

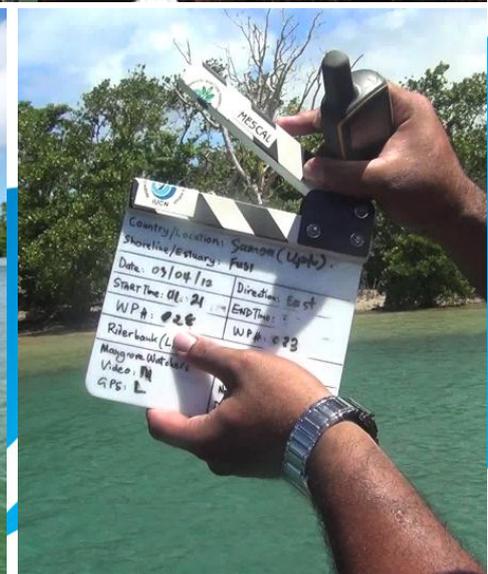
MESCAL

MangroveWatch assessment of shoreline mangroves in Samoa

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1 EXECUTIVE SUMMARY

- 1) This report documents findings from the program of works for 2012-2013 directed by Dr Norm Duke with the Samoa MESCAL Technical Working Group involving their training, support and consultation, prescription of methodology and approach, as well as the compilation and preliminary assessment of data received.
- 2) This report details data generated from recent 2013 shoreline video assessment MangroveWatch surveys undertaken by MESCAL Samoa Technical Working Group and associates. The data in this report has been analysed and compiled by the MangroveWatch science hub at the Australian Centre for Tropical Freshwater Research (TropWATER), James Cook University, Townsville, Australia.
- 3) The information in this report is designed to serve as a baseline for future mangrove monitoring along targeted coastlines, enabling future fringing mangrove health to be monitored effectively and providing a means to compare mangroves along the target shoreline with nearby areas in Samoa and elsewhere in the Pacific
- 4) The information presented here is designed to assist natural resource managers to identify and target specific issues that threaten mangroves in Le Asaga Bay, Samoa.
- 5) A key outcome of these initial MangroveWatch surveys is a long-term visual baseline of mangrove extent, structure and condition along 7.8 km of Le Asaga Bay shoreline that will provide an accurate means of assessing future change in years to come.
- 6) The results of this survey demonstrate the effectiveness of engaging local staff and community members to assess mangrove shoreline habitats using the MangroveWatch shoreline video assessment method (SVAM) with assistance from external experts to identify local threats and monitor habitat condition.
- 7) Mangroves in Le Asaga Bay are of high ecosystem value and provide a valuable buffer between land and sea due to their high structural complexity. Damage from high winds during Cyclone Evan is evident along 40% of the mangrove shoreline. Clearing of mangroves in front of houses and infrastructure has likely contributed to coastal erosion in cleared areas. Bank hardening is obvious along most cleared shorelines. Mangrove cutting and harvesting present along 5% of mangrove shoreline shows that greater awareness of the importance of fringing mangroves for shoreline protection and sea level rise buffering is needed locally. Communities should be encouraged to protect fringing mangroves from damage, particularly in currently exposed areas.
- 8) This report provides baseline data and imagery that presents a unique opportunity to monitor mangrove recovery after Cyclone Evan and determine appropriate management response to improve mangrove resilience in the future.
- 9) Information regarding the extent to which fragmentation and disturbance of fringing mangroves can occur without greatly reducing habitat function and integrity is required for sustainable management. Broad scale assessments of mangrove shorelines combined with long-term monitoring will provide this information. The MESCAL project provides a first step towards achieving this goal.

TABLE OF CONTENTS

1	Executive summary	i
2	Introduction	4
2.1	What is MangroveWatch?	4
2.2	MangroveWatch Mission Statement	5
2.3	Why monitor shoreline mangroves – the importance of mangroveswatch	5
2.4	The importance of fringing mangroves	6
2.5	The MangroveWatch approach	7
2.6	Benefits of the MangroveWatch Approach	8
3	Methods	9
3.1	Shoreline Video Assessment Method (SVAM)	9
3.2	Shoreline Video Assessment Method (SVAM) survey location	9
3.2.1	Video imagery assessment	10
3.2.2	Features assessed and assessment criteria	10
3.2.2.1	Mangrove forest presence and biomass	11
3.2.2.2	Mangrove condition	12
3.2.2.3	Mangrove value	14
3.2.2.4	Shoreline change and mangrove forest process	15
3.2.2.5	Habitat fragmentation	16
3.2.2.6	Drivers of Change	17
4	Results	18
4.1	Survey area covered	18
4.2	Forest presence, biomass, physical value and habitat diversity	18
4.3	Condition of fringe mangrove forest	23
4.4	Forest process	23
4.5	Fragmentation of fringe mangrove forest	26
4.6	Drivers of change	26
5	Discussion	29
6	References	32

2 INTRODUCTION

In April 2013 MESCAL Samoa Technical Working Group and associates undertook a survey of fringing mangrove habitats in Le Asaga bay at the MESCAL demonstration site using the MangroveWatch Shoreline Video Assessment Method (SVAM). This report details the results of this survey, with assessment provided by the MangroveWatch hub at JCU.

This report adds to previous progress reports summarising new findings and observations about biodiversity, structure and condition of mangrove ecosystems in the five MESCAL countries, Fiji, Samoa, Tonga, Vanuatu and Solomon Islands. This data within this report specifically focuses on the structure and condition of fringing mangroves in the surveyed area and details natural and anthropogenic threats that affect mangrove function and resilience.

This component of the MESCAL project has 4 key activities in each of the five countries – mapping and verification (A), floristics and biodiversity (B), biomass and carbon evaluation (C), and shoreline health monitoring (D). This combination of activities makes up an important part of this Coastal Health Archive and Monitoring Program for the region.

This shoreline assessment work has only been possible after receipt of sufficient information collected by participants, with significant primary data received up to April 2013. These data have now been carefully assessed and processed with considerable effort made in checking data quality and its veracity, as far as practical.

2.1 What is MangroveWatch?

MangroveWatch is a community-science partnership and monitoring program aimed at addressing the urgent need to protect mangroves and shoreline habitat worldwide.

The MangroveWatch program began in 2008 in the Burnett-Mary region of Australia with support from Caring for Our Country; an Australian Government Initiative.

MangroveWatch is now currently operating in Australia and 5 Pacific Island Nations; Fiji, Samoa, Solomon Islands, Tonga and Vanuatu.

In Australia, MangroveWatch monitoring is occurring in the Torres Strait, Daintree River, estuaries in the Port Curtis and Coral Coast region, the Burnett, Elliott and Burrum rivers, Tin Can Bay, Noosa River, Pumicestone Passage, Brisbane River and Moreton Bay. There are currently over 300 registered MangroveWatch volunteers from 20 different corporate, non-government and government organizations.

The MangroveWatch scientific hub is based at the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Townsville.

2.2 MangroveWatch Mission Statement

To provide coastal stakeholders with a tool to assess and monitor local shoreline habitats that;

- *is scientifically valid*
- *engages and empowers local people*
- *promotes effective coastal resource management*
- *provides a visual baseline from which to assess future change.*

For more information on MangroveWatch visit: www.mangrovetwatch.org.au



Figure 2.1 Samoa MESCAL mangrovetwatching in Le Asaga Bay,

2.3 Why monitor shoreline mangroves – the importance of MangroveWatch

Mangroves provide important goods and services to coastal environments that support and protect local economies, and social, cultural and heritage values of coastal communities.

These values are commonly referred to as ‘ecosystem services’. Mangroves provide 7 key ecosystem services to Pacific Island communities;

- **Providing fish habitat & supporting nearshore fisheries** (Manson et al. 2005, Meynecke et al. 2008)
- **Shoreline protection** (Alongi 2008, McLeod et al. 2008, Mclvor et al. 2012a, Mclvor et al. 2012b)
- **Providing timber and non-timber forest resources** (Prescott 1989, Rohorua and Lim 2006, Walters et al. 2008, Warren-Rhodes et al. 2011)
- **Water quality improvement** (Alongi 2002, Adame et al. 2010)
- **Visual & recreational amenity** (Salem and Mercer 2012)
- **Carbon Storage** (Donato et al. 2011)
- **Supporting local biodiversity** (Traill et al. 2011, Wilson et al. 2011)

For further information on mangrove ecosystem services refer to Barbier et al. (2011) and Warren-Rhodes et al. (2011)

Despite their importance, mangroves continue to be directly destroyed and degraded by poor catchment and coastal zone management. Globally, 30% of the world’s mangroves have been lost in the past 30 years (Duke et al. 2007, Polidoro et al. 2010). Mangroves are increasingly threatened in the Pacific by anthropogenic pressures such as over exploitation of resources, coastal development, pollutants and altered hydrology in the coastal zone (Ellison 2009). These factors may not reduce mangrove extent, but they do influence habitat quality, reducing the capacity of mangroves to provide ecosystem services (Gilman et al. 2006, Alongi 2008).

Mangrove habitat degradation greatly reduces the capacity of mangroves to respond to the impact of future climate change (Gilman et al. 2008). The location of mangroves at the shoreline edge places them in the direct line of climate change impacts; sea level rise, more severe and frequent storms and more frequent drought and floods (Alongi 2008, Hoegh-Guldberg and Bruno 2010, Knutson et al. 2010) (Lovelock and Ellison 2007). Reduced habitat condition, reduced biodiversity and habitat complexity and altered ecosystem processes reduce the capacity of mangroves to withstand climate impacts and their capacity of mangroves to buffer these impacts and protect adjacent coastal areas (McLeod and Salm 2006). While it is not possible to prevent climate change at the local scale, it is possible to reduce direct human related impacts that are likely to reduce capacity of mangroves to resist and recover from climate change impacts. The capacity of mangroves to respond to climate change impacts depends directly on improving local mangrove management (Gilman et al. 2008).

To effectively manage anthropogenic impacts on mangroves, it is important to identify the location of impacts and the extent to which they threaten high value habitat. This can only be achieved through systematic assessment of mangrove extent, structure and condition in relation to identified threats, and through long-term monitoring.

2.4 The importance of fringing mangroves

Fringing shoreline mangroves are extremely important components of mangrove ecosystems. The shoreline edge is where the greatest interaction and tidal exchange between the marine and mangrove habitats occurs, meaning that these fringe zones are sites of great material exchange (Rivera-Monroy et al. 1995), aquatic habitat value (Meager et al. 2003, Nagelkerken et al. 2008), and are highly important for shoreline protection and water quality improvement (Kieckbusch et al. 2004). As such maintaining the condition of fringing mangroves is essential to maintaining mangrove ecosystem services and protection of inner forest areas where they are present.

2.5 The MangroveWatch approach

MangroveWatch provides data on the extent, structure and condition of shoreline habitats in estuaries and along protected coastlines. The generation of this information relies on the annual collection of geo-tagged video imagery of shoreline habitats using the Shoreline Video Assessment Method (SVAM) employed by trained community members and organisations.

MangroveWatch is a 5-step process (see Figure 2.2);

- 1. Community Training and Information Session by the MangroveWatch Hub.**
MangroveWatch participants are provided with a MangroveWatch kit, trained in data collection methods and discuss the importance of mangroves, local threats and issues.
- 2. Community video monitoring**
MangroveWatchers collect geo-tagged video of local shorelines
- 3. Data Transfer**
Video and GPS data is transferred to MangroveWatch science team at James Cook University
- 4. Data assessment by mangrove scientists**
MangroveWatch video data is analysed by scientists to determine extent, structure and condition of shoreline habitats.
- 5. Data feedback to coastal stakeholders.**
Data is presented back to the community in report form.

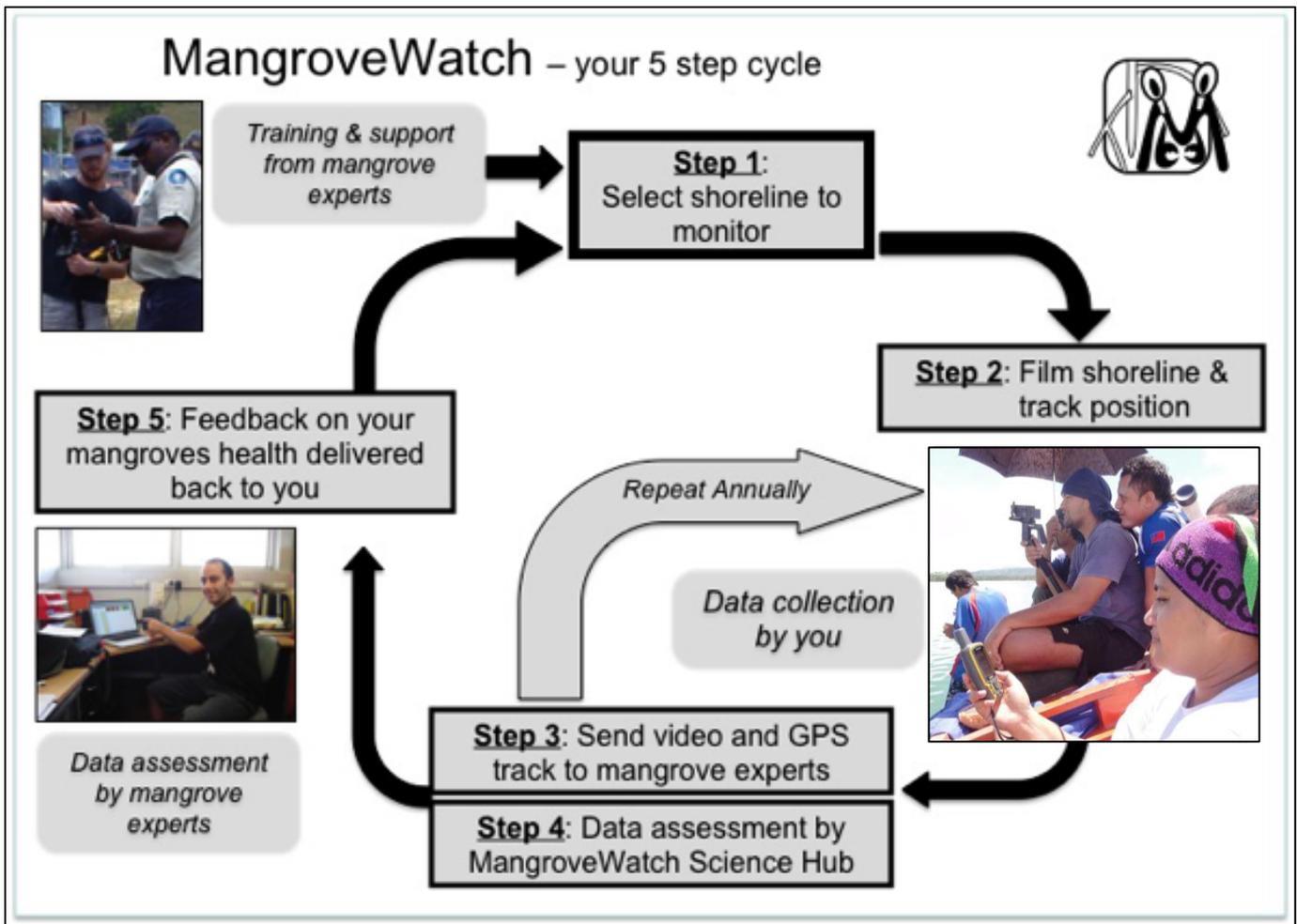


Figure 2.2 The MangroveWatch approach

2.6 Benefits of the MangroveWatch Approach

The Shoreline Video Assessment Method (SVAM) used for MangroveWatch is the perfect tool for citizen science. The advantages of SVAM are that it is;

Easy to do - only limited technological skills are required to operate a video camera, handheld GPS and digital still camera

Scientifically valid - No objective decision making is required by community participants as all imagery is assessed remotely by mangrove experts. Video data enables data quality control. The GPS track ensures repeatability. Video image assessment is backed up by groundtruthing and accuracy assessments

Rapid – Video imagery can be collected quickly allowing large areas to be assessed with minimal time commitment from MangroveWatch community participants. On average, 10km of shoreline only requires 1 hour of filming.

A permanent visual record – video imagery data provides a permanent visual record from which to assess future change and overcomes shifting baseline of environmental perception. Our intention in the near future is to make all video image data available via the MangroveWatch website.

A whole of system assessment – A continuous collection of geo-tagged shoreline images allows for the quantification of data across entire estuaries, rather than from a collection of random points along the bank or within the forest. This allows shoreline habitat features and process to be seen within the context of the whole system that better informs estuary and coastal management.

Partnering scientists with local people greatly improves our understanding of shoreline habitats and is one of the major advantages of the MangroveWatch approach.

Working with local people enables;

Local knowledge input – Local people provide locally relevant information that enhances scientific assessment and provides local context to shoreline habitat assessment. Local observations of change, historical information and knowledge of local values are highly valuable insights.

Large spatial coverage – there are very few mangrove scientists and many keen local mangrove enthusiasts. Working with local people means that more information can be gathered from more places to improve our understanding of shoreline habitats.

Community education, empowerment and environmental stewardship– When local communities are informed they are empowered. By working with scientists, local people can gain more information on the value of their local mangroves and the issues that affect them, empowering them to take action at the local scale.

3 METHODS

3.1 Shoreline Video Assessment Method (SVAM)

Mangroves have the distinction of forming a unique marine habitat that is both forest and wetland. As such, they form an important component of a number of international conventions that recognize their uniqueness and immense value to both coastal and marine communities, and mankind in general (eg. Duke et al. 2007). It is essential that the assessment of such a valuable resource be conducted in a rigorous and practical way.

The MangroveWatch SVAM approach enables a whole-of-system assessment of shoreline mangrove forest structure and condition using georeferenced continuous digital video recording of shoreline. Video imagery is collected using a Sony Handycam from a shallow-draft boat travelling parallel to the shoreline at a distance of ~25 m, at a speed between 4 and 6 kts. The video camera is positioned to record directly perpendicular to the direction of travel at all times. Shoreline video imagery is collected with a concurrent time-synchronised 2-second interval GPS track to provide spatial reference to the imagery. Voice recording of observations on mangrove species composition, structure, condition and threats are made during recording with local observations and context provided by a local MangroveWatchers.

3.2 Shoreline Video Assessment Method (SVAM) survey location

The MESCAL Samoa Technical Working Group surveyed fringing mangrove habitat along Le Asaga Bay shoreline, on the south coast of Upolu (Figure 3.1). Le Asaga Bay is the MESCAL demonstration site in Samoa, lying within Safata, one of two, district-wide, Marine Protected Areas in Western Samoa (Govan 2009). Samoa experienced significant tsunami impacts during September 2009. The tsunami caused widespread damage to coral reefs and coastal ecosystems, infrastructure, and losses of human life (Fritz et al. 2011, McAdoo et al. 2011, Richmond et al. 2011). During late 2012, Cyclone Evan, the worst cyclone since 1991 affected Samoa,

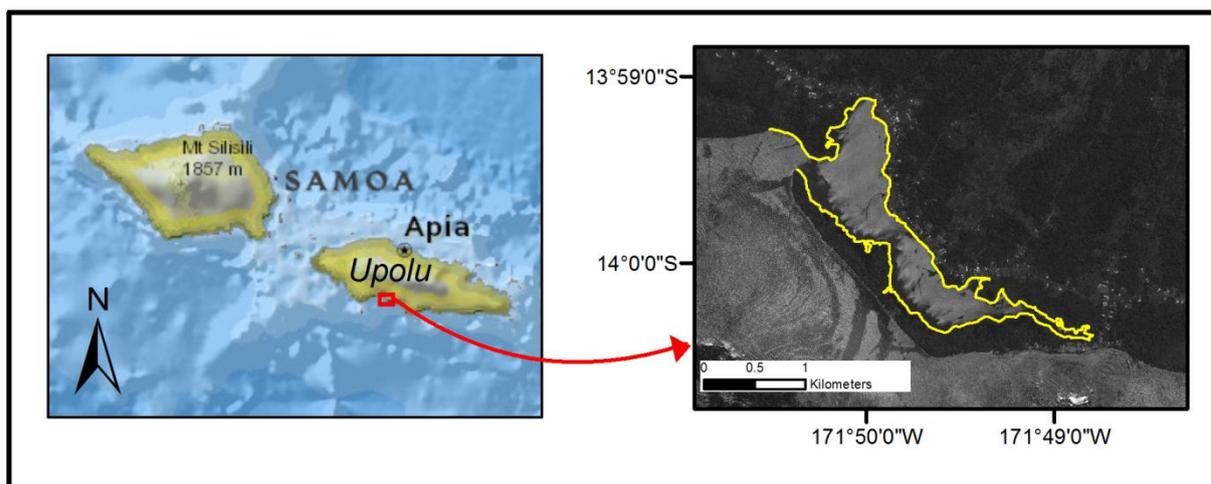


Figure 3.1 Location of MESCAL demonstration site at Le Asage Bay, Upolu

3.2.1 Video imagery assessment

Shoreline mangrove forest features are recorded from the video using visual criteria-based classification. The video is first divided into 1-second jpeg frame images. The video time stamp and GPS track enable each frame to be related to a position along the shoreline (+/- 10 m). Using ArcGIS 10.0, the shoreline is divided into 10 m sections and each section related to a video frame such that the imagery seen between 2 frame locations represents 10 m of shoreline. The 10 m sections of coastline are then classified according to a set of visual criteria designed by the MangroveWatch Hub. All classification is based on the visible fringing mangroves intersecting the centre line of the video frame.

A number of factors influence the ability for video imagery to be accurately assessed remotely, and/or accurately geo-referenced to a 10 m shoreline section. Where the following occurs, a *No Data* value is given to the shoreline section, and projected on mapping products;

- Where the boat is positioned far from the shoreline (more than 150 m offshore), the boat does not follow the curvature of the coastline or is travelling at a speed greater than 10 kts per hour, the quality of the imagery collected may not good enough to be accurately assessed and so is excluded from the assessment.
- Where the boat distance becomes greater than 150 meters from the shore, the boat does not follow the curvature of the coastline, or an accurate GPS track from the Garmin GPS is not available, a match between GPS track and adjacent shoreline cannot be made. As such, no assessment data can be related to the 10 m shoreline section, and the imagery data is excluded from the assessment.
- In instances where no Garmin GPS track has been provided, the GPS track is reconstructed from data from the Sony Handycam. As this track is less accurate and not as 'smooth' as the Garmin track, the likelihood of null values occurring is increased.

3.2.2 Features assessed and assessment criteria

3.2.2.1 Mangrove forest presence and biomass

Mangrove biomass describes the mass (kg/ha) of mangrove within an area. It can be used as a proxy for mangrove carbon storage and productivity and more generally relates to the overall functional value of a forest. Forest biomass is related to the size of the trees and their density. For SVAM assessment, the biomass score is a composite score of fringing mangrove *canopy height classification* and *mangrove forest structure classification*. The biomass score is a relative score that is indicative only but enables comparison between areas within the same region.

Canopy height was visually estimated using height classifications based on forest biomass assessments in the region (Duke et al. 2013) and local knowledge recorded during the surveys (Table 1). Recent results comparing visual height estimates to actual heights recorded using a laser hypsometer have shown these visual estimates are accurate to within 2 m (Duke & Mackenzie, 2010). Canopy height of mangrove forests has recently been shown to be highly correlated with mangrove biomass (Duke et al. 2013).

Mangrove forest structure classification describes the stem density of the forest (Table 1). The mangrove biomass score is calculated using estimated heights factored to a score out of five based on the upper height value recorded (Table 1). The factored height score represents the biomass score at maximum stem density (5 =closed-continuous forest). Where forest stem density is less than 5, the biomass score is reduced relative to the stem density as a proportion of the maximum (e.g. where stem density is 4, open-continuous forest, the biomass score equals height score * 0.8). The biomass score is a relative score that is indicative only but enables comparison between areas within the same region.

Examples of mangrove forest assessed as of biomass scores 1 to 5 are provided in Figure 3.2

Table 1 Mangrove biomass assessment criteria

<i>Mangrove Biomass Score</i>	0	1	2	3	4	5
Height classification	No Mangrove	Canopy height <2m	Canopy Height 2-4m	Canopy Height 4-6m	Canopy Height 6-8m	Canopy Height >8m
Forest structure classification	N/A	Scattered mangrove – individual trees. 1 or 2 trees	Sparse mangrove – individual trees >2m apart or small patches.	Open forest. Linear mangrove presence but spaces between canopy crowns	Open-continuous forest. Canopy crowns touching and overlapping.	Closed-continuous forest. Crown canopies intermingling

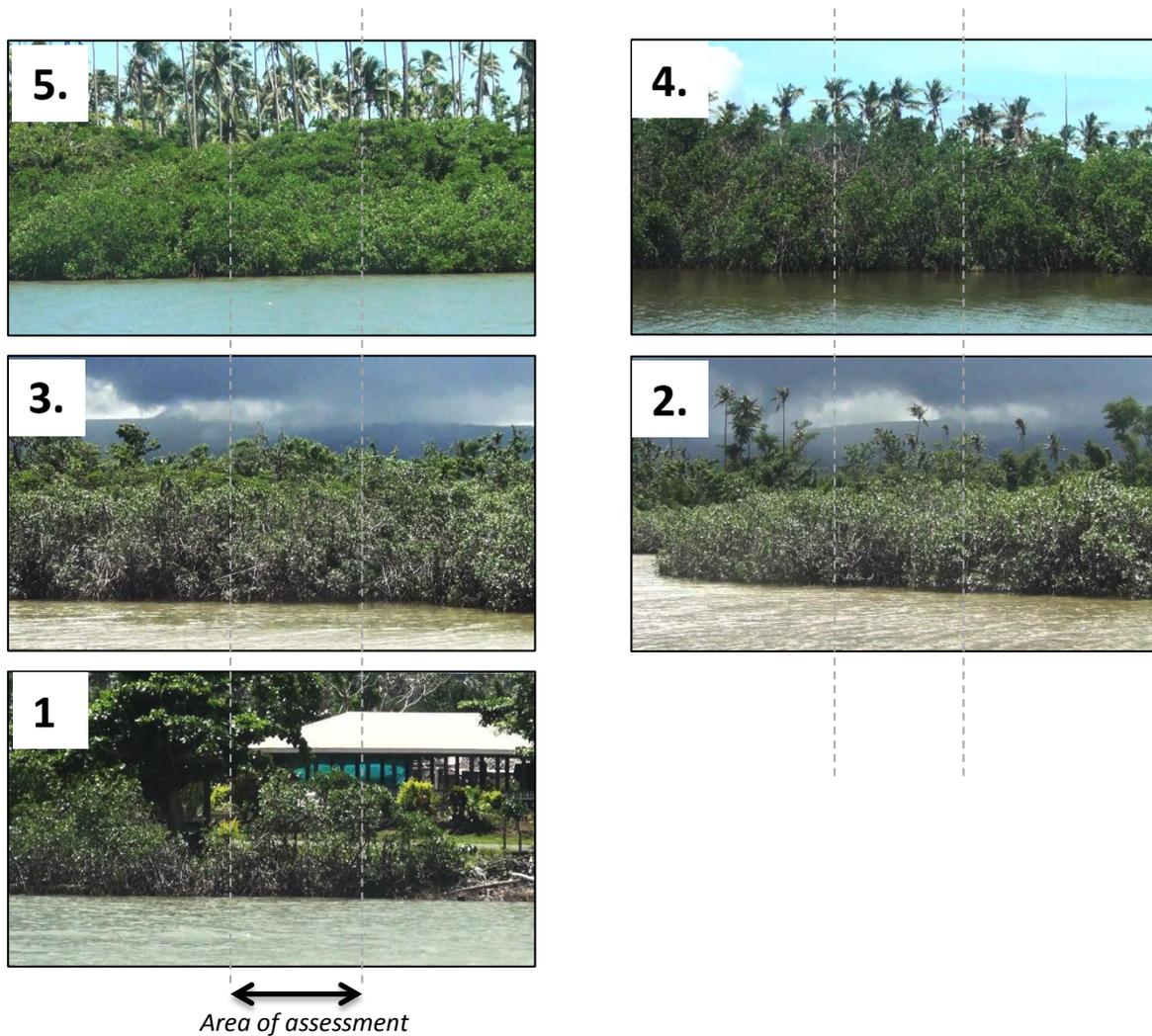


Figure 3.2 Example video stills of mangrove biomass assessment scores

3.2.2.2 Mangrove condition

The mangrove condition score describes the overall health of the fringing mangrove forest. Mangrove condition is visually assessed using presence of canopy dieback, dead trees and canopy density. Canopy dieback describes the presence of visible dead stems and branches ranked from 0 to 5, with 0 being the presence of dead trees. Examples of mangrove forest conditions scores 1 to 5 are provided in Figure 3.3. Canopy density describes mean percentage canopy cover for fringing mangroves and the dominant canopy layer ranked from 1 to 5 as outlined in Table 2. Overall mangrove condition scores were generated by the following equation, giving a total score between 0 (unhealthy) and 5 (healthy);

$$\text{Mangrove condition score} = (\text{dieback score} * 2 + \text{canopy score}) / 3$$

Table 2 Mangrove condition assessment criteria

Mangrove Condition	0	1	2	3	4	5
Dieback classification	Dead tree(s) present	Severe Dieback. Many dead branches. Obvious crown retreat. Bare twigs on less than 50% of the tree and ~75% of the tree affected	Moderate Dieback – Many dead twigs, canopy retreat, dead branches present. ~50% of tree affected.	Low level Dieback - Many dead twigs present. ~25% of tree affected	Very low level Dieback – a few sticks and twigs visible. ~5% of tree affected	No Dieback present
Canopy cover classification	N/A	Very low leaf cover. Majority of branches bare or near twigs, <10% estimated leaf cover.	Low leaf cover. Visible branches with 10-30% estimated cover.	Moderate leaf cover. Visible branches with 30-60% estimated cover.	Dense leaf cover. Visible branches with estimated 60-90% estimated cover.	Full lush leaf cover, Visible branches with >90% estimated cover.

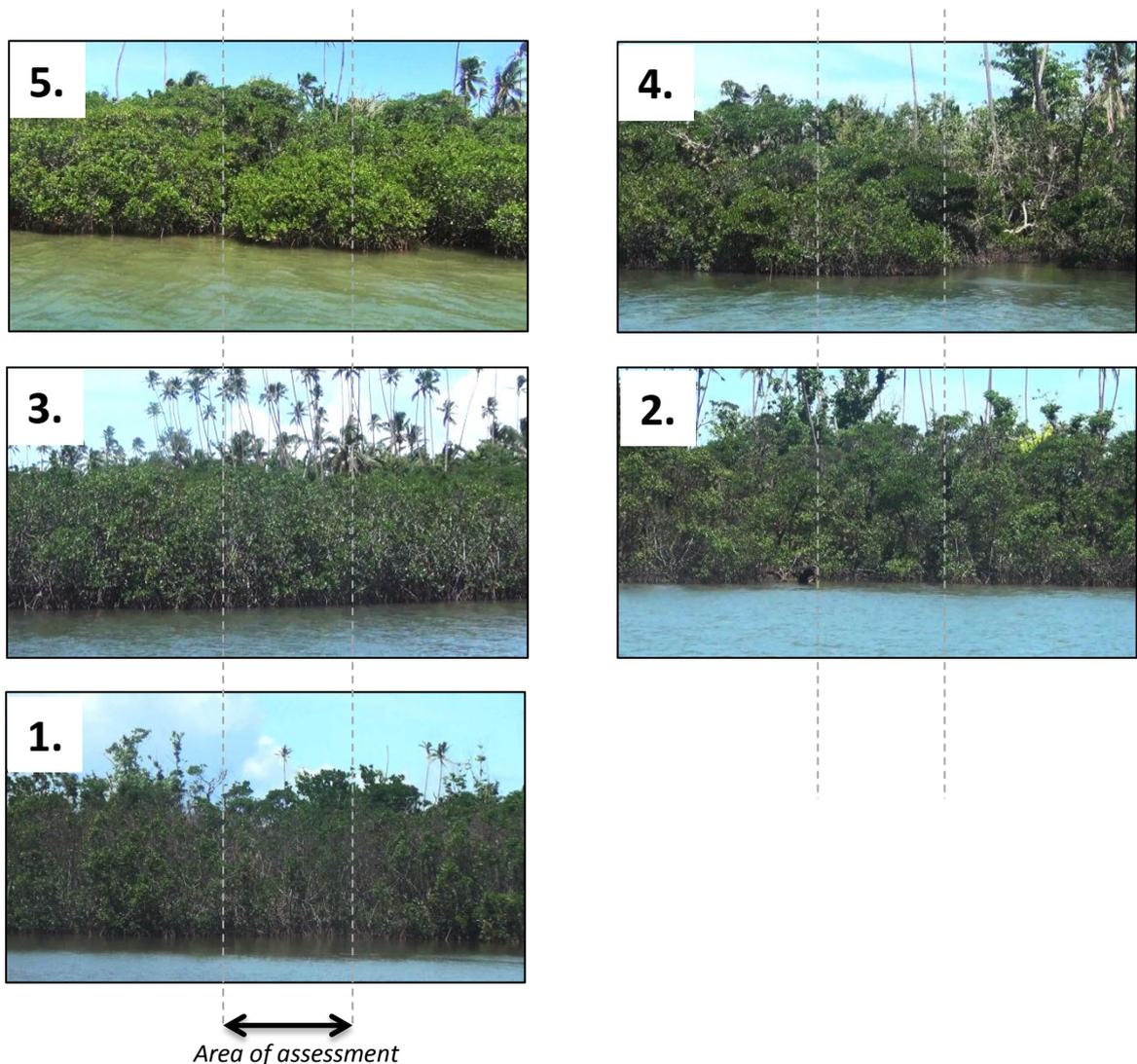


Figure 3.3 Example video stills of mangrove condition assessment scores

3.2.2.3 Mangrove value

Mangrove structural attributes are key factors determining the capacity of fringing mangroves to provide ecosystem services (Mclvor et al. 2012a, Mclvor et al. 2012b, Alongi 2008, Nagelkerken et al. 2008). Forest structure comprised of stem density, canopy cover and species diversity relates both the physical integrity of the forest fringe and also the habitat types available. Defining forest structure provides insight into the ecosystem service capacity of mangrove forests both at specific locations and at the landscape scale. Fragmentation of fringing habitat due to human activities (cutting, clearing), or natural impacts (storm damage) have obvious effects on mangrove structural integrity, and therefore impact the physical value scores generated for this assessment.

The physical value score is used as an indicator of the capacity of the fringing mangrove habitat to provide wave attenuation, shoreline stability and water quality improvement services. The physical value of mangroves used in this assessment defines the structural complexity at each shoreline location based on stem density (forest structure classification in Table 1), canopy cover (as described in Table 2), and the presence of inter-tidally submerged canopy and aerial root structures. Examples of mangrove forest assessed as of physical value scores 1 to 5 are provided in Figure 3.4

The habitat value of mangroves along a shoreline is dependent not so much on mangroves having high structural complexity *per se*, but is shaped by the presence of a variety of different habitat structures across a highly interconnected landscape (Sheaves 2005). In this assessment, the habitat value score considers the richness, structural diversity and evenness of mangrove habitat structure in relation to stem density, canopy cover, inter-tidally submerged canopy, root structural diversity and forest structural diversity using Simpsons Diversity Index, where Richness (R) is the number of different structural habitat 'types', Diversity (D) is the reciprocal sum of squares of the proportion of shoreline represented by each habitat type and Evenness (E) is D/R .

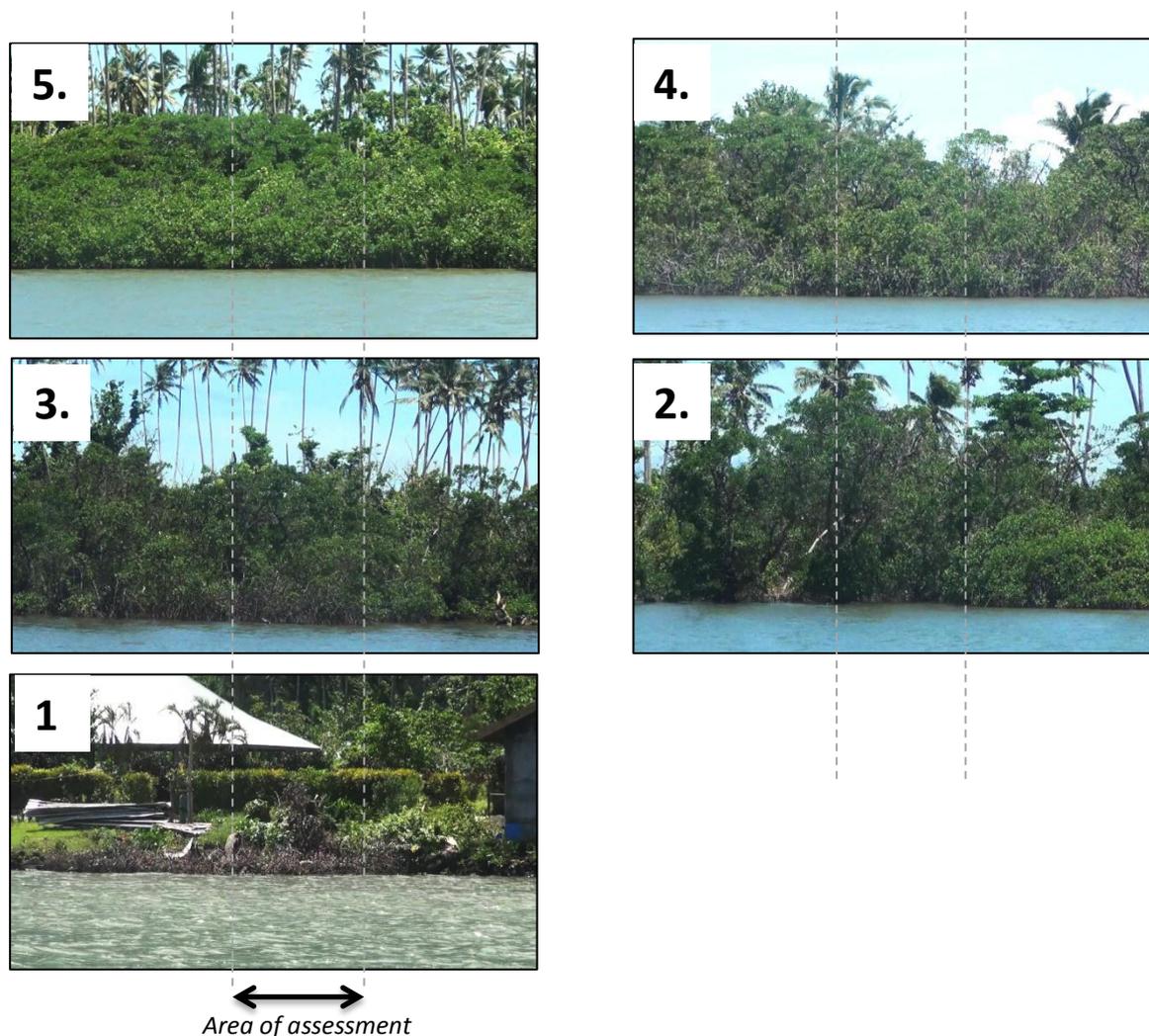


Figure 3.4 Example video stills of mangrove physical value assessment scores

3.2.2.4 Shoreline change and mangrove forest process

Mangrove forest process describes shoreline mangrove habitat identified as retreating, exposed, stable, growing or expanding. Visual indicators were used to classify these conditions (Figure 3.5, Table 3). Exposed bank is assumed to equate to high erosion potential.

Table 3 Mangrove forest process assessment criteria

Mangrove forest process	Retreating	Exposed	Stable	Growing	Expanding
Classification criteria	Undercut banks, bank slumping, fallen trees or sharp changes in bank elevation. (>45° angle)	Exposed roots and sediment visible. The absence of a mangrove fringe and obvious delineation between mangroves and shoreline with no height gradient to the shore	No visual indicators of process noted.	Emergent stems and canopy protruding above the mean canopy height. Trees have a noticeable 'pine tree' like appearance.	Dense seedlings present at the seaward mangrove edge. A noticeable height gradient decreasing to the shoreline in fringing mangroves

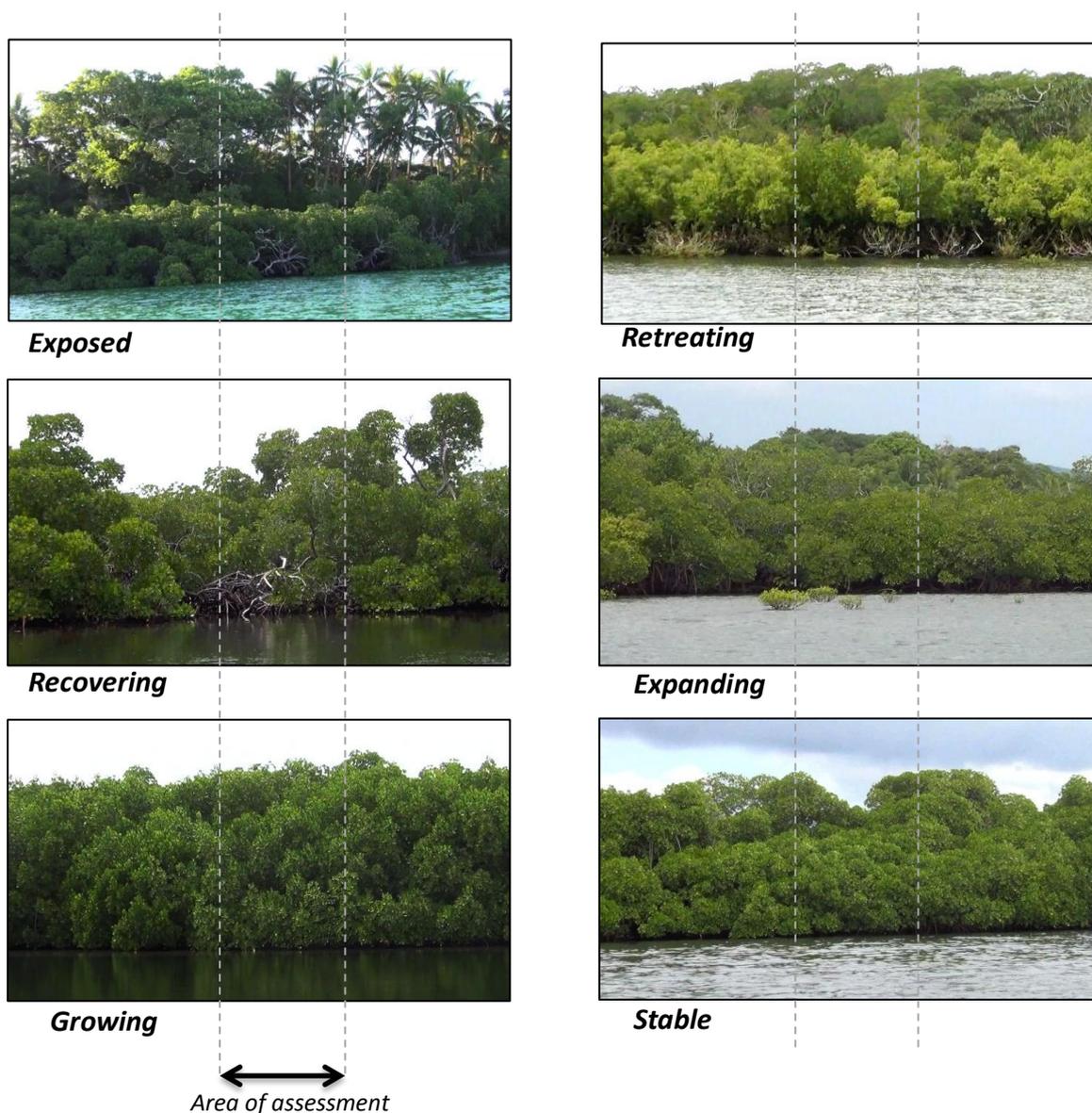


Figure 3.5 Example video stills of mangrove forest process assessment

3.2.2.5 Habitat fragmentation

Habitat fragmentation was assessed by identifying gaps in continuous mangrove stands. Gaps were classified as either naturally occurring or human generated. Human generated gaps were identified as areas where mangroves had been likely cleared for shoreline structures, shoreline access or wood harvesting. The habitat continuity score is the number of total gaps per kilometre of shoreline, as described in Table 4. The percentage of shoreline with gaps made by human activities determines the human modification score, as described in Table 4.

Table 4 Habitat fragmentation score classification

Score	0	1	2	3	4	5
Habitat continuity classification	>50 gaps/km	20-50 gaps/km	10-20 gaps/km	5-10 gaps/km	2-5 gaps/km	<2 gaps/km
Human modification classification	>40% mangrove shoreline modified	30-40% mangrove shoreline modified	20-30% mangrove shoreline modified	10-20% mangrove shoreline modified	0-10% mangrove shoreline modified	0% mangrove shoreline modified

3.2.2.6 Drivers of Change

Mangrove forests are impacted by both natural and anthropogenic drivers of change. Natural drivers include impacts from wind, waves and lightning strikes, as well as dieback associated with extended periods of low rainfall. Lightning is one of main natural drivers of mangrove forest turnover (Amir 2012), and can be easily identified by the presence of circular 'light-gaps' in the mangrove canopy. Dead trees radiate from the point of lightning contact. Here, the presence of light-gaps and canopy dieback in the fringing mangrove forest were quantified.

Natural causes of mangrove canopy dieback include drought conditions (Lovelock et al. 2009, Eslami-Andargoli et al. 2010), and storm damage which can defoliate and snap mangroves, or can lead to more indirect tree mortality through changes in sediment elevation, compaction or chemistry (Smith et al. 1994, Gilman et al. 2008).

Anthropogenic disturbance can also cause mangrove dieback, as well as often being the source of mangrove clearing and removal in populated areas. Alterations to natural hydrological regimes, for example through the creation of walls, barriers or roads in intertidal zone, can significantly alter the tidal regime of an area and cause widespread mangrove loss (Turner and Lewis III 1996). Harvesting of mangroves for timber products is common throughout the Pacific region (Warren-Rhodes et al. 2011). Root burial from sediment deposited during construction or from land-based runoff can cause loss of mangrove condition and eventually death (Ellison 1999). This assessment quantifies human impacts on fringing mangroves of the Samoa MESCAL demonstration area, such as the presence of access paths, cutting, mangrove removal for coastal development and root burial.

4 RESULTS

4.1 Survey area covered

The MESCAL Samoa Technical Working Group surveyed 7.8 km of the shoreline of Le Asage Bay on the 18th April 2013. Figure 4.1 provides detail of the GPS track of survey travel and adjacent surveyed shoreline.

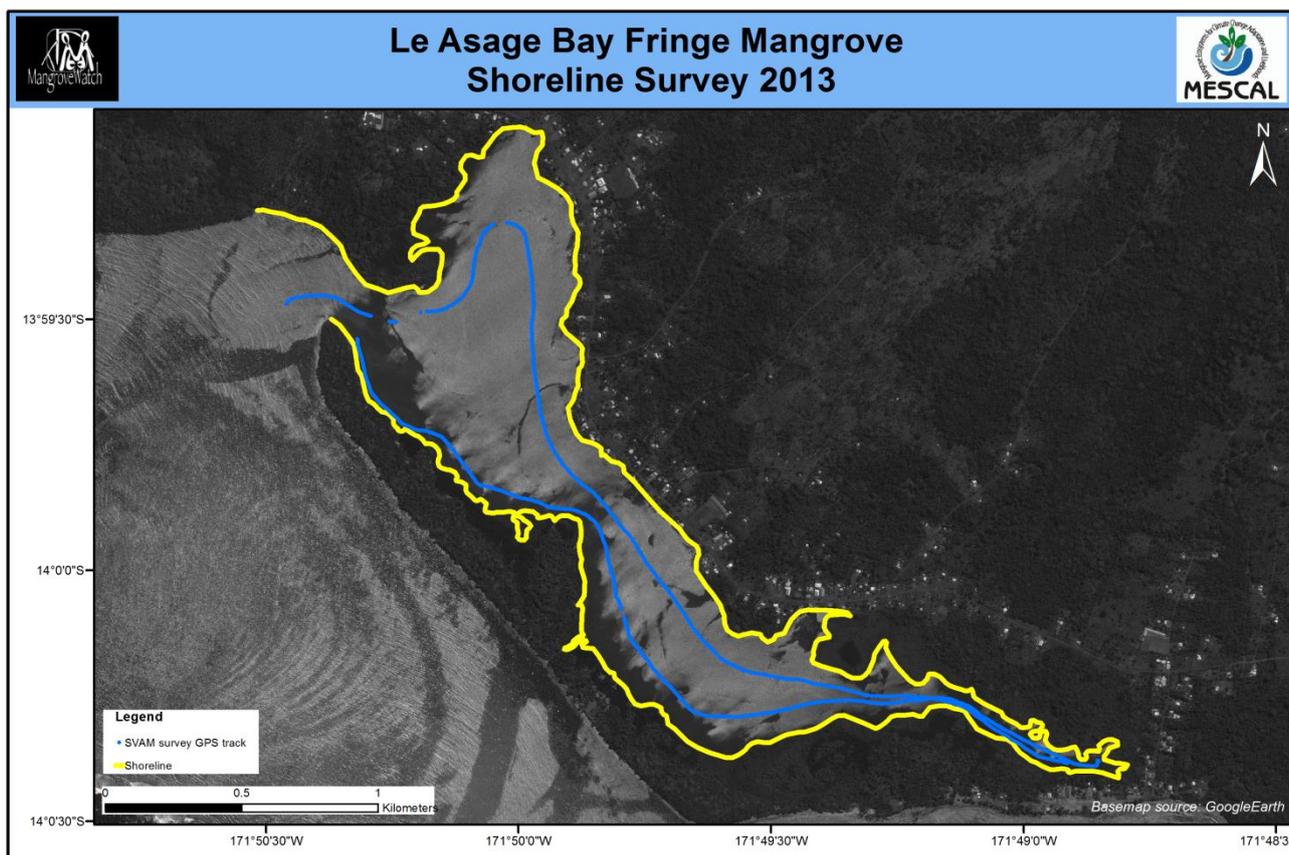


Figure 4.1 Shoreline video assessment, Le Asage Bay

4.2 Forest presence, biomass, physical value and habitat diversity

Mangroves were observed to occupy 5.96 km out of the total 7.8 km representing 76% of 10 m shoreline segments assessed. Mean shoreline mangrove percent cover was 71%. Mean forest height was relatively short at ~6 m. The fringing forest is mostly of moderate biomass (54%; Figure 4.2). Forest biomass was greatest along south-eastern shorelines in the protected areas of the lagoon. Mean mangrove forest height, structure score and biomass scores are provided in Table 5 and Table 6 provides a breakdown for the assessed forest structure, height, biomass and physical value scores. Figure 4.3 shows the distribution of physical value scores along the surveyed shoreline.

Table 5 Summary of fringe mangrove forest structure and habitat diversity. ¹Relative score as described in methods. ²Percentage of surveyed shoreline where part of the mangrove canopy becomes submerged during the tide cycle

Mean Height (m)	Mean biomass score ¹	Mean structure score ¹	Mean canopy cover score ¹	Intertidal canopy ²	Mean physical value score ¹
4 ± 0.02 <i>Tall</i>	2.8 ± 0.04 <i>Moderate</i>	4.5 ± 0.01 <i>Closed-continuous</i>	4.3 ± 0.03 <i>60-80% cover</i>	68%	3.9 ± 0.05 <i>High</i>

Table 6 Percentage of surveyed shoreline classified as falling within each forest structure score

Score	1	2	3	4	5
Height	6%	13%	26%	43%	12%
Forest structure	1.5%	6%	5.5%	13%	74%
Biomass	11%	15%	54%	19%	1%
Physical value	8%	6%	12%	34%	39%

Mangroves along the Le Asage Bay shoreline have high structural diversity along the shoreline with variation in stem density and canopy layers but with little variation in species diversity and height. The most common mangrove forest types are closed-continuous forest stands dominated by *Rhizophora* and *Bruguiera*, species with high canopy density extending to the tidal zone.

Rhizophora samoensis dominates the 75% of the shoreline, with *Bruguiera gymnorhiza* dominant or co-dominant along almost half this area (Table 7). No other dominant fringing mangrove species were identified.

Table 7 Fringe mangrove species dominance. Note; percentages add to >100% where species are co-dominant

Species name	<i>Rhizophora samoensis</i>	<i>Bruguiera gymnorhiza</i>	Co-dominant <i>R. samoensis</i> and <i>B. gymnorhiza</i>
% of shoreline dominated by species	75%	46%	21%

Fringing mangroves in Le Aasage Bay have high structural diversity ($D=11.3$) and habitat type richness ($r=50$) owing to differences in species associations and stem density along the shoreline (see Table 9). The 5 most common habitat types (Table 8) represent the mangrove habitats along the entire surveyed shoreline. This is reflected in the low habitat evenness score ($E=0.23$) showing the dominant representation by only a few habitat types.

Table 8 Five most common fringe mangrove habitat ‘types’ contributing to habitat type richness.
¹Percentage of surveyed shoreline where part of the mangrove canopy becomes submerged during the tide cycle

Habitat ‘type’	Stem density	Canopy cover	Intertidal canopy ¹	Aerial root structures	Canopy layers	% Shoreline
1	Closed-Continuous	80-100%	Yes	Prop Roots & Knee Roots	Fringe & Upper Canopy	37%
2	Closed-Continuous	80-100%	Yes	Prop Roots	Upper Canopy Only	29%
3	Closed-Continuous	60-80%	Yes	Prop Roots & Knee Roots	Fringe & Upper Canopy	22%
4	Closed-Continuous	60-80%	Yes	Prop Roots	Upper Canopy Only	19.5%
5	Closed-Continuous	60-80%	No	Prop Roots	Upper Canopy Only	12.5%

Dense closed continuous fringing forest generally has very high structural complexity that is beneficial to mangrove shoreline protection capacity and water quality improvement. As such the fringing mangroves surveyed have an overall high mean physical value score (3.9 ± 0.0 ; Figure 4.3). The value of these mangroves was reduced by poor condition resulting from cyclone Evan. The recovery of mangroves should be actively facilitated to restore the shoreline protection value as quickly as possible.



Le Asage Bay Fringe Mangrove Relative Biomass 2013

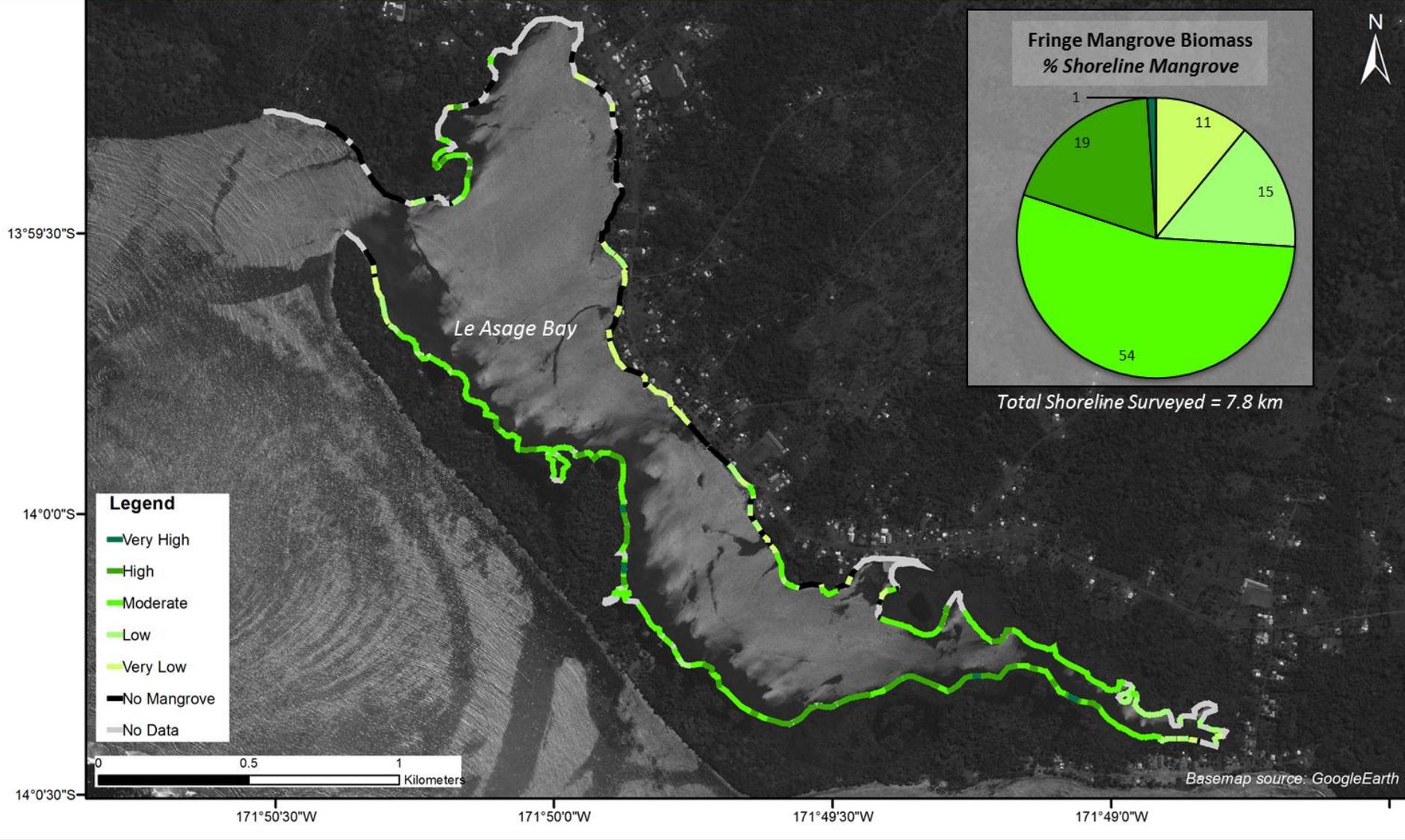


Figure 4.2 Forest biomass, Le Asage Bay fringe mangroves



Le Asage Bay Fringe Mangrove Physical Value 2013

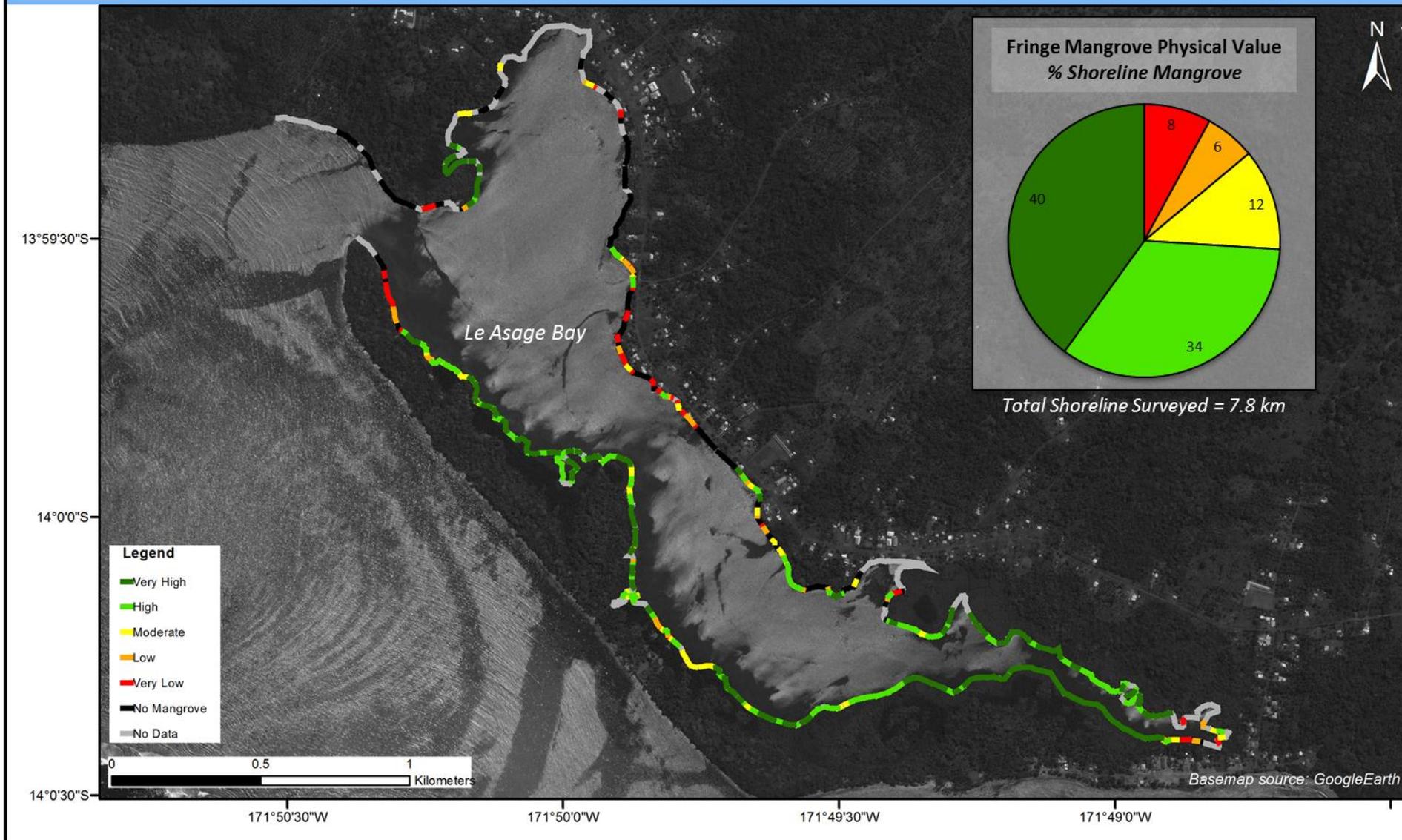


Figure 4.3 Physical value score, Le Asage Bay fringe mangroves

4.3 Condition of fringe mangrove forest

The majority of fringing mangroves along the surveyed shoreline are in very good or good health (68%) with a mean mangrove condition score of 3.8 ± 0.04 . However, only 15% of mangroves showed no sign of damage or dieback, and a moderate level of dieback was evident along almost one third of the surveyed mangrove shoreline (Table 9; Figure 4.4). Close to 10% of fringe mangroves were in poor condition. Nearly all mangroves patches exhibited signs of damage from cyclone Evan, however two sections of shoreline in the central and eastern outer lagoon had less damage than elsewhere (Figure 4.4). Forty-five individual dead trees were observed, with 7.6 dead trees per km. The mean canopy cover score was high (~60-80%); 4.3 ± 0.03 (see also Table 9 Mangrove health score distribution).

Table 9 Mangrove health score distribution

<i>Score</i>	1	2	3	4	5
<i>Dieback</i>	2.5%	14%	31%	38%	15%
<i>Canopy cover</i>	0.5%	2.5%	9%	42%	46%
<i>Mangrove condition</i>	3%	6.5%	22%	47%	21.5%

4.4 Forest process

Fringe mangrove forest is stable along 83% of the surveyed shoreline, and exhibits clear signs of retreat along 12% of the shoreline (Figure 4.5). The majority of the stable shoreline is located on the western and southern sides of the bay. Notable shoreline retreat and exposed mangroves are occurring along the central part of the eastern shoreline and mostly where mangroves stem density is low. Less than 1% of mangroves showed signs of recovery, growth and expansion.



Le Asage Bay Fringe Mangrove Forest Condition 2013

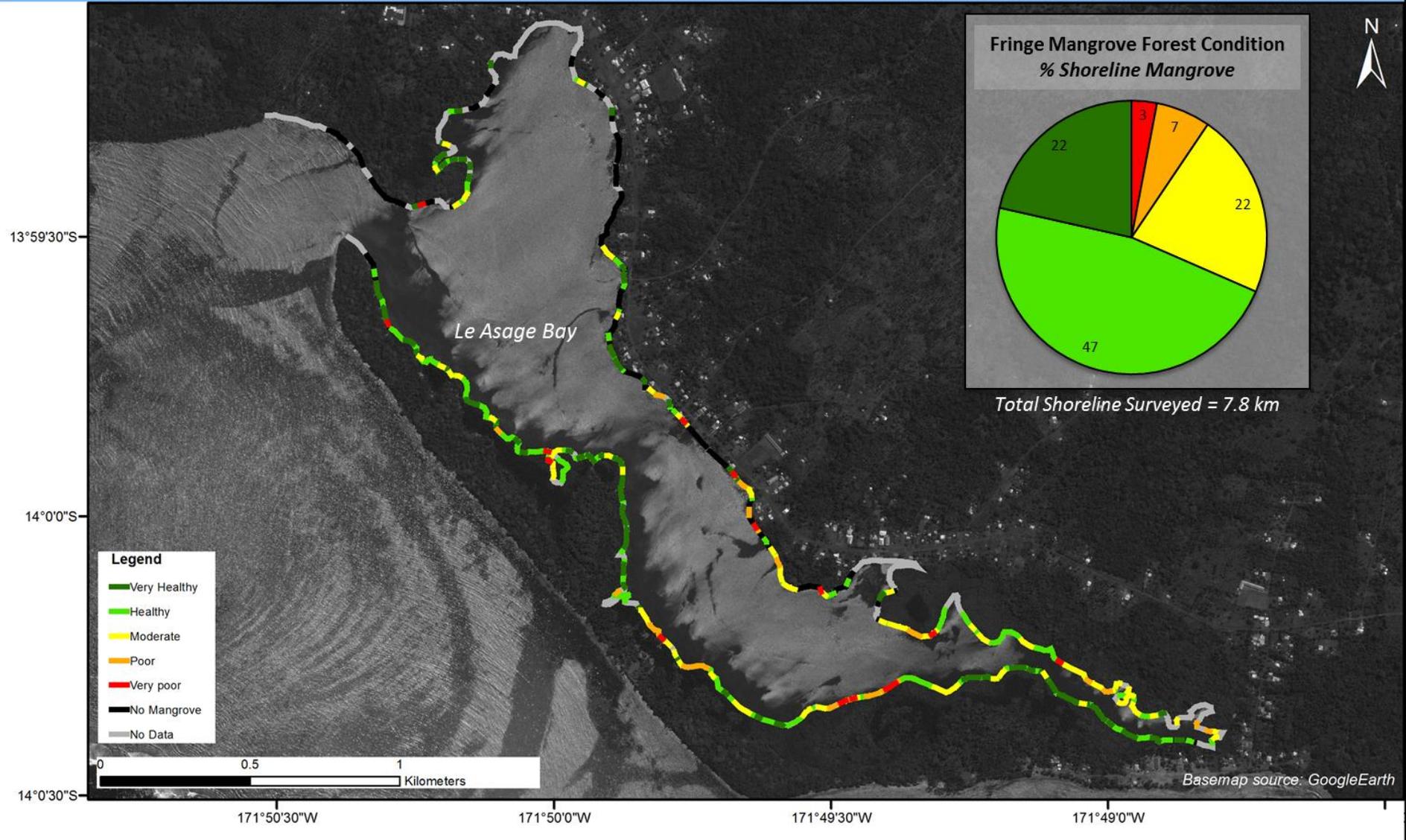


Figure 4.4 Forest condition, Le Asage Bay fringe mangroves

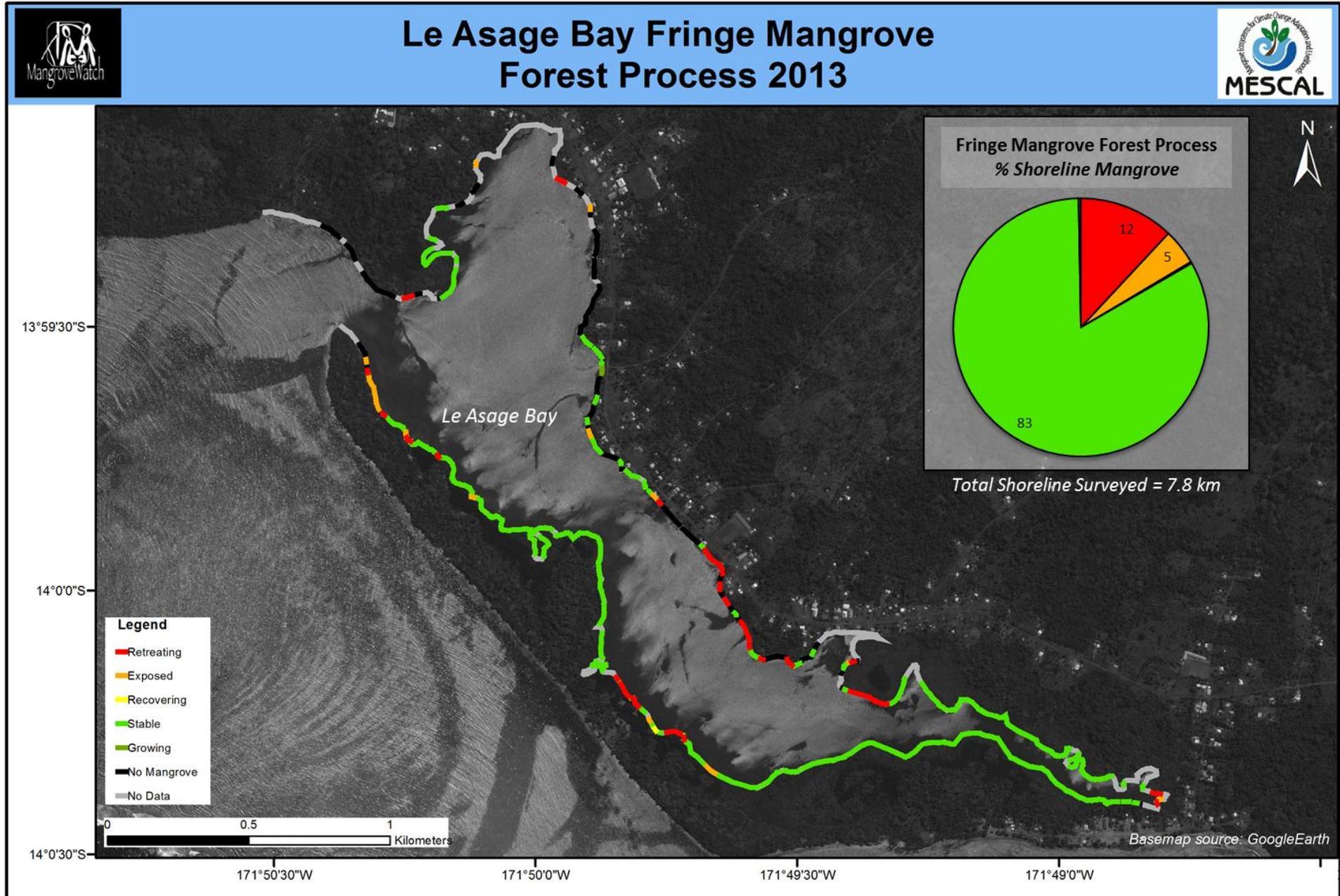


Figure 4.5 Forest process Le Asage Bay fringe mangrove

4.5 Fragmentation of fringe mangrove forest

Signs of habitat fragmentation are evident in the mangroves of Le Asaga Bay. Thirteen unnatural gaps in the fringing forest were observed from a total of 40 gaps. In total there were 5.1 gaps per kilometre of shoreline, and 2.2 unnatural gaps per kilometre of mangrove. These scores suggest that human related habitat fragmentation is moderate and of concern. The overall continuity of mangroves is high, but suggests a level of patchiness that may influence habitat and physical value. The average length of fringe forest patches was 164 m (Figure 4.6).

4.6 Drivers of change

Wind (very likely experienced during Cyclone Evan) has been a major recent driver of change in the Le Asaga Bay mangroves; crown damage from exposure to wind was obvious along 40% of the fringing forest (Table 10; Figure 4.7). Photos taken during November 2012 reveal the generally high health and low rates of dieback evident in Le Asaga Bay mangroves prior to Cyclone Evan. Waves and currents, also possibly cyclone related, have caused exposure and erosion along 17.5% of the fringing forest (Figure 4.5 and Figure 4.7). This may also have been related to the recent 2009 tsunami. The effect of both recent cyclone and tsunami events are reflected in the large amounts of low to moderate level dieback evident in the fringing forest.

Anthropogenic disturbance in the form of clearing was present for 7.5% of fringing mangrove shoreline. Litter and debris, mostly related to cyclone Evan, were obvious along ~3.5% of the shoreline (Table 10; Figure 4.7). Bank hardening was observed along 4% of the coastline. Overall, the majority of the shoreline (74%) is experiencing some degree of modification or natural damage.



Figure 4.6 Drivers of change in Le Asaga Bay mangroves: example of mangrove condition pre Cyclone Evan, Nov 2012 (top left), example of mangrove condition post Cyclone Evan, April 2013 (top right), bank hardening (bottom left), shoreline vegetation damage and debris (bottom right).

Table 10 Drivers of change in fringing mangrove forest

<i>Source</i>	<i>Driver</i>	<i>Shoreline affected (m (%of assessed shoreline))</i>
<i>Anthropogenic</i>	<i>Unnatural gaps</i>	100 (1%)
	<i>Clearing</i>	580 (7.5%)
	<i>Litter</i>	100 (1%)
	<i>Debris</i>	190 (2.5%)
	<i>Hardening</i>	320 (4%)
<i>Natural</i>	<i>Light-gap</i>	10 (<1%)
	<i>Wind</i>	3100 (40%)
	<i>Erosion</i>	1380 (17.5%)



Le Asage Bay Fringe Mangrove Drivers of Change 2013

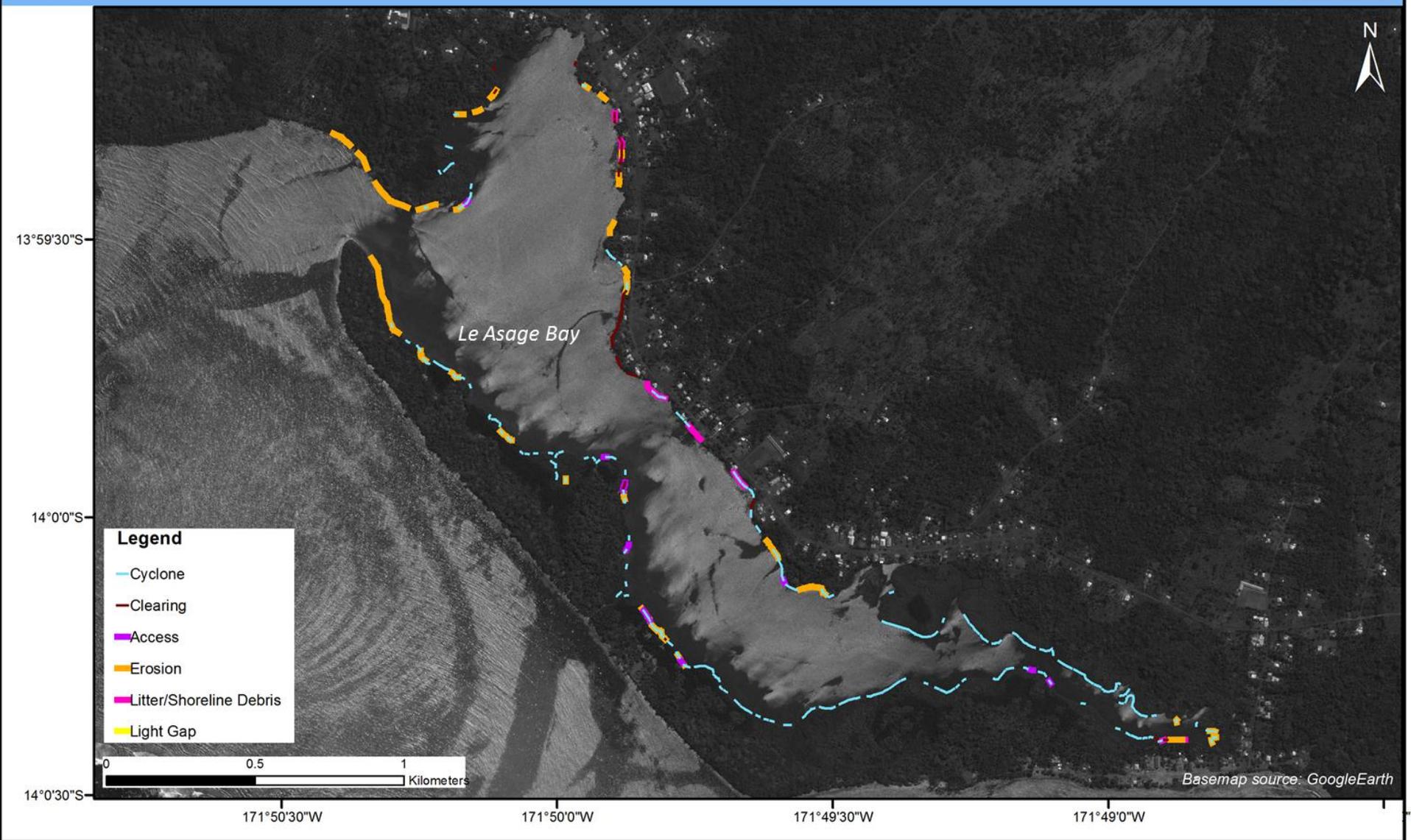


Figure 4.7 Drivers of change, Le Asage Bay fringe mangroves

5 DISCUSSION

This report provides critical baseline information to inform future management of valuable fringing mangrove habitats in Samoa for the maintenance and improvement of mangrove ecosystem resilience to climate change. Pacific Island Countries and Territories (PICTs) are especially vulnerable to climate change impacts due to their often low elevation and large coastal frontage relative to landmass (SPREP 2012). Mangroves are particularly susceptible to changes in sea level and increases in storm intensity due to their location within the tidal zone at the shoreline edge (Lovelock and Ellison 2007, Alongi 2008, Hoegh-Guldberg and Bruno 2010, Knutson et al. 2010). Tropical cyclones are the most destructive force facing the coastal environments and communities of PICTs (Kuleshov et al. 2012, SPREP 2012). In the Pacific region, climate change predictions indicate tropical cyclone intensity will increase, and the frequency of cyclones will change in the over the coming decades (Kuleshov et al. 2012, Walsh et al. 2012). Shoreline vegetation can provide significant shoreline protection to coastal communities by buffering wave action and reducing the impact of storm surge upon adjacent infrastructure (Mclvor et al. 2012a, Mclvor et al. 2012b). Tropical cyclone induced increases to wind and wave intensity have dramatic implications for mangrove forests, defoliation or snapping trees, and changing the soil elevation profile or chemistry, all of which cause mortality (Smith et al. 1994, Gilman et al. 2008).

The capacity of coastal vegetation to adapt to sea level rise and survive storm events is affected by the health and extent of the ecosystems (Alongi 2008). Reductions in extent, structural complexity, and condition of mangrove ecosystems can lead to accelerated coastal erosion, with serious implications for coastal developments and human safety (SPREP 2012).

The management of coastal vegetation for its protective capacity is identified as a worthwhile adaptation measure already being pursued in the Pacific region (SPREP 2013). The habitat value of mangroves is also well recognised, particularly for supporting local and commercial fisheries (Nagelkerken et al. 2008). Mangroves are increasingly becoming recognised as a valuable carbon store that can help in efforts to minimise destructive climate change (Donato et al. 2011). Overexploitation, pollution, deforestation, and ill-advised infrastructure development have been identified as human induced pressures facing the mangroves and coastal vegetation of PICTs generally (World Bank 2000). Management of these human pressures will help to build resilience in coastal vegetation communities (Alongi 2008), will enhance their capacity to protect coastlines and communities from erosion and storm damage (Mclvor et al. 2012a, Mclvor et al. 2012b) and will maintain other ecosystem service values such as habitat (Alongi 2002, Nagelkerken et al. 2008) and carbon storage (Donato et al. 2011). There remains, however, an insufficient level of understanding of the condition and extent of coastal vegetation communities throughout the region from which to make informed management decisions. Data presented in this report provides an assessment of 7.8 km of fringing mangrove forest of Le Asaga, Upolu; the MESCAL demonstration site in Samoa. From this data, informed management actions can be taken to ensure mangrove condition and structural integrity is maintained and the mangrove resource managed sustainably.

This data present the first quantitative assessment of the status, condition and biomass of fringing mangroves along 7.8 km of Le Asaga Bay shoreline in the Safata Marine Protected Area. Mangroves in Le Asaga Bay support subsistence and commercial fisheries for the surrounding villages. The Safata Marine Park Area (MPA) is reported as one of the most important areas for mangrove crab artisanal fisheries on Upolu (Siamomua-Momoemausu 2011). The Safata MPA, and associated 62 community managed areas, are widely regarded a success due to the positive impact they have generated for the local communities and the environment (Young 2013). There are reports of increases in fish catch abundances since MPA declaration (Young 2013), and these are supported by feedback from local communities (Govan et al. 2009). Along with improved fisheries management, the protection of mangrove ecosystems is a goal identified by the Safata fisheries management plan

(Young 2013). The mangrove ecosystem within Safata MPA is protected from degrading activities under a mangrove reserve declaration (Siamomua-Momoemausu 2011). While the extent of mangroves within the MPA has been quantified previously, the data presented here represent a significant advance to the baseline information available surrounding the condition and relative value as for habitat, shoreline protection and biomass in the Safata MPA. This data is essential to detect future changes in mangrove ecosystem health or functional value in the Safata MPA; and as such allows determination of successes or failures of the Safata MPA and fisheries management plans to deliver the stated goal of conserving Safata's mangrove ecosystems.

The 2009 tsunami caused widespread shoreline erosion in Samoa, resulting in damage to coastal vegetation and sediment transportation in both landward and seaward directions (Richmond et al. 2011). Whilst the district of Safata was not the worst affected region of Samoa, it received waves ~5 meters high (Fritz et al. 2011), which caused substantial coastal erosion in the Safata area (Dominey-Howes 2009). Further impacts on vegetation communities were caused by the high speed wind gusts experienced during Cyclone Evan in 2010. Wind gusts of up to 210 km/h were reported during this cyclone event (Strachan and Camp 2013); high winds and rain caused further damage to natural systems as well as infrastructure and loss of human life.

Although the damage to mangroves caused by cyclone Evan was extensive, it was not severe. This assessment has found that most mangroves in Le Asage Bay experienced only low to moderate crown damage. The data presented in this report indicates that Le Asage mangroves have a high capacity to withstand a large external stressor such as a cyclone, likely due to good management and healthy condition prior to the cyclone event. However, their capacity to recover from this event is still yet to be determined. The speed and extent of recovery of these mangroves will provide insight into the overall resilience of mangroves in Samoa. It is essential that during the mangrove recovery phase, extra care be taken by the Samoan people to reduce other anthropogenic stressors that may affect mangrove recovery, such as cutting and damaging mangroves, and pollution.

The implementation of on-ground rehabilitation strategies to assist and enhance mangrove recovery in targeted areas within Le Asage lagoon should be considered. It is clear from this initial assessment that some areas of mangrove experienced less damage during the cyclone than others. This may be related to the extent of the mangrove fringe, the shoreline aspect, or the absence of additional stressors. Further investigation is required to determine what factors were important in increasing mangrove resistance capacity to the cyclone event. This information may provide greater insight into how mangroves may be managed to improve climate change adaptation capacity and resilience. This assessment provides a visual baseline of mangrove condition directly after Cyclone Evan, and provides a unique opportunity to monitor mangrove recovery and determine appropriate management response to improve mangrove resilience in the future.

Erosion is widespread along the coastline of Samoa (Solomon and Forbes 1999), with around 80% of being sensitive to erosion, flooding or landslips (Daly et al. 2010). Evidence suggests that the island is subsiding at around 1 mm per year (Richmond 1992), which may be contributing to erosion issues. However, it is likely that several other factors such as sand mining, loss of coastal vegetation, and poorly designed shoreline protection infrastructure are also contributing to erosion problems in Samoa (Solomon and Forbes 1999). These erosion issues, combined with the frequency of cyclones experienced in this part of the Pacific, makes the coastal environments and communities of Samoa extremely susceptible to increases in the intensity of cyclone events predicted to occur with climate change.

Shoreline retreat is notable along the central section of the eastern shoreline of Le Asage Bay. Vegetation along a large part of this retreating shoreline has been altered to provide access to the water; mangroves are absent from a ~270 m section of shoreline, and mangrove health is very poor in this area. Coastal hardening, through the creation of rock walls or similar structures, can provide

some protection against shoreline erosion. These structures, however, are expensive to install and must be maintained to ensure they do not become undermined by wind, wave and current action. This maintenance requirement presents a significant challenge to the communities living along the shoreline; there are obvious examples of rock walls which are actively eroding in Le Asage Bay. Shoreline vegetation such as mangroves can offer better protection against erosion than hardened structures as their natural growth pattern allows them to keep pace with small changes in surface elevation. Additionally, bank hardening can reduce the capacity of shoreline habitats such as mangroves to adapt to sea level rise, preventing landward expansion and new colonisation (Lovelock & Ellison, 2007).

In some areas of Safata, evidence of significant shoreline stabilisation offered by coastal vegetation was reported following the 2009 tsunami (Dominey-Howes 2009). Planting appropriate vegetation to minimise coastal erosion is the most commonly proposed adaptation response included in Coastal Infrastructure Management Plans (CIMS) in Samoa. The UNDP, in partnership with the Samoa Ministry of Natural Resources and Environment (MRNE) secured funding in 2012 to deliver vegetation planning in at least 60 km of coastline and 50 km of riparian zones by October 2015 (UNDP 2011). MRNE are reported to recommend mangroves, along with various other coastal tree species, for these planting projects (UNDP 2011). Without careful monitoring, it is difficult to assess the success of planting vegetation as a mechanism to protect coastlines from erosion. There are numerous examples of poorly designed and executed mangrove planting projects (see Kamali and Hashim 2011 and references therein). Failure is alarmingly common where the causes of degradation or lack of presence in an area is not defined prior to planting efforts. Mangroves will naturally grow in areas where the tidal inundation is appropriate as long as seedling/propagule delivery is not limited. On exposed shorelines, wave action and erosion can wash away seedlings, significantly impacting survivorship. Planting along eroding coasts is likely to fail unless structures are in place to protect seedlings from erosion and wave action. Often the provision of such a protected area will allow seedlings to become naturally established, with no need to actively plant (Martinuzzi et al. 2009). Careful planning and ongoing monitoring to detect and duplicate local successes are essential components of successful mangrove restoration programs (Lewis III 2000). Without these, planting efforts may follow the examples set in the Philippines, where mangrove planting projects over the last two decades have achieved only 10-20% long term survival rates, wasting millions of dollars and immense time and effort from local communities (Primavera and Esteban 2008).

Conclusions

This report highlights the importance of managing anthropogenic disturbance to maintain fringing mangrove habitat structural integrity, ecosystem function and climate change adaptation and resilience capacity, particularly to sea level rise. The information presented here provides a baseline from which to assess future habitat change, cyclone recovery and monitor the success of management actions. The maps presented in this report highlight areas of fringing habitat that have low structural integrity and reduced condition, with key drivers of change spatially identified. Maintaining fringing mangrove habitat integrity and condition should be considered a management priority.

The data presented here applies specifically to the demonstration site surveyed, but the issues reported are likely indicative of general trends in mangrove forest management issues for mangroves throughout the Pacific. Presently there is little data available on the condition and structure of mangrove forests in the Pacific and presence, extent and intensity of natural and anthropogenic pressures that may reduce mangrove ecosystem function and their climate change adaptation and resilience capacity. More information is required regarding sustainable use of mangrove forests and the extent to which fragmentation and disturbance of fringing mangroves can occur without greatly reducing habitat function and integrity. This information is particularly relevant in the context of climate change and increasing population pressure in the Pacific coastal

zone. Such information can only be gained through broad-scale assessment of mangrove habitats in a variety of locations and from long-term monitoring using methodologies such as SVAM. Engaging local communities in mangrove assessment, monitoring and management through a program such as MangroveWatch will strengthen efforts to maintain mangrove habitat function and value, balanced with local resource needs.



6 REFERENCES

- Adame, M. F., D. Neil, S. F. Wright, and C. E. Lovelock. 2010. Sedimentation within and among mangrove forests along a gradient of geomorphological settings. *Estuarine, Coastal and Shelf Science* **86**:21-30.
- Alongi, D. M. 2002. Present state and future of the world's mangrove forests. *Environmental Conservation* **29**:331-349.
- Alongi, D. M. 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science* **76**:1-13.
- Amir, A. A. 2012. Canopy gaps and the natural regeneration of Matang mangroves. *Forest Ecology and Management* **269**:60-67.
- Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* **81**:169-193.
- Daly, M., N. Poutasi, F. Nelson, and J. Kohlhase. 2010. Reducing the climate vulnerability of coastal communities in Samoa. *Journal of International Development* **22**:265-281.
- Dominey-Howes, D. 2009. Preliminary assessment of the impacts and effects of the South Pacific tsunami of September 2009 in Samoa. Page 03 in AGU Fall Meeting Abstracts.
- Donato, D. C., J. B. Kauffman, D. Murdiyarto, S. Kurnianto, M. Stidham, and M. Kanninen. 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* **4**:293-297.
- Duke, N. C., J. Mackenzie, and A. Wood. 2013. Preliminary assessment of biomass and carbon content of mangroves in Solomon Islands, Vanuatu, Fiji, Tonga and Samoa.
- Duke, N. C., J.-O. Meynecke, S. Dittmann, A. M. Ellison, K. Anger, U. Berger, S. Cannicci, K. Diele, K. C. Ewel, and C. D. Field. 2007. A world without mangroves? *Science* **317**:41-42.
- Duke, N., and J. Mackenzie. 2010. Coastal forest vulnerability assessment, in Albert, S., A. Grinham *et al* (eds.) *Building social and ecological resilience to climate change in Roviana, Solomon Islands*. The University of Queensland, Brisbane.

- Duke, N., N. Wilson, J. Mackenzie, Hai Hoa Nguyen, and D. Puller. 2010. Assessment of Mangrove Forests, Shoreline Condition and Feasibility for REDD in Kien Giang Province, Vietnam. Development of the Kien Giang Biosphere Reserve Project. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Kien Giang, Vietnam.
- Ellison, J. C. 2009. Wetlands of the Pacific Island region. *Wetlands Ecology and Management* **17**:169-206.
- Eslami-Andargoli, L., P. E. R. Dale, N. Sipe, and J. Chaseling. 2010. Local and landscape effects on spatial patterns of mangrove forest during wetter and drier periods: Moreton Bay, Southeast Queensland, Australia. *Estuarine, Coastal and Shelf Science* **89**:53-61.
- Fritz, H. M., J. C. Borrero, C. E. Synolakis, E. A. Okal, R. Weiss, V. V. Titov, B. E. Jaffe, S. Foteinis, P. J. Lynett, and I. Chan. 2011. Insights on the 2009 South Pacific tsunami in Samoa and Tonga from field surveys and numerical simulations. *Earth-Science Reviews* **107**:66-75.
- Gilman, E., J. Ellison, V. Jungblut, H. Van Lavieren, L. Wilson, F. Areki, G. Brighthouse, J. Bungitak, E. Dus, and M. Henry. 2006. Adapting to Pacific Island mangrove responses to sea level rise and climate change. *Climate Research* **32**:161-176.
- Gilman, E. L., J. Ellison, N. C. Duke, and C. Field. 2008. Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany* **89**:237-250.
- Govan, H. 2009. Status and potential of locally-managed marine areas in the South Pacific: meeting nature conservation and sustainable livelihood targets through wide-spread implementation of LMMAs., Secretariat for the Pacific Regional Environment Programme (SPREP), Apia, Samoa.
- Govan, H., A. Tawake, K. Tabunakawai, A. Jenkins, A. Lasgorceix, E. Techera, H. Tafea, J. Kinch, J. Feehely, and P. Ifopo. 2009. Community Conserved Areas: A review of status & needs in Melanesia and Polynesia. ICCA regional review for CENESTA/TILCEPA/TGER/IUCN/ GEF-SGP.:66.
- Hoegh-Guldberg, O. and J. F. Bruno. 2010. The impact of climate change on the world's marine ecosystems. *Science* **328**:1523-1528.
- Kamali, B. and R. Hashim. 2011. Mangrove restoration without planting. *Ecological Engineering* **37**:387-391.
- Kieckbusch, D. K., M. S. Koch, J. E. Serafy, and W. Anderson. 2004. Trophic linkages among primary producers and consumers in fringing mangroves of subtropical lagoons. *Bulletin of Marine Science* **74**:271-285.
- Knutson, T. R., J. L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J. P. Kossin, A. Srivastava, and M. Sugi. 2010. Tropical cyclones and climate change. *Nature Geoscience* **3**:157-163.
- Kuleshov, Y., D. Jones, and C. Spillman. 2012. Climate extremes in the Pacific: improving seasonal prediction of tropical cyclones and extreme ocean temperatures to improve resilience. Page 79 in EGU General Assembly Conference Abstracts.
- Lewis Iii, R. R. 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. *Ecological Engineering* **15**:191-198.
- Lovelock, C. E., M. C. Ball, K. C. Martin, and I. C. Feller. 2009. Nutrient enrichment increases mortality of mangroves. *Plos One* **4**:e5600.
- Lovelock, C. E. and J. Ellison. 2007. Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change. Lough, J. M (ed) *Climate Change and the Great Barrier Reef: a vulnerability assessment*. Great Barrier Reef Marine Park Authority.
- Manson, F., N. Loneragan, G. Skilleter, and S. Phinn. 2005. An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions. *Oceanography and Marine Biology: An Annual Review* **43**:483-513.
- Martinuzzi, S., W. A. Gould, A. E. Lugo, and E. Medina. 2009. Conversion and recovery of Puerto Rican mangroves: 200 years of change. *Forest Ecology and Management* **257**:75-84.
- McAdoo, B. G., J. S. Ah-Leong, L. Bell, P. Ifopo, J. Ward, E. Lovell, and P. Skelton. 2011. Coral reefs as buffers during the 2009 South Pacific tsunami, Upolu Island, Samoa. *Earth-Science Reviews* **107**:147-155.

- McIvor, A., T. Spencer, I. Möller, and M. Spalding. 2013. The response of mangrove soil surface elevation to sea level rise. The Nature Conservancy, University of Cambridge, and Wetlands International, Cambridge, UK
- McIvor, A., I. Möller, T. Spencer, and M. Spalding. 2012a. Reduction of wind and swell waves by mangroves. Natural Coastal Protection Series: Report **1**.
- McIvor, A., T. Spencer, I. Moller, and M. Spalding. 2012b. Storm surge reduction by mangroves. Natural Coastal Protection Series: Report **2**.
- McLeod, E., R. Salm, A. Green, and J. Almany. 2008. Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment* **7**:362-370.
- McLeod, E. and R. V. Salm. 2006. Managing mangroves for resilience to climate change. World Conservation Union (IUCN).
- Meager, J., D. Vance, I. Williamson, and N. Loneragan. 2003. Microhabitat distribution of juvenile *Penaeus merguensis* and other epibenthic crustaceans within a mangrove forest in subtropical Australia. *Journal of experimental marine biology and ecology* **294**:127-144.
- Meynecke, J.-O., S. Y. Lee, and N. Duke. 2008. Linking spatial metrics and fish catch reveals the importance of coastal wetland connectivity to inshore fisheries in Queensland, Australia. *Biological Conservation* **141**:981-996.
- Nagelkerken, I., S. J. M. Blaber, S. Bouillon, P. Green, M. Haywood, L. G. Kirton, J. O. Meynecke, J. Pawlik, H. M. Penrose, A. Sasekumar, and P. J. Somerfield. 2008. The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquatic Botany* **89**:155-185.
- Polidoro, B. A., K. E. Carpenter, L. Collins, N. C. Duke, A. M. Ellison, J. C. Ellison, E. J. Farnsworth, E. S. Fernando, K. Kathiresan, and N. E. Koedam. 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. *Plos One* **5**:e10095.
- Prescott, F. 1989. The management of mangrove resources in Tonga. Phd Thesis. University of Sydney, Sydney.
- Primavera, J. H. and J. Esteban. 2008. A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. *Wetlands Ecology and Management* **16**:345-358.
- Richmond, B. M. 1992. Coastal geology of Upolu, Western Samoa. Pages 101-125 *Geology and offshore mineral resources of the central Pacific Basin*. Springer.
- Richmond, B. M., M. Buckley, S. Etienne, C. Chagué-Goff, K. Clark, J. Goff, D. Dominey-Howes, and L. Strotz. 2011. Deposits, flow characteristics, and landscape change resulting from the September 2009 South Pacific tsunami in the Samoan islands. *Earth-Science Reviews* **107**:38-51.
- Rivera-Monroy, V. H., J. W. Day, R. R. Twilley, F. Vera-Herrera, and C. Coronado-Molina. 1995. Flux of nitrogen and sediment in a fringe mangrove forest in Terminos Lagoon, Mexico. *Estuarine, Coastal and Shelf Science* **40**:139-160.
- Rohorua, H. and S. Lim. 2006. An inter-sectoral economic model for optimal sustainable mangrove use in the small island economy of Tonga. *Proceedings of the 2006 Conference of Agricultural and Resource Economics Society*.
- Salem, M. E. and D. E. Mercer. 2012. The economic value of mangroves: a meta-analysis. *Sustainability* **4**:359-383.
- Sheaves, M. 2005. Nature and consequences of biological connectivity in mangroves systems. *Marine Ecology Progress Series* **302**:293-305.
- Siamomua-Momoemausu, M. 2011. MESCAL demonstration site profile for Le Asaga Bay mangroves, Safata., IUCN Oceana, Suva, Fiji.
- Smith, T. J., M. B. Robblee, H. R. Wanless, and T. W. Doyle. 1994. Mangroves, hurricanes, and lightning strikes. *BioScience* **44**:256-262.
- Solomon, S. M. and D. L. Forbes. 1999. Coastal hazards and associated management issues on South Pacific Islands. *Ocean & Coastal Management* **42**:523-554.
- SPREP. 2012. Pacific Environment and Climate Change Outlook. Secretariat of the Pacific Environment Programme (SPREP), Apia, Samoa.
- SPREP. 2013. Adapting to Climate Change in the Pacific: the PACC programme. Secretariat of the Pacific Region Environment Programme (SPREP), Apia, Samoa.

- Strachan, J. and J. Camp. 2013. Tropical cyclones of 2012. *Weather* **68**:122-125.
- Traill, L. W., K. Perhans, C. E. Lovelock, A. Prohaska, S. McFallan, J. R. Rhodes, and K. A. Wilson. 2011. Managing for change: wetland transitions under sea-level rise and outcomes for threatened species. *Diversity and Distributions* **17**:1225-1233.
- Turner, R. E. and R. Lewis III. 1996. Hydrologic restoration of coastal wetlands. *Wetlands Ecology and Management* **4**:65-72.
- UNDP. 2011. Enhancing resilience of coastal communities of Samoa to climate change (UNDP ID 4667). Adaptation Fund, Washington DC.
- Walsh, K. J. E., K. L. McInnes, and J. L. McBride. 2012. Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific — A regional assessment. *Global and Planetary Change* **80–81**:149-164.
- Walters, B. B., P. Rönnbäck, J. M. Kovacs, B. Crona, S. A. Hussain, R. Badola, J. H. Primavera, E. Barbier, and F. Dahdouh-Guebas. 2008. Ethnobiology, socio-economics and management of mangrove forests: a review. *Aquatic Botany* **89**:220-236.
- Warren-Rhodes, K., A. Schwarz, L. N. Boyle, J. Albert, S. S. Agalo, R. Warren, A. Bana, C. Paul, R. Kodosiku, and W. Bosma. 2011. Mangrove ecosystem services and the potential for carbon revenue programmes in Solomon Islands. *Environmental Conservation* **38**:485-496.
- Wilson, H. B., B. E. Kendall, R. A. Fuller, D. A. Milton, and H. P. Possingham. 2011. Analyzing variability and the rate of decline of migratory shorebirds in Moreton Bay, Australia. *Conservation Biology* **25**:758-766.
- World Bank, W. 2000. *Cities, Seas, and Storms*. The World Bank, Washington, D.C.
- Young, J. 2013. *Catch shares in action: Samoan Safata District Customary User Rights Program*.