant
Potato	Bakua -6 months	VC	Variety can perform well during dry seasons/weather, average growth and harvest 3 -6months.
	Barasipo – 3 months	VC	
	Hako Boni- 6 months	L	
Swamp Taro	Swamp Taro	R	Stay long time on wet or dry weather. Average harvest period is about a year
	Voruku	R	
Banana	Tamora	C	The different variety performs well during dry seasons/weather. Average growth to harvesting is about six months
	Richard	VC	
	Tiobea	C	
Yam	Vanuatu	C	Crop can perform during dry weather/season, take up to 8 months for harvest
Cassava	One boil	VC	Variety can perform during dry weather/season, average harvesting period is 3 months
	Bougainville	C	
	Curry Cassava	VC	Stay Long

Risk Identification and analysis

Risk Identified	Priority (L,M,H)	Which areas are affected	Priority action to manage these risks.
Farmers not attend because of Weather	M	Rendova	Organizing network among women

Annex 5 – Crop Diversity and Seasonal Calender– Kalikile Resources Management Region (A)

Months / Food Type	Jan	Feb	mar	April	may	June	July	aug	sept	Oct	Nov	Dec
Cassava	P/H	P	P/ H	P /H	P/H	P	P/H	P	H		P/H	H
Banana	P/H	P/H	P	P		P/H	P	P	H	P/H	P	P
Tomato		P/H	P	P	P/H	P/H			H		H	P
Cabage		P/H	P/H	P/H	P/H	P/H	P/H				P	
Taro	P		P	H		P	P/H	P		P		P
Potato	P/H	P	P	P	P/H	P/H	P/H	P/H	P	P	P/H	P/H
Bean	P	P	P	P/H	P/H	P/H	P/H	P	H			
Vanuatu/African yam	P	P				P						
Kakake		P			P	H	P					P
Pana	P	P		P		P/H	P/H					H
Karovera		P			H	P					H	
Yam local									P			
Peanut	P	P/H	P	H			P/H				P/H	
Corn												
Chilli Paper	P	P	P		P/H	H	P	P	P			H
Pumpkin		P	P		P	P	P/H			P	P	P
S/ calendar	Sun/Rain			Hot Sun		Rain/Sun	Heavy rain/Wind			Windy Rain		
Crop Harvesting	Good Harvesting Time			Food Shortage Bad harvesting					Good Harvesting time			

Buki Resources Management Region

Key: P – Planting Periods; H – Harvesting periods Climate Change Adaptive alternatives –Rice, Kakate, Lokete, Kalavera

Months Food Type	Jan	Feb	mar	apri	may	june	july	aug	sept	Oct	Nov	Dec
Vuruku	P	P	P						H			H
Kakake	P	P		P	P							H
lokete		P										H
Kalovera	P	P	H	P	P	P/H	P		H			H
Potato	P	P	P/H	P/H	P	P/H	P	P/H	P	P	P/H	P
Yam		H		P		H			P	H	P	
Cassava	P	P	P/H	P	P	P/H	H/P	H/P	H/P	H	H	
Banana	P		P		P	H	H	H	P	H		
Bean	P	P/H	P	P	P/H	P/H	P/H	P/H	P/H	P/H	P/H	P
Slippery Cabbage	P	P	P/H	P/H	P/H	H		P	P/H	P	P	P/H
Taro	P	P/H		P	1		H	P		P	P/H	
Pana	P	P	P	P/H	P	P	P/H	P/H		P	P	
Annual weather patterns	Rainy period				Sun/rain (not too heavy light)							
						Dada Sunny - really dry season/rain someday & period of dry						
Yield production of crops	Bad Times/Less fruit		Good fruit	Medium food production		Masuku – good food production					Masuku – good food production	
Planting	Good planting		Best Planting	Mixture of planting events – good and bad planting months during the year								
Hangere Period	No good fruit			Medium hangere time				Medium Hangere time				

ANNEX 6 –FLORA CHECKLIST: COASTAL AND MANGROVES PLANTS

Scientific Names:	Family:	Plant Type:
1. *Aegicerus corniculatum*	*Aegiceratаceae*	*Shrub/Tree*
2. *Acanthus ebracteatus*	*Acanthaceae*	*Shrub/Herb*
3. *Acanthus ilicifolius*	*Acanthaceae*	*Shrub/Herb*
4. *Avicennia marina*	*Avicenniaceae*	*Tree/Shrub*
5. *Avicennia sp. Nov?*	*Avicenniaceae*	*Tree/Shrub*
6. *Barringtonia asiatica*	*Lecythidaceae*	*Tree*
7. *Bruguiera cylindrica*	*Rhizophoraceae*	*Tree*
8. *Bruguiera hainsii*	*Rhizophoraceae*	*Tree*
9. *Bruguiera gymnorhyza*	*Rhizophoraceae*	*Tree*
10. *Bruguiera parviflora*	*Rhizophoraceae*	*Tree*
11. *Calophyllum inophyllum*	*Clusiaceae*	*Tree*
12. *Ceriops tagal*	*Rhizophoraceae*	*Tree/shrub*
13. *Cycas rumphii*	*Cycadaceae*	*Cycad/Palm-like*
14. *Buchanania arborescense*	*Anacardiaceae*	*Tree*
15. *Decaspermum sp.*	*Myrtaceae*	*Tree/Shrub*
16. *Excoecaria agallocha*	*Euphorbiaceae*	*Tree/Shrub*
17. *Intsia bijuga*	*Caesalpiniaceae*	*Tree*
18. *Lumnitzera littorea*	*Combretaceae*	*Tree/Shrub*
19. *Macaranga dioica*	*Euphorbiaceae*	*Tree/shrub*
20. *Ficus septica*	*Moraceae*	*Tree/Shrub*
21. *Ficus variegata*	*Moraceae*	*Tree/Shrub*
22. *Ficus wassa*	*Moraceae*	*Tree/Shrub*
23. *Pemphis acidula*	*Lythraceae*	*Shrub/Small tree*
24. *Premna corymbosa*	*Verbenaceae*	*Tree/Shrub*
25. *Timonius pulposus*	*Rubiaceae*	*Tree/Shrub*
26. *Timonius timon*	*Rubiaceae*	*Tree/Shrub*
27. *Syzygium sp.*	*Myrtaceae*	*Tree/Shrub*
28. *Scaevola floribunda*	*Goodeniaceae*	*Shrub/Small tree*
29. *Scaevola taccada*	*Goodeniaceae*	*Shrub/Small tree*
30. *Dolichandrone spathacea*	*Bignoniaceae*	*Tree*
31. *Nypa fruticans*	*Arecaceae*	*Mangrove Palm*
32. *Sonneratia alba*	*Sonneratiaceae*	*Tree*
33. *Sonneratia caseolaris*	*Sonnneratiaceae*	*Tree*
34. *Rhizophora apiculata*	*Rhizophoraceae*	*Tree*
35. *Rhizophora mucronata*	*Rhizophoraceae*	*Tree*
36. *Rhizophora stylosa*	*Rhizophoraceae*	*Tree*
37. *Rhizophora X lamarkii*	*Rhizophoraceae*	*Tree*
38. *Heritiera littoralis*	*Sterculiaceae*	*Tree*
39. *Hibiscus tiliaceus*	*Malvaceae*	*Tree*
40. *Tournefortia argentea*	*Boraginaceae*	*Tree/Shrub*
41. *Terminalia catappa*	*Combretaceae*	*Tree*
42. *Xylocarpus granatum*	*Meliaceae*	*Tree*
43. *Acrosticum speciosum*	*Pteridaceae*	*Mangrove Fern*

44. *Cordia subcordata*	*Ehretiaceae*	*Tree*
45. *Desmodium umbellatum*	*Fabaceae*	*Tree/Shrub*
46. *Derris trifoliata*	*Fabaceae*	*Vine/Creeper*
47. *Pandanus compressus*	*Pandanaceae*	*Pandanus*
48. *Terminalia sp.*	*Combretaceae*	*Tree/Shrub*
49. *Alstonia spectabilis*	*Apocynaceae*	*Tree*
50. *Rhus taitensis*	*Anacardiaceae*	*Tree*
51. *Diospyros sp.*	*Ebenaceae*	*Tree/ Shrub*
52. *Morinda citrifolia*	*Rubiaceae*	*Tree*
53. *Alpinia oceanica*	*Zingiberaceae*	*Herb*
54. *Alpinia purpurata*	*Zingiberaceae*	*Herb*
55. *Litsea perglabra*	*Lauraceae*	*Tree*
56. *Flagellaria gigantea*	*Flagellariaceae*	*Climber/Herb*
57. *Myristica fatua*	*Myristicaceae*	*Tree*
58. *Wollastonia biflora*	*Asteraceae*	*Shrub/Herb*
59. *Pleomele angustifolia*	*Liliaceae*	*Herb/Shrub*
60. *Euodia elleryana*	*Rutaceae*	*Tree/Shrub*
61. *Melochia umbellata*	*Sterculiaceae*	*Tree/Shrub*
62. *Cananga odorata*	*Annonaceae*	*Tree*
63. *Casuarina equisetifolia*	*Casuarinaceae*	*Tree*
64. *Phyllanthus sp.*	*Euphorbiaceae*	*Tree/Shrub*
65. *Sophora tomentosa*	*Fabaceae*	*Tree/Shrub*
66. *Erythrina sp.*	*Fabaceae*	*Tree*
67. *Cassytha filiformis*	*Lauraceae*	*Creeper/Epiphytic*
68. *Pandanus lamphrocephalus*	*Pandanaceae*	*Pandanus*
69. *Scyphiphora hydrophylacea*	*Rubiaceae*	*Shrub*
70. *Spathoglottis plicata*	*Orchidaceae*	*Orchid/Herb*
71. *Thespesia populnea*	*Malvaceae*	*Tree*
72. *Vitex trifolia*	*Verbenaceae*	*Tree/Shrub*
73. *Guettarda speciosa*	*Rubiaceae*	*Tree*
74. *Inocarpus fagifer*	*Fabaceae*	*Tree*
75. *Hernandia nymphaeifolia*	*Hernandiaceae*	*Tree*
76. *Crinum asiaticum*	*Amaryllidaceae*	*Herb*

CHAPTER 8

ASSESSMENT OF VULNERABILITY AND ADAPTATION

Kirsten Abernethy

KEY MESSAGES

- Local experts indicate climate change is not the primary concern for the future wellbeing of Roviana people
- Major factors contributing to vulnerability of Roviana are:
  - Changing values
  - Decrease in food security
  - Increase in youth issues
  - Resource depletion
- Government and NGO support needed **alongside** community efforts to address threats
- Need to increase local awareness of climate change impacts

OVERVIEW

This chapter summarises activities carried out by the WorldFish Center, subcontracted to University of Queensland (UQ), as part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program (PASAP) in Roviana and Vonavona Lagoons, Solomon Islands.

An indicator approach to vulnerability assessment developed by WorldFish has been adapted and applied in Roviana and Vonavona lagoons by UCSB researchers led by Dr Aswani. This will be reported on by UCSB. While the indicator based questionnaire approach is effective at identifying community level vulnerability, its time consuming nature has limitations for adaptation planning. Accordingly WorldFish has also developed an expert elicitation methodology to inform adaptation planning at the lagoon scale.

Based on PASAP project findings and current climate change predictions, four important climate changes and their likely impacts on the region were identified and used in an expert elicitation to further understanding of how Roviana communities could adapt to climate change in the face of other drivers of change, the types of options that may be feasible, and the constraints to adaptation.

The expert elicitation identified that the most important issues requiring urgent action were not necessarily climate change related but rather included changing value systems, decreasing food security, increasing youth problems, and resource degradation. In order to address these issues, almost all solutions suggested by experts required outside support from NGOs and government commitment and assistance alongside community engagement. Experts gave advice on how adaptation to climate change could be mainstreamed into activities that enhance capacity of communities, including raising awareness, building strong resources and communities to be resilient, using the existing structures and knowledge available in communities, and targeting women and youth.

This research begins to identify climate change adaptation options within the broad Roviana context, and provides advice from experts on suitable ways forward for planning. The next step requires a participatory approach and long-term engagement between communities, local and national organizations and government to appraise options, make decisions, and implement a process of mainstreaming adaptation to climate change.

Findings will be presented to the Roviana Conservation Foundation for use in their planning activities with communities, to the CTI National Coordinating Committee (NCC) and the Solomon Islands Government Climate Change Working Group (CCWG).

INTRODUCTION

As part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program (PASAP) aims to enhance the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans, mainstream adaptation into decision-making, and inform robust long-term national planning and decision-making in partner countries. The Department of Climate Change and Energy Efficiency contracted University of Queensland (UQ) and University of California, Santa Barbara (UCSB) to lead the project: "Building social and ecological resilience to climate change in Roviana, Solomon Islands" (2010-2012). Under this project

The WorldFish Center was subcontracted to undertake outputs 5 and 6 of Objective three: (5) Review of climate change evidence and projections for the study area (Brokovich and Schwarz 2011) and (6) Vulnerability and adaptation assessment for the study area. This report addresses the second of these and outlines the methods used and the results.

In 2010 WorldFish developed and tested an indicator based vulnerability assessment methodology under the USAID Coral Triangle Support Partnership (CTSP) funding to Solomon Islands. In context of there being few environmental data available to determine differential exposures to climate change and variability at the community scale, the focus of the assessment was on indicators of the capacity of coastal communities to adapt in both a generic sense and to climate variability. After being piloted by WorldFish in a small number of communities under CTSP, the methodology was then adapted for Roviana and Vonavona Lagoons by UCSB researchers led by Dr Aswani. Under PASAP, UCSB researchers collected data using questionnaires in seven communities and WorldFish has partnered with USCB to make a significant contribution to analysis of this data which will be presented in PASAP reports prepared by USCB.

While the questionnaire and indicator approach is effective at identifying community level vulnerability, it's time and resource consuming nature has limitations for adaptation planning. Accordingly, through PASAP WorldFish has also focused on developing appropriate methodology to incorporate the adaptation planning component of vulnerability and adaptation assessment. The development and application of the methodology for Roviana Lagoon is presented in detail in this report.

Findings will be presented to the Roviana Conservation Foundation (RCF) for use in their planning activities with communities. In addition the results of this research will be presented to the CTI National Coordinating Committee (NCC) and the Solomon Islands Government Climate Change Working Group (CCWG) to inform future prioritization of adaptation assistance to RCF and the communities of Roviana and Vonavona lagoons.

BACKGROUND

In the last ten years, the emphasis for climate change research and action has shifted from one of mitigation to adaptation. Adaptation to global climate change in the human context can be defined as "a process, action or outcome in a system such as a household, community, group, sector, region, or country, that enables the system to better cope with, manage or adjust to actual or expected climatic stimuli, their effects or impacts (stress, hazard, risk or opportunities)" (Smit et al. 2000, Smit and Wandel 2006).

A recent World Bank report found that the global costs of adaptation would be in the range of USD75–100 billion per year between 2010 and 2050 (WorldBank 2010) and the UNFCCC predicts that by 2030 developing countries would need USD27-66 billion per year to adapt (UNFCCC 2007), a figure reported to be an underestimation (Parry et al. 2009). In the Solomon Islands National Adaptation Plan of Action , it was estimated priority sectors require USD17 million to get adaptation to climate change projects underway (Solomon Islands Government 2008). In the past few years, Solomon Islands has been active in establishing the institutions required to address climate change, including the restructuring and staffing of the Ministry of Environment, Climate change, Disaster Management and Meteorology (MECDM), and attracting necessary project funds. However, due in part to a lack of capacity to mobilise funds and ground truth suitable methodologies, adaptation activities are still in planning stages and have been slow to be implemented.

DEFINITION OF ADAPTATION

There are multiple definitions of adaptation in the literature and in policy documents and these can be interpreted and employed in a number of ways. It can be confusing, therefore it is essential to be clear and define terms, concepts and assumptions that will be used prior to an assessment as this will influence what will be measured, how it will be measured, who can use the information produced and how (Winograd 2005). This section defines what is meant by adaptation to climate change. The next section defines what we believe to be an appropriate approach to think about climate change adaptation given WorldFish experience in the Solomon Islands and current debate. This approach framed the methods used to elicit the data presented and discussed.

Adaptation to climate change can occur along different dimensions. It can be defined by the spatial scale, by the sector of interest, by the phenomenon of interest (e.g. social, biological), by action type (e.g. technological, institutional, legal, educational and behavioural), and by temporal scale (e.g. adapting to climate changes occurring in the immediate, short or long-term time scales). Adaptation itself can manifest in many ways. It can be undertaken by an individual for their own benefit, it can be actions by organizations or groups to meet collective goals, or it can be made up of actions by governments and public bodies to protect their citizens (Adger et al. 2005). Adaptation has also been defined as autonomous or planned (IPCC 2007). Autonomous adaptation does not constitute a conscious response to climatic stimuli, but rather is a response triggered by ecological changes in natural systems and by market or welfare changes in human systems. Planned adaptation is the result of a deliberate decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain or achieve a desired state.

VULNERABILITY AND ADAPTIVE CAPACITY

Adaptation to climate change is intimately associated with concepts of vulnerability and adaptive capacity. According to the IPCC, vulnerability is “a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.” (McCarthy et al. 2001 p.995). In IPCC terminology, exposure refers to the nature and degree to which a system is exposed to significant climatic variations, and sensitivity is the degree to which a system will respond to a change in climatic conditions. Adaptive capacity is the ability of a system to evolve in order to accommodate climate changes or to expand the range of variability with which it can cope. Adaptation is an action or change in behaviour that will either a) reduce exposure – generally mitigation measures, b) reduce sensitivity – often a measure to reduce dependence on resources impacted by climate change, or c) enhance adaptive capacity that increases actor’s ability to make adaptation decisions. This can also be taken a step further to transform capacity into action and implement decisions. This study, which attempts to identify options for adaptation in Roviana and Vonavona lagoons at the community level, focuses on adaptation measures that enhance adaptive capacity. There are several reasons for this focus (outlined further in the Methods Development section), including the fact that it is difficult to address exposure at the community scale, when the causes of the changes occur elsewhere in the world and mitigation needs to occur there. It is also difficult to address reducing dependence on resources when there are few alternatives for communities for livelihoods and the dependence for food security is great. Thus, addressing adaptive capacity is assumed to be the most feasible focus at the community-scale.

COMMUNITY-BASED PRACTICAL ADAPTATION

The focus of this study was to examine the role of climate change adaptation at the community level, and to assess the feasibility of practical initiatives identified by communities. Community-based adaptation (CBA) is a 'bottom up' approach to research and development that is lead by the community and driven by community needs. The investigation of the adaptive capacity and the adaptive needs within communities assists them to identify possible adaptation initiatives and means of enhancing adaptive capacity, which are tailored to their needs. There has been relatively little research on the processes that facilitate practical implementation of adaptation at the community level. However, although it is not called 'adaptation', there are close links with the process of implementation of community-based natural resource management initiatives, and some of the lessons from this area of research are pertinent. Fundamental lessons that have been learned about CBA are: (i) the dimensions of adaptation need to be defined, (ii) the determinants of adaptive capacity are defined by the communities themselves, (iii) the decision-making processes need to be legitimate, (iv) measures are unlikely to be undertaken in response to climate change alone and there needs to be consideration of the interactions with political, cultural, economic, institutional, and technological forces, (v) the process needs to be equitable among and between communities, and (vi) the CBA process will be context specific and not likely to be suitable for scaling-up (although lessons can be learned and passed on).

SITE DESCRIPTION

The site for this research was Roviana Lagoon, Western Province, Solomon Islands (Figure 132). There are approximately 30 coastal communities in Roviana Lagoon, living on New Georgia Island and the fringing islands.

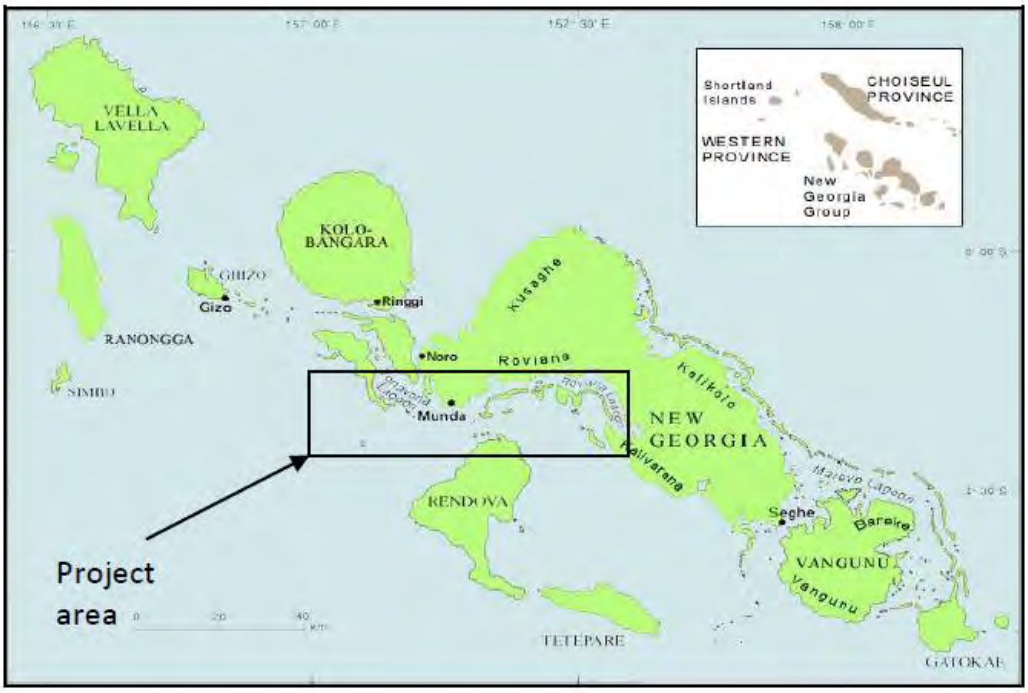

Figure 132 Map of Western Province, Solomon Islands highlighting Roviana and Vonavona Lagoons

METHOD DEVELOPMENT

CONTEXT FOR THE APPROACH

Methodology development was a central part of this work and was based on WorldFish experience of working with communities in Solomon Islands and current debate amongst climate change scientists. Some areas of consensus to build on from this debate include: (i) there is a long record of societies adapting to change, (ii) adaptation can be examined through the lens of coping ranges and adaptive capacity, (iii) climate change needs to be considered within the wider environment, (iii) a no regrets approach may be the most appropriate way forward. Each of these is now examined in more detail.

(i) Adaptation is not new

Although climate change as a defined concept is relatively new, adaptation isn't. Societies have a long record of adjusting what they do in response to variability, including to the impacts of weather and climate change, using approaches that include crop diversification, irrigation, water management, insurance schemes and food storage. In addition most activities considered in climate change adaptation are not new, and include well-established practices from disaster risk management, coastal management, resource management, spatial planning, urban planning, public health and agricultural outreach (Fussel 2007). Solomon Islands has experienced high climatic variability over time and people have methods to cope (Rasmussen et al. 2009). However, climate change now poses risks that may be outside the range of experience of coastal communities. For example, in discussions with communities, it is common to hear people say they can no longer predict the seasons of wind direction and rain, and some say they are not sure how to cope with this. An approach which encompasses strategies that build on existing coping and adaptation tactics while also considering necessary new innovation is used in this study. Adding to this argument, overstating the dangers of climate change needs to be considered. If this is internalized by local people, it may lead to practices of unsustainable development as communities respond to the idea of climate change rather than the actual changes in ecosystems driven by climatic processes (Barnett and

Adger 2003). Campbell (1997) further argues that discourses of vulnerability downplay the resilience of communities and casts them as powerless and need to be 'saved' when this is not the case.

(ii) Coping ranges and adaptive capacity

Adaptive capacity has been analysed in many ways including in terms of thresholds and coping ranges (Smit and Pilifosova 2003, Fussel 2007). Figure 133 illustrates the concept of a coping range. It shows a hypothetical time series of a climate attribute, for example rainfall. It is assumed that most communities can cope and adapt to normal climatic conditions or moderate deviations from the norm, called the coping range. The community can also bear damages by the occasional slight exceedance outside the coping range. If the climate attribute exceeds the coping range substantially due to an extreme event such as a cyclone, coping may still be possible but costly. If unusual extreme events become increasingly common, the community may start to associate these with climate change and decide to take action to extend their coping range. In Roviana lagoon, extreme events such as cyclones rarely impact communities, but predictions about increased rainfall events or drought events may be appropriate for this type of model.

There can be variation in the coping range over time due to external factors. For example, political instability and violence may narrow the coping range. Changes in economic, social, political and institutional conditions can also alter the coping range. For example marine resource depletion may gradually reduce the coping range, while economic growth may increase it. Cumulative effects of a high number of events near the limit of the coping range may result in communities exceeding a threshold, or tipping point, beyond which the system cannot recover. For example, high rainfall causing reduced productivity of gardens may be coped with for a couple of years, but after many consecutive years, it may reach a point from where the system cannot recover.

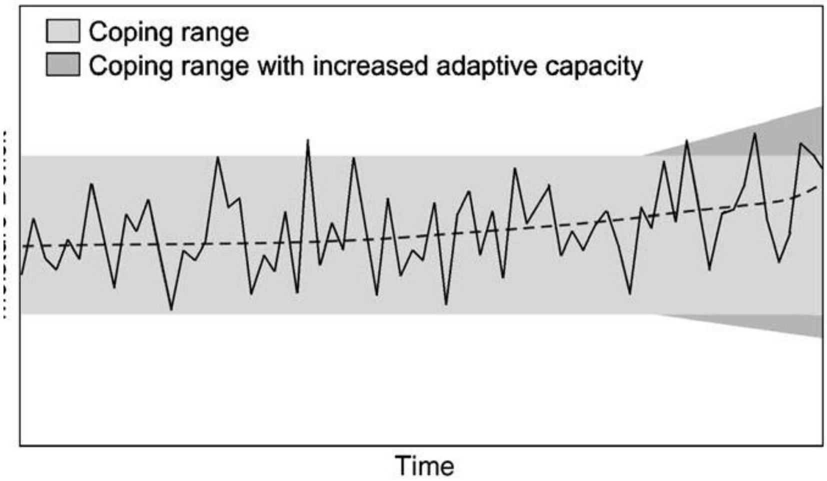

Figure 133 Coping range (figure taken from Smit and Pilifosova (2003))

(iii) Climate change needs to be considered within the wider environment

Adaptation is a continuous stream of activities, actions, decisions and attitudes that informs decisions about all aspects of life and that reflect existing social norms and practices. Climate change adaptation is not isolated from other decisions, and needs to be considered in terms of the wider environment the community exists in. For example, institutional processes such as regulatory structures, property rights and social norms associated with rules in use may constrain the adaptive capacity of communities. It can be difficult to separate climate change adaptation decisions or actions from actions triggered by other social or economic events (Adger et al. 2005).

(iv) No-regrets

No-regrets adaptation means options (or measures) that would be justified under all plausible future scenarios, including the absence of human induced climate change. Given the uncertainty of climate change impacts at the community scale in Solomon Islands, when they will occur, and other environmental, social and economic issues facing communities, a no-regrets approach has advantages. Elsewhere, common adaptation strategies which have been applied in this sense are: modifying an existing resource management strategy, livelihood enhancement, or a sustainable development program. See Figure 134 for examples of adaptation under different levels of uncertainty.

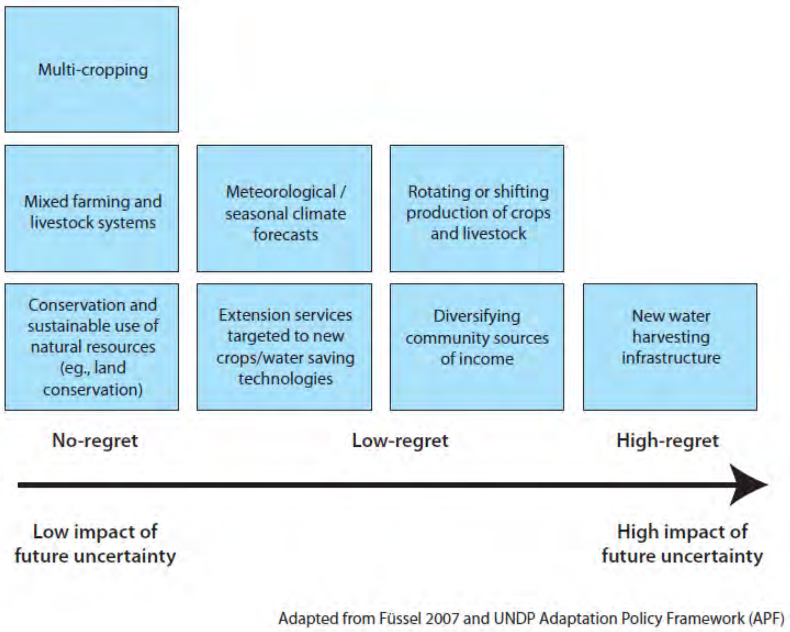

Figure 134 Consideration of uncertainty in adaptation investments (http://climatechange.worldbank.org)

The methodology developed for Roviana Lagoon was designed to work at the scale of the whole lagoon to identify adaptation options which address the climate change impacts facing coastal communities in the context of other drivers of change. The approach was divided into three parts:

1. Identify climate changes and impacts
2. Identify appropriate climate change adaptation options for Roviana lagoon
3. Appraise adaptation options

IDENTIFICATION OF CLIMATE CHANGES AND IMPACTS

Global and regional trends and predictions relevant to Solomon Islands were compiled by the WorldFish Center for Output 5 of Objective 3 (Brokovich and Schwarz 2011). Based on the latest available data (PCCSP 2011b), the predictions for the Solomon Islands are:

- Increase in air temp 0.5-1.5 degrees by 2030
- Increase in sea surface temperature of 1 degree by 2050
- Ocean acidification below threshold for healthy coral by 2060
- Sea level rise since 1996 has increased 8mm per year. There are global predictions of 0.5-1.4m by 2100
- Rainfall – small increase with more intense floods
- Fewer cyclones, but stronger ones

During a meeting with the project leader for Objective 3, Dr Simon Albert from the University of Queensland, held in September 2011, preliminary results from ecological data collected for the project specific to Roviana and Vonavona lagoon were incorporated into the predictions, to produce Table 50 below. Changes in cyclone intensity were omitted as Western Province is rarely affected by cyclones compared to southeast Solomon Islands provinces (Brokovich and Schwarz 2011). The last cyclone that caused significant damage was in 1986. The table was then used in the expert elicitation detailed in the next section.

Table 50 Climate change predictions and impacts for Roviana and Vonavona lagoons

Change	Impacts
Sea level rise Sea level is expected to rise by 50cm in the next 50 to 100 years. This is a conservative estimate. It is possible the level could be higher or the rise be faster	There will be inundation of villages. In low lying places such as Nusa Hope, it has been shown that up to 40% of the village will be inundated with water at high tides. Families will need to move, and this may cause fracturing and splitting of communities. For communities with coconut plantations and gardens on low lying sites, these will be inundated with sea water causing loss of productive areas, reducing soil quality and limiting the range of crops that can be grown
Air temperature increase In Munda, temperature records show that the mean, minimum and maximum temperature have all been increasing and temperature is expected to continue to rise	Increasing air temperature will mainly impact on agriculture, although it may indirectly increase sea temperatures in shallow areas. Crops have a maximum heat tolerance especially in traditional crops like taro, yam, and arrowroot which can cause reduced productivity, crop failure, increased pest and disease incidence.
Sea temperature increase The sea temperature is predicted to rise by 1 degree in the next 100 years	Coral reefs can be very sensitive to temperature changes, and small changes can cause bleaching and increased disease. However the lagoon already experiences high variability in temperature compared to the offshore barrier islands which experience very little variability and show more disease and bleaching. Therefore the offshore barrier island reefs are likely to be more affected by climate related sea temperature increase than the lagoon area which may be resilient to temperature change. This may have knock-on negative consequences for productivity of marine resources around the offshore barrier islands.
Rainfall patterns The overall amount of rain per year is not expected to change significantly (perhaps 5%). But there are likely to be more extremes in rainfall – particularly more intense rain.	Dry periods followed by intense rainfall is likely to cause the loss of topsoil and erosion of soil and nutrients. This sediment can flow into the lagoon which puts stress on reefs as water quality decreases and algal growth increases. However, as shown from logging run-off, the degree of impact depends on the natural water flow and depth of the area. There may be direct effects of intense rainfall on crop productivity, damage, disease and pests, which can result in food shortages. Increased rainfall is predicted to increase the incidence of water and vector borne disease such as malaria where drainage is poor.

Identification of appropriate climate change adaptation options

Expert elicitation interviews were conducted in October 2011, primarily with individuals in Munda, but others were visited by boat throughout the lagoon. We first conducted exploratory unstructured interviews with people from Roviana lagoon, talking with them about climate change impacts and how communities might best adapt. However, although respondents showed interest and concern over the predicted climate changes, respondents showed an unwillingness to suggest adaptation options specific to the four different predicted climate change impacts. However, they were keen to discuss other issues of concern facing Roviana communities and ways to adapt to these (see discussion in approach section).

Therefore it was deemed more appropriate to develop an understanding of factors that were influencing the vulnerability of communities in the context of change which included climate change, not climate change exclusively. In light of the exploratory process, we revised the research questions to:

1. (a) What are the most critical issues of concern and drivers of change in Roviana communities? (b) What are options to address these and improve adaptive capacity?
2. How important are the predicted climate change impacts to communities and how should they be addressed?

Expert elicitation method

Expert elicitation is 'a systematic approach to synthesize subjective judgment of experts'. It seeks to make explicit the unpublished knowledge and wisdom of experts, based on their accumulated experiences and expertise (Slottje et al. 2008). Often underlying drivers of socio-economic development pathways are defined through expert's judgments (Abildtrup et al. 2006) and this process has proved useful when used in situations of high uncertainty and complexity and when the number of relevant experts on the topic is nonetheless high (Slottje et al. 2008).

One of the critical issues of an expert elicitation is defining the group of experts that is going to be involved. First, a definition of what is an expert must be decided. The knowledge required for identifying appropriate coastal community level adaptation to climate change options here is defined by sector, and by expertise. Expertise was not assessed based on level of authority or education of the expert, but rather on experience. The identification process was an iterative one: sectors and experts were identified or dropped throughout the process. The sectors initially identified were based on WorldFish Center scientists' experience in the climate change programs and projects of the Solomon Islands and elsewhere in developing countries and included environmental, economic and social sectors.

'Experts' often refer primarily to professionals (E.g. scientists, technicians, physicians), although in this case, we argue that people with expertise and experience of coastal communities in their sector is required, and expertise is more likely to be acquired through experience rather than level of formal education or research capacity. Climate change knowledge was an obvious bonus but realistically was not a defining characteristic of the experts selected. We follow the criteria for identifying 'subject-matter experts' (Kotra et al. 1996)[4], but adapt this to include experiential expertise.

[4] Subject-matter experts typically are at the forefront of a specialty relevant to the problem and are recognized by their peers as authorities because of their sustained and significant research, *practical or policy experience* on the topic. They are the prime experts from whom judgments are elicited.

The qualities required by all experts were: the ability to understand the basic science and impacts of climate change on coastal communities (even if they are not a climate change expert), in depth knowledge of their sector (formal or *informal*), substantive experience in sector (formal or *informal*), and ability to synthesise their knowledge and experiences to provide their opinion on suitable adaptation options. Knowledge, expertise and the ability to address the topic of the elicitation were assessed using the criteria in Table 51. To be included in this elicitation process, experts had to meet the first two criteria listed in Table 51, meet one Level 1 criteria (be identified as one of three types of expert), and meet one of Level 2 criteria (have demonstrated their expertise).

Table 51 Criteria for expertise

Criteria for technical knowledge and expertise	**Requirement**
Expert currently active in their field of expertise	Required
Expert has spent a 'significant' amount of time in the Solomon Islands	Required
Professional experience in sector (This expert will have research, consulting, project or other employment-based knowledge and experience in several communities in field of expertise)	Level 1 Expert meets one of these criteria
Non-formal and local knowledge and experience in sector (The emphasis for this expert is on experience and understanding of communities rather than formal employment or education. For example, this may be people who have worked as missionaries and lived in communities, or older people who give advice and solve problems – the best fishermen or the garden expert in the lagoon recognised by several communities)	
Decision-making experience in field of expertise (In formal and non formal settings, this expert is in a position of influence at any level and has an understanding of the issues in several communities and in the sector)	
Shown leadership in professional or community-based societies/meetings in their sector	Level 2 Expert meets one of these criteria
Has published peer reviewed articles or reports in field of expertise (disciplines such as ecology, economics, fisheries, gender studies, health)	
Has had prior participation in other expert consultations and committees related to Solomon Islands communities and/or climate change.	
Has knowledge of several communities and is considered an expert by other communities	
Climate change knowledge: Expert's sectoral expertise are also demonstrated in the field of climate change	

To ensure a good sample of experts, assessment requires:

- Composition: *"What kind of knowledge should the sample of experts have?"*
  Composition concerns the mix of expert knowledge and experience needed for the panel to understand, analyze, and draw sound conclusions about the issue before it. A well composed group of experts is competent to deal with the task.
- Balance: *"What kinds of value judgments may be relevant to the panel's task?"* Balance concerns the even representation of differing points of view that can be expected to affect the issue addressed. A well balanced sample of experts has excellent prospects of achieving impartiality in the final conclusions and recommendations.

To reduce potential bias in the group, respondents with different backgrounds and affiliations were selected. In addition when possible, care was taken in selecting candidates to ensure representation (age, gender). Table 52

Table 52 Representation of experts

Diversity in Affiliation	**Diversity in Representation**
1. Scientists (Academia and Research institutions)	1. Gender
2. Practitioners (Paid work in sector, government or non-government)	2. Age
3. Independent and non-formal experts (e.g. fishers, farmers)	

An initial list of potential experts was identified using project partners who all had extensive field experience in the region. The most appropriate method for interviewing was found to be face-to-face. Snowball sampling was used to identify more experts as required.

The expert elicitation interviews were semi-structured interviews. The average time for an interview was two hours. The interview guide used is presented in Annex A. Notes were taken during each interview and written up on the same day as the interview occurred. The interviewing approach was based on anthropologist H. Russell Bernard's guidelines for the conduct of semi-structured interviews (Bernard 1994). Knowing that the respondent can influence the direction of the interview, the interviewer needs to ensure that the overall objectives of the interview guide are covered to a sufficient depth without leading the respondent. Questions were open and allowed for a natural conversation to take place and were phrased in such a way that answers were not prompted by the interviewer. Care was taken not to introduce the interview as part of a climate change project. The introduction to climate change issues was introduced in the middle of the interview. Field notes were systematically coded according to each theme of interest, to ensure that data were not used selectively.

The outline of the interview followed five main areas of inquiry:

1. Issues of critical concern known to the respondent, appropriate solutions, including discussion of whether these solutions had been tried and had worked in the past or not.
2. Description of climate predictions and impacts. This was an opportunity to share information two ways, on the concept of climate change and on the predicted impacts based on locally derived scientific evidence.
3. Importance of climate change in comparison to the issues discussed in 1.
4. Climate change impacts of most concern to communities.
5. Ways climate change could be addressed by communities.

Appraising adaptation options

From the list of solutions to issues of concern listed by experts, four criteria were used in combination to qualitatively score each option, which were then used for prioritization purposes: need, benefit, feasibility and cost (affordability) (Table 53) (Marshall et al., 2010). The purpose of this part of the research was to outline a method that could be used to rapidly make an initial assessment, generate discussions among stakeholders about appropriate adaptation implementation processes, and to examine trade-offs.

Table 53 Prioritisation matrix

Criteria	Action 1	Action 2	Action 3	Action 4
Need				
Benefit				
Feasibility				
Affordability				
Overall priority				

Ideally, we would advocate a participatory approach where the experts are consulted again in a workshop setting and the criteria themselves would be generated by the stakeholders. Experts could score criteria on a Likert-type scale; high, medium, low; or important to not important. The criteria themselves could also be weighted by importance. From this, the overall priority score could then be calculated and used for the basis of discussion. However, within the time frame for this project, this approach was not feasible. Instead, the information collected in this research will be disseminated to Roviana Conservation Foundation to be used in the Roviana adaptation planning workshop in April 2012. Many of the stakeholders who will attend the workshop were also participants in this study.

Results and Discussion

Identification of appropriate climate change adaptation options

(i) The experts

A total of 18 experts were interviewed, all were currently active in their field of expertise. All except two grew up in Roviana and had spent a significant proportion of their lives there. The other experts had been residing in communities for periods of between 18 months and three years, and were judged to have spent enough time in Roviana to have suitable expertise. Table 54 shows the number of respondents for each criteria for expertise and for affiliation and representation. The expertise covered environmental, economic and social sectors including: gender, climate change, resource management, sustainable development, fishing, agriculture, education, governance (community and local), and health.

Table 54 Number of respondents for each criteria for expertise and for affiliation and representation

Criteria for expertise	Number of respondents
Professional experience in sector	9
Non-formal and local knowledge and experience in sector	9
Decision-making experience in field of expertise	7 1 x professional 6 x non-formal
Shown leadership in sector	11

Has published peer reviewed articles in field of expertise	3
Has had prior participation in other expert consultations	4
Has knowledge of several communities/considered an expert by other communities	18
Climate change knowledge	2
Diversity in affiliation and representation	
Scientists	0 2 x science qualifications
Practitioners	9
Independent and non-formal experts	9
Gender	
Men	13
Women	5
Age	
Young < 35/40	3
Mid 40 - 55/60	5
Old > 50/60	11

(ii) Issues of critical concern

In response to the question *"from your experiences and knowledge, what you know about Roviana communities, and what you have seen over the years, list the three most critical issues facing Roviana communities"*, answers were coded into eleven themes. The experts ranked their three issues. The first issue was given a score of 3, the second a score of 2, and the third a score of 1. Each theme was then given a score by adding up the responses (Figure 135). Each theme is now explained in turn; note that the themes overlap at times and are inter-related:

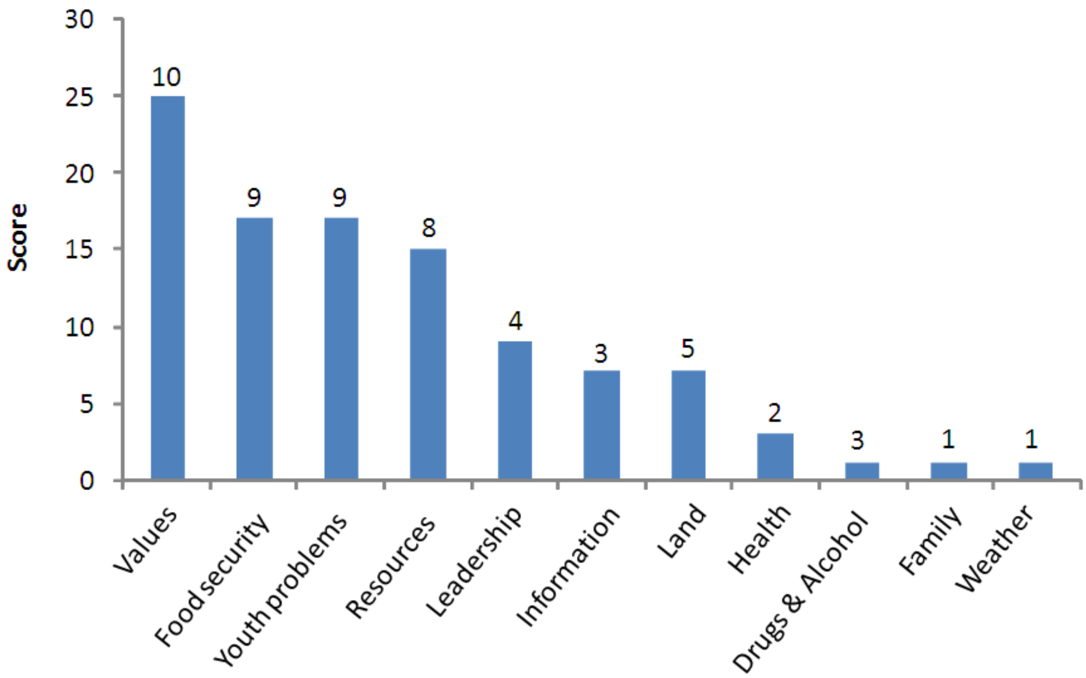

Figure 135 The total score for each category issue. The numbers above each bar are the number of times the category was identified as an issue.

- Values

More than half of the respondents felt that changing values and the breakdown of kinship was the biggest cause of concern in Roviana. The main cited cause of the change has been the shift from a subsistence lifestyle to a cash economy. Seeking money has resulted in more individualistic behaviour, changing family values, and a breakdown of support systems in the community and family. Preferences are changing as people desire material goods and imported foods, rather than living within the means of the land and sea. This cited change is not new or a surprise. The introduction of Christianity, colonialism, foreign business and aid has left its mark of change over the last century. However, the fact that it is still being cited as an issue means that it is still changing at a rate that is noticeable and a concern to both old and young respondents. Some common responses were: *"Social changes are causing confusion. The two worlds of the old and the new are clashing. This is not just confusing for young people but also for parents who are trying to teach their kids"* (respondent 13). *"Before when you needed something, you could ask your neighbour, but now they want you to pay. There is no sharing. People now don't want to work in the gardens and go fishing, they want to be able to buy things…so, if people run out of money, they now run out food"* (respondent 16). The concern is that there are few systems in place for people to manage their money: *"they don't know how to manage their money and spend it as quickly as they get it. Investing and saving is not in people's way of life because people have in the past relied on their families for what they need"* (respondent 7).

- Food security

Issues related to food security were also a high priority of concern. There are three sub-issues including productivity of subsistence crops, changing preference for daily activities, and nutrition. First, people have noticed reduced productivity in their gardens for several reasons including pests, and reduced soil fertility. Second, the young people and men are helping less in the gardens then they have in the past. There are defined gender roles in communities and the responsibility of putting food on the table falls traditionally to the women. *"With [reduced productivity] and less help, this is placing an increasing burden on women"* (respondent 1). Third, eating habits from a traditional diet of root crops, vegetables and sea food, to a preference for imported rice, instant noodles and tinned meat and fish high in sugar and salt, combined with lack of exercise is causing health problems, identified particularly by the health sector. The rate of diabetes is very high and it has been observed that children are malnourished. *"There is no reason why people cannot be healthier. The food is available and diet can be reasonable"* (respondent 14).

- Youth problems

Probably one of the most common things to hear when asking about community issues anywhere in the world is problems with young people and *"lack of respect".* This was true of the respondents in Roviana, but almost all also specifically pointed out that it was directly related to unemployment, and the frustration that co-occurs, leading to abuse of alcohol and drugs. The Solomon Islands has high and growing youth unemployment (Ministry of Development Planning and Aid Coordination 2011). Of the nine people who mentioned youth problems, four people believed it was due to the education system. *"Children are educated to be employed and there is an expectation they will get a job. When there is no job, they stay at home and become troublesome for their families. Why don't they go fishing or to the gardens? It is because they have been manipulated to think only of cash and a job"* (respondent 8).

- Degradation of resources

Degradation of resources on the land and in the sea is believed to be driven by increased population and the desire for cash. It was also identified by one expert that people *"don't realise that we live in paradise and that the ecosystem can sustain us. So they keep harvesting. Some people realise the consequences, but others ignore the problem"* (respondent 18). Respondents were concerned about over harvesting of marine fisheries and selling land to loggers. *"From the 1960s the cash economy started, and there was the ability to get quick cash. Since then, there has been a need for cash especially for school fees. Logging has been a way to get quick and big cash"* (respondent 17). *"It is like free money"* (respondent 6).

- Weakened leadership

Weakened community leadership was explicitly mentioned by four respondents. Traditionally, there was strong leadership in the communities but this has been eroded in several places and was mentioned by almost all respondents in the context of other issues. *"Leaders and chiefs have lost respect because of the example they are setting. Leaders are self-interested now, corrupt, and want money from logging. The problem is that they do not distribute the money to the community which means the young people don't have respect for the leaders, communities argue and they are falling apart"* (respondent 11). The church in Roviana has a strong presence in every community, but people were concerned that it is starting to have less of an influence on people's behaviour: *"the values of the church are only practiced inside the church, not outside"* (respondent 5).

- Access to information

Access to information empowers people, and there was concern that firstly, there is an overall lack of information which means that people are unaware of global drivers of change such as climate change and other social changes, and that *"people are missing opportunities for business because they are not aware of the options available"* (respondent 4). Also, there was concern especially from women experts that the dissemination of information excludes the uneducated and illiterate, women and young people given the hierarchy of power in Roviana communities, which impacts on these groups, particularly young women's ability to gain power. For example, *"in Roviana women are the landowners. Women don't have power or control over what happens on the land because they don't have the information. Men will go ahead and sell land for logging without considering the ownership rights of women"* (respondent 1).

- Land disputes increasing

Although not the top issue cited by respondents, five respondents mentioned land disputes as increasingly problematic in Roviana communities. It was believed to be due to population increase and the desire for the money that can be made by selling rights to logging companies. *"When the benefits are not shared equally, there are disputes over land boundaries, which ultimately results in lack of wealth for all"* (respondent 3). One respondent gave a recent example of new land rights recently evolving. *"On Parara Island, logging has created new land rights. People used to have small plots of land by the sea to live and communal land on top [behind] for gardens. They have now brought their land back in a straight line from their houses by the sea and land is now divided into narrow strips, privatising once communal land"* (respondent 2).

- Health problems

Two health experts spoke of health related issues that were causing problems in Roviana communities. As well as diabetes (see food security), smoking-related illnesses and a very high prevalence of STIs were the three main health issues in the region.

- Drugs and Alcohol

Although drug and alcohol abuse were identified as 'youth problems', they were also mentioned by three people as a more systemic issue within all ages in Roviana communities, particularly among men. When money is earned, *"it is spent on alcohol rather than supporting the livelihood of the family and the kids school fees. It can also lead to domestic violence. In the Solomon Islands two-thirds of women are abused and this is an underreported number"* (respondent 1).

- Family planning

One health expert believed that lack of family planning was a health issue of concern. *"It is common that there is a lot of blood loss during childbirth. This is because women have ten children, and they give birth in the village. Even though there is surprisingly low mortality, there is very high neonatal infection"* (respondent 15).

- Weather changes

Only one person mentioned changes in the weather as important, and this was ranked as their third issue of concern. The concern was that weather, mainly rainfall, was less predictable than it used to be. This makes it difficult to plan gardening activities using old systems that worked, and crops are often ruined.

(iii) Solutions to issues of critical concern

A total of 56 solutions and actions were proposed to address the eleven issues of concern. In a few cases, respondents did not know how to address their issue raised, in other cases the respondent had more than one idea. All solutions are listed, alongside the characteristics of the respondent and a categorisation of solutions derived from coding responses in Annex B. There was a range of innovative and interesting ideas, and a summary is given below.

84% of solutions given by experts explicitly required assistance outside of the community. Respondents either specifically mentioned the church, government or NGO assistance, or did not specify where the help would come from. Of note was that actions to address issues of resource depletion and land disputes tended to require government assistance.

Actions were coded into six main themes, and could fall into more than one action type (See Table 55 for overall summary, and Table 56 for summary for each issue of concern). 50% of all solutions were based on improving or building awareness and having trainings (e.g. youth training schemes on new livelihood opportunities). 13% of solutions were suggestions of activities in community development (e.g. provision of services, savings schemes). There was an emphasis on development of income earning livelihood activities (16%) to address unemployment and growing needs for cash (e.g. generating new business ideas). Solutions given to issues of food security and resource depletion were to improve productivity and sustainability of resources (total 18%). These included planting pest-resistant crops, and closing marine areas to fishing. The need for laws and regulations (18%) was commonly cited as a solution to issues of resource depletion and land disputes. For example, while communities do have marine protected areas in place, experts felt they needed 'back up' for them to achieve their goals in the form of government-led enforcement and policing of rules. One quarter of all actions explicitly mentioned using traditional knowledge or kastom ways, suggesting that any adaptation action would benefit by being aligned with and build on existing systems and processes in place.

Table 55 Summary of solutions to issues of critical concern by actor and action type

Actor type	**%**
Church	7
Government	27
NGO	6
Non specified expertise	55
Action type	
Awareness and training	50
Community development activities	13
Income earning livelihood activities	16
Improved productivity and sustainability of resources	18
Regulatory	18
Traditional or kastom methods	25

Table 56 Summary of solutions for each issue of concern, categorized by actor and action type

Issue	**Total Number Actions**	**Actor**				**Action**					
		Church	**Gov't**	**NGO**	**Outside experts**	**Awareness & training**	**Development activities**	**Income earning livelihood activities**	**Improving productivity & sustainability of resources**	**Regulation**	**Traditional or kastom method**
Changed values	8	1	1	1	5	5	1	1			2
Food security	10		1	2	8	5	3	2	3		3
Youth problems	9	1	1	1	6	7	2	3			4
Resource depletion	11		7	2	5	4		1	6	5	
Weakened community leadership	5		1							1	4
Lack of access to information	3				2	3		1			
Increasing land disputes	5	1	4			1			1	4	1
Health	2				2	1	1				
Drugs and alcohol	1				1	1					
Family planning	1	1			1	1					
Unpredictable weather	1				1			1			

(iv) Importance of climate change in the context of issues of critical concern

After a detailed discussion with each expert about climate change predictions and impacts for Roviana, respondents were asked how important climate change is in comparison to other issues of concern mentioned. 44% said that climate change will exacerbates existing problems facing communities. For example; *"Climate change needs to be considered and recognised at the very least, if not addressed. It will cause more conflict due to land tenure as the sea level rises, increase the problems of reduced resources as population increases. If the way people resolve conflicts is not addressed then it could be solved with bush knives. We need to address the issue by talking to young people now, making them aware and training them"* [respondent 1]. Another common response was; *"There is a big interaction between climate change, land ownership and food security. Changing rainfall patterns will make the food security issue of poor productivity and the fact people don't want to grow their own food any more, worse"* [respondent 2].

33% said that climate change is not as important as addressing issues of concern immediately. Although Roviana people have been noticing changes in weather patterns, the changes are not considered to be harmful to communities. For example; *"You can rely on nature to recover and it already adapts to change, so I don't think it is important, especially if we look after our resources in the first place"* [respondent 7], and *"We need to have strong communities before we can do anything about climate change"* [respondent 5].

Almost a quarter of experts said they didn't know (23%). Everyone interviewed had heard of climate change, but they either a) didn't think it was something that would affect communities directly: *"I don't think climate change impacts will affect people's health. Most of the soil has good drainage, so water-borne diseases are unlikely and there is malaria already"* [respondent 14], or b) it was considered a problem far into the future and not relevant. *"Climate change is going to be a difficult issue to address in Roviana because people don't forward think or plan for the future. It is like the future does not exist"* [respondent 1].

(v) Climate change impacts of most concern

Sea level rise and relocation, and changes in rainfall patterns affecting garden productivity were the climate changes and impacts that experts felt were most relevant to Roviana. 39% (7) of experts mentioned sea level rise as a noticeable climate change impact, particularly for communities on the small low-lying islands. However, more than half of these felt there was plenty of land to cater for communities that needed to relocate. One respondent highlighted that there may be difficulties in relocation because people would not want to leave their tribal land and sea. Two experts felt that relocation would cause land tenure issues.

44% of experts felt that climate change is "*mostly a worry for resources, gardens especially*" [respondent 12]. Communities are already suffering from reduced productivity in gardens due to pests and soil infertility. Unreliable rainfall and threats of more flooding and drought periods will cause further losses and food insecurity: *"I'm particularly worried about the impact on root crops, as women bear the burden of the work of feeding the family. If it is harder to grow crops, then women will need to work harder to feed their family. If there is not enough food to grow, they will need to buy food. This means rice. But they need money to buy rice and there are few ways to make money except by selling their produce. I think this could lead to greater nutritional problems"* [respondent 1]

(vi) Adaptation actions for climate changes

Given the lack of priority given to climate change impacts as an issue of concern for Roviana communities, a list of adaptation options to specifically address climate change impacts was not possible. However, in depth discussions of climate change adaptation and how it should be incorporated into actions to address issues of concern, and reduce the vulnerability of communities generically was discussed. A list of common themes or 'advice' given by experts is listed below:

- Communities need to be aware of climate change and how it will impact them. Information needs to be appropriately disseminated in an understandable, relevant, open and creative forum, and delivered by people who are perceived as legitimate and appropriate. It needs to be delivered by people who understand Roviana (language, culture and contemporary issues).

- Improving resource productivity and managing resources for the future will help to buffer against climate change impacts. This needs to be a partnership between communities, government and outside experts

- Increasing the strength (leadership, cohesiveness) of communities will empower communities to be more able to cope with disturbances in the future such as climate changes

- Using existing organizational structures that are in place to implement action such as the church and community groups, in combination with outside expertise and government support will increase the chance of achieving desired outcomes

- Interventions should build on existing traditional knowledge

- Considering the whole system – all sectors and scales – is important when implementing action. In particular, enabling markets is crucial for developing new livelihood and income generating activities

- Women are likely to be most adversely affected by climate change impacts as they are responsible for food security in the household. While interventions should be beneficial to everyone, women need to be explicitly considered

- Interventions could be carried out by youth. They are the generation who will be affected by climate change, yet they are often left out in decision making. *"Young people see things with fresh eyes, they see change and want to change, they want things to do, and are relatively easy to motivate because there is nothing else for them to do in the villages"* [respondent 1]

APPRAISING ADAPTATION OPTIONS

We used the framework of Marshall et al (2010) to appraise the list of actions suggested by experts as solutions to issues of concern. There were 56 solutions and actions in total. In order to manage the number of responses, we only used the solutions from the top four issues of concern: Changing values, food security, youth problems and resource degradation. These represent 72% of the (weighted) responses. Actions suggested were often similar, so where appropriate these were collapsed. A total of 21 options are examined (See Table 57) in terms of who the target beneficiary may be, the types of personnel and financial resources required, and how each solution may address the four main issues of concern: changing values, food security, youth problems and resource degradation.

In order to compare these actions, a score was given to determine the need, cost, feasibility and benefits. 'Need' was measured as the number of issues of concern the action can potentially address (Scores: 1 = addresses 1 issue of concern, 2 = addresses 2 issues of concern, 3 = addresses 3 or 4 issues of concern). Addressing multiple needs which provide co-benefits is desirable. Cost was measured as an average of the personnel and financial resources required. Personnel were scored as: 1 = government, 2 = experts, 3 = local organizations in Roviana. If more than one personnel type was recorded, then the lowest score was taken. Financial resources required was measured as: 1 = high financial and ongoing support required, 2 = medium level of financial input to run a limited number of workshops, 3 = low financial input, such as equipment only. Feasibility was measured using data collected on past experience. If the initiative type had never been attempted before = 1, 2 = had not been done before but experts believed it was possible, or it had been tried but was unsuccessful for reasons that could be rectified, 3 = had been done before in some form. These scores were summed to get an overall score. A higher score indicates an 'easier' option (See Table 58). Determining the future social benefits was not possible given the time limitation. However we list beside the scores who the likely beneficiary would be. There is a limitation to not scoring the benefits. For example, actions which require government support are at the bottom of the priority list because they have high costs and low feasibility. However, the benefits may be great, and would drive these action-types higher up the priority list.

Table 57 Technological, institutional, legal, educational and behavioural solutions listed by experts, the target beneficiary, the personnel and financial resources required, and how each solution may address the four main issues of concern: changing values, food security, youth problems and resource degradation.

Action	Target / beneficiary	Personnel outside community required for delivering action	Financial resources required	Changing values	Food Security	Youth problem	Resource degradation
Training - Leadership skills using outside experts and respected local leaders	Community leaders	Experts & community leaders	Money for workshops	X		X	X
Local sports club	Youth	Church	Money for equipment	X		X	
Mobile in-community and family support/advice program	Families in need	Church	Money for church members to travel to communities regularly	X		X	
Training - Positive parenting to build self respect and self esteem in their children	Parents in communities	Local organisations such as YWCA	Money for workshops	X		X	
Training - Managing finances and maximising existing opportunities	Whole communities	Experts	Money for workshops	X	X		
Planting pest resistant crops	Women	Experts - Kastom Garden	Money for training workshops, seeds	X	X		X
Training - Composting for increased soil fertility	Whole community	Experts - Kastom Garden	Money for training workshops		X		X
Training - Sustainable harvesting practices	Resource users in communities	Experts	Money for training workshops		X		X
Traditional knowledge field school	Youth	Community representatives, experts	Money for building, staffing and running field school	X	X	X	X
Introduction of new income earning livelihood activities - plantations	Whole community with	Various experts with local knowledge and	Money for training workshops on different livelihood activities		X	X	X

Action	Target / beneficiary	Personnel outside community required for delivering action	Financial resources required	Changing values	Food Security	Youth problem	Resource degradation
- tourism - researchers - mariculture/aquaculture - handicrafts - food for sale - village businesses - livestock - sewing	focus on youth	government	Funding for start-up activities Government assistance and funding for expertise and assistance in setting up markets				
Implementation of community-based co-management with government support	Whole communities	Experts, NGOs & government	Money for workshops and long term engagement	X	X	X	X
Introduction of community group savings clubs	Community groups	Experts & local government	Money for training workshops Money for safes & locks	X	X		
Training - Healthy eating and exercise	Whole community, although different groups may be targeted for specific problems	Health experts	Money for training workshops		X		
Provision of support groups to address problems (e.g. Alcoholism, Domestic violence)	Community members in need	Experts	Money for support group leader and site for meetings	X		X	
Training - Negotiating with developers	Whole communities	Experts	Money for training workshops				X
Training - How to access funding sources for community activities	Whole communities	Experts & government	Money for training workshops				X

Action	Target / beneficiary	Personnel outside community required for delivering action	Financial resources required	Changing values	Food Security	Youth problem	Resource degradation
Education reform to include traditional knowledge and kastom	School children	Government	Unknown	X	X	X	
Healthcare services provided in-community	Communities without health services	Health experts & government	Money for building and staffing health service		X		
Enforcement and policing of land and sea resources	Whole community	Local rangers & government	Money to develop regulations Money to train and pay local rangers Money for transport		X	X	X
Fisheries regulation	Government	Government	Unknown		X		X
Logging regulation	Government	Government	Unknown				X

Table 58 Prioritisation matrix

Action	Need	Cost	Feasibility	Total	Beneficiary
Training - Leadership skills using outside experts and respected local leaders	3	2	3	**8**	Community
Local sports club	2	3	3	**8**	Youth
Mobile in-community and family support/advice program	2	2.5	3	**7.5**	Vulnerable people
Training - Positive parenting to build self respect and self esteem in their children	2	2.5	3	**7.5**	Youth
Training - Managing finances and maximising existing opportunities	2	2	3	**7**	Community
Planting pest resistant crops	3	2	2	**7**	Women Community
Training - Composting for increased soil fertility	2	2	3	**7**	Women Community
Training - Sustainable harvesting practices	2	2	3	**7**	Community
Traditional knowledge field school	3	1.5	2	**6.5**	Youth
Introduction of new income earning livelihood activities - plantations - tourism - researchers - mariculture/aquaculture - handicrafts - food for sale - village businesses - livestock - sewing	3	1	2	**6**	Individuals who take up activity
Implementation of community-based co-management with government support	3	1	2	**6**	Community
Introduction of community group savings clubs	2	2	2	**6**	Groups who take up activity
Training - Healthy eating and exercise	1	2	3	**6**	Community
Provision of support groups to address problems (e.g. Alcoholism, Domestic violence)	2	2	2	**6**	Vulnerable people
Training - Negotiating with developers	1	2	3	**6**	Community
Training - How to access funding sources for community activities	1	1.5	3	**5.5**	Community
Education reform to include traditional knowledge and kastom	3	1	1	**5**	Youth
Healthcare services provided in-community	1	1	3	**5**	Community
Enforcement and policing of land and sea resources	3	1	1	**5**	Community
Fisheries regulation	2	1	1	**4**	Community
Logging regulation	1	1	1	**3**	Community

As stated earlier, this method is not able to directly assess how effective adaptation options are in reducing vulnerability to increasing climate change or variability. Given the lack of priority given to climate change impacts by experts in Roviana, it makes sense to focus on generalized measures to enhance capacity[5]. The CGIAR program on Climate Change, Agriculture and Food Security (CCAFS) is at the forefront of climate change adaptation research in developing countries. CCAFS promote a move from a 'vulnerability-based' adaptation to a 'capacity-based' adaptation approach. There is increasing attention on ***how*** climate change will happen rather than whether it will happen. Climate change impacts require new capacities among individuals, households and institutions to deal with incremental change and major transformations. Capabilities and competencies are at the centre of a capacity enhancement approach. In other words, enhancing a person, community or organizations ability to increase their "own ability to achieve their objectives efficiently and effectively". This involves building internal capacities such as skills and knowledge of individuals or groups. Enabling people to enhance their own capacity is more likely to be effective rather than 'delivering capacity development'. This is especially important for less empowered groups, such as women and youth in Solomon Islands, who have considerable capacity that can be built upon. However, often wider institutional capacity needs to be built if there are institutions in place which limit the capability of less empowered groups. There may also need to be financial capital built if resources are a limiting factor.

The assessment of adaptation options presented here is a first, but necessary step, to identify some practical options to address issues of concern and for enhancing the capacity of Roviana communities, as identified by Roviana communities. According to the ranking, the priority actions emphasise training and awareness, building leadership and cohesiveness of communities and also supporting more vulnerable groups (women, youth, people 'in need'). This falls within generic capacity enhancement of the resilience and well-being of communities, which will enable communities to increase their own ability to cope with change. A strong theme throughout this analysis is the need for information and training. Including climate change awareness programs such as the one currently being conducted by the Roviana Conservation Foundation could form the foundation for developing recognition and concern about present and future climate change impacts, and motivation for changes in behaviour.

However, it is also important not to simply re-label generic development assistance as climate change adaptation. How actions can reduce communities' vulnerability to climate change need to still be considered explicitly. One way to do this is to consider climate-sensitive domains that have been identified by climate change predictions and that are also considered to be important and relevant to stakeholders. In the case of Roviana, the impacts of climate change on the agricultural domain were identified by the experts as being of highest concern. Reduced productivity of crops due to pests and reduced fertility of soil is unprecedented and there are concerns for the impact for food security in general and on women. Climates changes reported by older community members (unpredictability of rainfall – see results from Component 1) are exacerbating the situation. Respondents felt that new ideas and development of new options are required to cope with unprecedented conditions. Activities suggested that improve productivity of gardens, such as planting crop varieties that are resistant to pests and composting were high on the priority list. Organizations such as

[5] It is important to note here that the lack of priority may not only be because of a discounted concern (given other issues of greater immediate concern), there is also a lack of awareness of the impacts of climate change in communities which needs to be addressed throughout the Solomon Islands [pers comm. Climate change minister, MECDM]

Kastom Garden have seed programs that transfer knowledge and deliver seeds to key farmers (who then teach others). Kastom Garden can also propagate and distribute hardy varieties that can weather climate variation.

Planned adaptation to climate change needs to use information about present and future climate changes to review the suitability of current and planned actions. A question that needs to be answered is: 'Do the expected climate changes matter to the intervention decisions being made?' (Fussel 2007). An approach such as the Social Return on Investment (SROI) method which is based on outcome mapping and theory of change, and requires extensive stakeholder involvement could be appropriate (Nicholls et al. 2012) to appraise specific options determined by communities. An alternative question is 'What are feasible and effective measures to address climate change risks and how can these be mainstreamed with capacity enhancement?' Considering climate change adaptation within the wider institutional context as presented here requires mainstreaming climate adaptation into existing activities and development planning (Huq et al. 2003). Once stakeholders are aware of the risks of climate change and are concerned, using the experience of others dealing with similar risks in already affected regions that have similar characteristics could be an effective strategy. Explicit consideration of potential climate risk should be a strategy that sits alongside no-regrets interventions as these do not depend on reliable climate projections and impacts.

SUMMARY

In Solomon Islands a broad assessment of climate change vulnerability has been made at the national level as part of the National Adaptation Programme of Action (NAPA), and for the marine sector as part of the Coral Triangle Initiative National Plan of Action (CTI NPoA). Both detail community-based adaptation as a national strategy to improve food security and well-being, and build adaptive capacity to climate change in the context of other pressures. There is evidence that community-based activities are effective in the Solomon Islands to enhance resilience and reduce vulnerability (Schwarz et al. 2011).

In Roviana Lagoon climate change was not raised as an issue of concern for communities by a set of experts from different sectors. This was due to climate change being a discounted concern compared to other issues facing communities, and a lack of awareness of climate change impacts.

The most important issues identified that required urgent action were changing value systems, decreasing food security, increasing youth problems, and resource degradation. In order to address these issues, almost all solutions suggested by experts required outside support from NGOs and government commitment and assistance alongside community engagement.

Almost half of the experts did acknowledge that climate change impacts were likely to exacerbate existing issues in Roviana. Of particular concern were the impacts on gardens that are already experiencing reduced productivity.

Experts gave advice on how adaptation to climate change could be addressed and how it could be mainstreamed into activities that enhance capacity of communities. The advice included: raising awareness, building strong resources and communities to be resilient, using the existing structures and knowledge available in communities, and targeting women and youth.

Appraisal of options suggested by experts to address issues of concern, through a climate change lens, suggested that the most appropriate and feasible actions emphasise training and awareness, building leadership and cohesiveness of communities and also supporting more vulnerable groups such as women and youth. Respondents felt that new ideas and development of new options are required to cope with unprecedented conditions. For example, interventions to plant crop varieties that are hardy to pests and can weather climate variation was a tangible climate change adaptation option identified.

This research provides a good starting point for identifying climate change adaptation options within the broad Roviana context, and provides advice from experts on suitable ways forward for planning. The next step requires a participatory approach and long-term engagement between communities, local and national organizations and government to appraise options, make decisions, and implement a process of mainstreaming adaptation to climate change.

ANNEX A: EXPERT SURVEY IN ROVIANA, SOLOMON ISLANDS

We have contacted you because of your understanding of communities in Roviana and because you are considered to be an expert in your field.

The WorldFish Centre are partners in a project that is looking at understanding current and future changes and issues that have been occurring in coastal Roviana communities. We are interested in the social, economic and environmental aspects of community life.

We would like to conduct a short survey with you, with your permission. The questions we will ask you are not of a personal nature but we will make sure to treat the interview confidentially. Your name will not be mentioned in any documentation. We will present aggregated information from all the experts so nothing can identify you as an individual. You are free to decline the interview all together or stop the survey at any time.

NAME: DATE/TIME:

LOCATION: RESPONDENT NO:

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1. For some background information, please tells us a little about:

a. How long you have lived/researched/worked in Roviana

b. The activities/research/type of work you do in your sector in the communities

c. Any other information you would like to add

2.

a. From your experiences and knowledge, what you know about Roviana communities, and what you have seen over the years, please list and describe what do you think are the most critical issues facing communities in Roviana? Please list three.

b. How do you think each of these issues can be addressed?

c. Has an action such as what you propose been done before in communities to your knowledge? Has it worked? Why/why not?

A. ISSUE	B. SOLUTION	C. PAST EXPERIENCE?
1.		
2.		
3.		

3. There are global changes that are happening in the Solomon Islands that are outside of the control of individuals and communities in Roviana: I am interested to know how you think climate changes will affect the issues you have identified in Question 2. First, here is some information:

Climate change:

The University of Queensland have been doing marine surveys looking at climate-related changes in Roviana and have also compiled the predictions from the latest models by CSIRO scientists in Australia. Below is a table which details the four main climate changes which will impact Roviana. Note that changes where there is high uncertainty around the impacts such as ocean acidification, and those unlikely to affect the Roviana region such as changes in cyclone intensity have been omitted. We have consulted with experts to understand what the impacts of these predicted climate changes will have in Roviana communities.

Change	Impacts
Sea level rise Sea level is expected to rise by 50cm in the next 50 to 100 years. This is a conservative estimate. It is possible the level could be higher or the rise be faster	There will be inundation of villages. In low lying places such as Nusa Hope, it has been shown that up to 40% of the village will be inundated with water at high tides. Families will need to move, and this may cause fracturing and splitting of communities. For communities with coconut plantations and gardens on low lying sites, these will be inundated with sea water causing loss of productive areas, reducing soil quality and limiting the range of crops that can be grown
Air temperature increase In Munda, the temperature gauge has shown that the mean, minimum and maximum temperature have all been increasing and temperature is expected to continue to rise	Increasing air temperature will mainly impact on agriculture, although it may indirectly increase sea temperatures in shallow areas. Crops have a maximum heat tolerance especially in traditional crops like taro, yam, and arrowroot which can cause reduced productivity, crop failure, increased pest and disease incidence.
Sea temperature increase The sea temperature is predicted to rise by 1 degree in the next 100	Coral reefs can be very sensitive to temperature changes, and small changes can cause bleaching and increased disease and more bleaching. The lagoon already experiences high variability in temperature compared

years	to the offshore barrier islands which experience very little variability and show more disease and bleaching. Therefore the offshore barrier island reefs are likely to be more affected by climate related sea temperature increase than the lagoon area. This may have knock-on negative consequences for marine resources around the offshore barrier islands.
Rainfall patterns The overall amount of rain per year is not expected to change. But there are likely to be more extremes in rainfall – more intense rain and more drought periods throughout the year	Drought periods followed by intense rainfall is likely to cause the loss of topsoil and erosion of soil and nutrients. This sediment can flow into the lagoon which puts stress on reefs as water quality decreases and algal growth increases. However, as shown from logging run-off, the degree of impact depends on the natural water flow and depth of the area. There are direct effects of drought and intense rainfall on crop productivity, damage, disease and pests, which can result in food shortages Increased rainfall is predicted to have increase the incidence of water and vector borne disease such as malaria. Drought periods will reduce access to clean drinking water

a. How important do you think climate change is compared to other issues we have already discussed?

b. Which climate change and associated impacts do you think is of most concern to Roviana communities and why?

c. Describe if/how you think each issue from Q2 will be further impacted by the four predicted climate changes.

Issue	SLR	Air temp increase	Sea temp increase	Intense rain/storms and drought	Most concern ✓
	Sea water inundation of gardens and plantations, relocation of part or whole communities	Agricultural impacts, root crops with low heat tolerance, increased pests	Coral reef bleaching and increased disease with knock on effects for marine life	Erosion, sediment runoff, direct impacts of drought and flooding of gardens, increased water borne disease and malaria, access to drinking water	
1					
2					
3					

d. Do you think there are suitable adaptation actions that can be done now in communities to address the impacts of climate change? Who will they benefit and how? What are the risks to it not working? What resources are needed?

e. For each climate change impact, has something like this occurred before in Roviana? What have communities done to adapt? Did it work? Why. Why not?

Climate change	**Adaptation action**	**Worked before?**
SLR Sea water inundation of gardens and plantations, relocation of part or whole communities		
Air temp increase Agricultural impacts, root crops with low heat tolerance, increased pests		
Sea temp increase Coral reef bleaching and increased disease with knock on effects for marine life		
Intense rain/storms & drought Erosion, sediment runoff, direct impacts of drought and flooding of gardens, increased water borne disease and malaria, access to drinking water		

ANNEX B: CHARACTERISTICS OF EXPERT AND SOLUTIONS FOR EACH ISSUE OF CONCERN, ACTOR AND ACTION TYPE

1. Changed values

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
3	M	Mid	1	2	Strengthen leadership by selecting chiefs by committee rather than heritary method, and training them in good leadership skills. This would need to be culturally specific and done by people who intimately understand Roviana.	Outside experts	Awareness & training Traditional & Kastom method
4	M	Old	2	2	Bring external experts to Roviana who can teach people how to maximise their money. These experts would need to live in the communities and get to know their ways	Outside experts	Awareness & training
7	M	Old	2	1	Strengthen leadership in communities by having wise leaders transferring their knowledge.	Not specified	Awareness & training Traditional & Kastom method
11	M	Old	2	1	The church needs to visit communities and families to encourage them, pray for them, and to help with spiritual and practical needs	Church	Development activities
13	F	Mid	1	2	Need trainings to teach positive parenting in communities, so that people can learn to value themselves, build self respect, and self esteem, especially women. This could be done through local organisations like the YWCA.	NGOs Outside experts	Awareness & training
16	F	Old	2	2	Need awareness trainings with parents to teach them how to be self sufficient, and give ideas for using resources to make money	Outside experts	Awareness & training
6	M	Old	1	1	Savings clubs where groups within the community set aside a certain amount of money for a commonly determined cause. This can help communities learn to manage money better and save for the future.	Not specified	Development activities

2. Food security

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
12	M	Old	2	1	Plant pest resistance crops such as cassava to improve subsistence garden productivity.	Not specified	Improving productivity and sustainability of resources
12	M	Old	2	1	Look for alternative livelihoods such as: planting cash crops such as copra, selling fish at market, selling traditional handicrafts, making food for sale.	Not specified	Income earning livelihood activities
15	F	Young	1	2	Increased awareness about health issues. This could include demonstrations on how to prepare healthy food. This would require more trained practitioners visiting communities	Outside experts	Awareness & training
4	M	Old	2	2	Provision of business opportunities within villages, for example all basic services and needs should be available in each village. This will also need to be supported with markets to export to other places in the Solomon Islands. Competitive businesses should be encouraged rather than community-based approaches because of in-fighting. Example given: High quality fish export to Honiara	Government Outside experts	Awareness & training Development activities Income earning livelihood activities
9	M	Old	2	1	Plant pest resistance crops. To do this, a variety of crops need to be planted and then observe what is resistent. Kastom Garden could help this.	NGOs Outside experts	Improving productivity and sustainability of resources Traditional or kastom method
9	M	Old	2	1	Trainings on composting to improve fertility. Kastom Garden could help this.	NGOs Outside experts	Awareness and training Improving productivity and sustainability of resources Traditional or kastom method
10	M	Old	2	1	Encourage a return to eating traditional foods through changes in the education system. The education system should be a combination of kastom teachings and standardised british system	Outside experts	Awareness and training Traditional or kastom method
14	M	Mid	1	2	Awareness and education to encourage people to exercise and on nutrition	Outside experts	Awareness & training
18	M	Young	1	2	Youth programs to encourage young people to help their families and communities with basic needs. This will help to teach them good values and respect. A focus should be on self sufficiency to reduce the need for cash	Outside experts	Development activities
18	M	Young	1	2	Providing services within communities such as health care so that money is not spent on travelling to clinics	Outside experts	Development activities

3. Youth problems

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
8	M	Old	2	1	Youth training programs for young people to be self-reliant. Teach youth to utilise their resources: fishing and gardening, carpenting, building, kastom craft, canoes, paddles, mats, carving etc.	Outside experts	Awareness and training Income earning livelihood activities Traditional or kastom method
10	M	Old	2	1	Change the primary education system to emphasise more kastom ways and traditional living	Government	Awareness and training Traditional or kastom method
14	M	Mid	1	2	Provide employment opportunities	Outside experts	Development activities
14	M	Mid	1	2	Provision of support groups such as AA	Outside experts	Awareness and training
2	M	Mid	1	2	Youth training programs based on field schools, passing on traditional knowledge	Outside experts	Awareness and training Traditional or kastom method
16	F	Old	2	2	Awareness programs and trainings for parents, teaching them ways to make money from the resources they have	Outside experts	Awareness and training Income earning livelihood activities
17	M	Old	2	2	Youth sports programs and local clubs. This could be organised by the local churches	Church	Development activities
7	M	Old	2	1	Youth training programs to teach traditional ways	Outside experts	Awareness and training Traditional or kastom method
11	M	Old	2	1	Youth training programs on new livelihood opportunities, such as chicken farming, piggeries, baking and sewing. These opportunities need to be suitable for the Roviana context. E.g. livestock species needs to be fed on what is cheap and available. NGOs should work with local organisations to do these trainings.	NGOs	Awareness and training Income earning livelihood activities

4. Resource depletion

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
6	M	Old	1	1	Top-down logging regulations	Government	Regulation
6	M	Old	1	1	Awareness events for communities to make them more savvy to logging companies, and more involved in the decision-making process which is normally exlusive to the tribal chiefs	Outside experts	Awareness and training
17	M	Old	2	2	Encourage community plantations (e.g. copra) as an alternative income source to logging. This requires transport facilities and a viable market Ecoresorts as an alternative income source to resource harvesting	Outside experts	Income earning livelihood activities
18	M	Young	1	2	Top-down marine regulations and enforcement. This could include a paid community-based enforcement program	Government	Regulation
3	M	Mid	1	2	Awareness trainings on sustainable harvesting	Outside experts	Awareness and training Improving productivity and sustainability of resources
3	M	Mid	1	2	Provincial and National government regulation and enforcement of harvesting (sea and land)	Government	Improving productivity and sustainability of resources Regulation
3	M	Mid	1	2	Provision of access to funding schemes for communities to carry out sustainable resource activities. Communities and individuals need to be trained on how to get funding	Outside experts	Awareness and training Improving productivity and sustainability of resources
3	M	Mid	1	2	Community-based management of resources with additional enforcement support from government	Government	Improving productivity and sustainability of resources

							Regulation
3	M	Mid	1	2	Form a taskforce for the lagoon with experts from different sectors, communities and government to identify the problem and carry out solutions	Government NGO	Improving productivity and sustainability of resources
6	M	Old	1	1	Marine protected areas with people paid to patrol. This could be a community/provincial government collaboration	Government NGO	Improving productivity and sustainability of resources Regulation
10	M	Old	2	1	Awareness trainings on how to maximise the community benefits from logging and mining companies. This requires government involvement and a legal framework to help in negotiations	Government Outside experts	Awareness and training

5. Weakened community leadership

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
2	M	Mid	1	2	Strengthen leadership, but not sure how	Not specified	Traditional or kastom method
5	F	Old	1	2	Stengthen leadership, and wisdom of leaders, but not sure how	Not specified	Traditional or kastom method
11	M	Old	2	1	Strengthen leadership to uphold traditional ways, but not sure how	Not specified	Traditional or kastom method
11	M	Old	2	1	Improve transparency of money dealings with logging companies, NGOs and donors within the whole community and not only the leaders, to prevent corrupt behaviour	Not specified	Other
18	M	Young	1	2	Legalise the traditional leadership structure. The chief should be subject to law and therefore there should be legal consequences to what he does. This means a corrupt chief can be removed and replaced with a chief with qualities of wisdom and fairness.	Government	Regulation Tradtional or kastom method

6. Lack of access to information

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
1	F	Young	1	2	Improve the way information is disseminated. It needs to be repeated, in a form which is easy to understand (in local language), and in a forum where people are free to ask questions. It should consider who is appropriate and legitimate to deliver the information. If the aim of the information is to change behaviour, then incentives need to be explained using local examples.	Outside experts	Awareness and training
9	M	Old	2	1	More awareness trainings which are condicted using an appropriate way where it is understandable and relevant. Dramas, video and drawing pictures have been shown to be good methods.	Outside experts	Awareness and training
4	M	Old	2	2	More awareness trainings on different opportunities for starting businesses and livelihood activities	Not specified	Awareness and training Income earning livelihood activities

7. Land disputes

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
3	M	Mid	1	2	The church should be involved in leading workshops to teach communities about the environment and sustainable resource use. The church is important because it reaches everyone and church leaders are respected	Church	Awareness and training Improving productivity and sustainability of resources
12	M	Old	2	1	A legal framework to register land is needed	Government	Regulation
2	M	Mid	1	2	A legalised land reform program is needed which will document the genealogy to determine tenure.	Government	Regulation
8	M	Old	2	1	A legal framework to register customary land and sea, using kastom methods	Government	Regulation Tradtional or kastom method
16	F	Old	2	2	Provincial government help to resolve land disputes	Government	Regulation

8. Health

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
15	F	Young	1	2	Awareness trainings on health issues	Outside experts	Awareness and training
14	M	Mid	1	2	Free supply and distribution of free condoms to prevent STIs	Outside experts	Development activities

9. Drugs and alcohol

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
1	F	Young	1	2	To solve the problem of important income spent on drugs and alcohol, relationship and conflict resolution training should be done with the young people and children. This would teach people how to resolve conflicts and have healthy relationships with each other which could circumvent violence	Outside experts	Awareness and training

10. Family planning

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
15	F	Young	1	2	Awareness trainings of women on family planning. However, it needs to be also done differently because culture and church beliefs prevent birth control in some cases	Church Outside experts	Awareness and training

11. Unpredictable weather

Expert ID	Gender	Age	Knowledge type*	Decision maker type**	Issue solution summary	Actor type	Action type
12	M	Old	2	1	Alternative livelihood options like making handicrafts to sell, to earn money	Outside experts	Income earning livelihood activities

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