Centre for Tropical Water and Aquatic Ecosystem Research

JAMES COOK UNIVERSITY AUSTRALIA

MESCAL

MangroveWatch assessment of shoreline mangroves in Tonga

Jock Mackenzie, Norman C Duke, Apanie Wood

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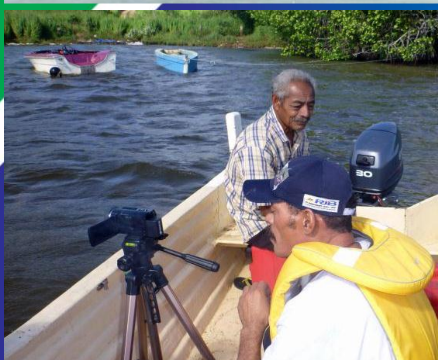

MangroveWatch assessment of shoreline mangroves in Tonga

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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 MESCAL Tonga Technical Working Group involving their training, support and consultation, prescription of methodology and approach, as well as the compilation and assessment of data received.

2) This report details data generated from recent 2013 shoreline video assessment MangroveWatch surveys undertaken by MESCAL Tonga 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 fringing mangrove health to be monitored effectively and providing a means to compare mangroves along the target shoreline with nearby areas in Tonga and elsewhere in the Pacific.

4) The information presented here is designed to assist natural resource managers to identify and manage specific issues that threaten mangroves in Fanga'uta Lagoon, Tonga.

5) A key outcome of these initial MangroveWatch surveys is a long-term visual baseline of mangrove extent, structure and condition along 4.75 km of Fanga'uta Lagoon 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) The mangroves of the surveyed area in Fanga'uta lagoon have high structural complexity and high ecosystem service potential. Surveyed mangroves were overall healthy, but a high proportion appeared to be experiencing low level dieback. Further investigation is required to establish the cause of reduced mangrove condition along the mangrove fringe.

8) 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.

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2 INTRODUCTION

In March 2013 MESCAL Tonga Technical Working Group and associates undertook a survey of fringing mangrove habitats in Fanga'uta Lagoon 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 focusses on the last (D) of four 4 key activities undertaken 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 the Coastal Health Archive and Monitoring Program for the region undertaken as part of the MESCAL project.

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.mangrovewatch.org.au*

Figure 2.1 Tonga MESCAL MangroveWatching

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, McIvor et al. 2012a, McIvor 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 always 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 (McIvor et al. 2012a, McIvor et al. 2012b). 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 negatively affect the capacity of mangroves to resist and recover from climate change impacts. The capacity of mangroves to respond to climate change 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.

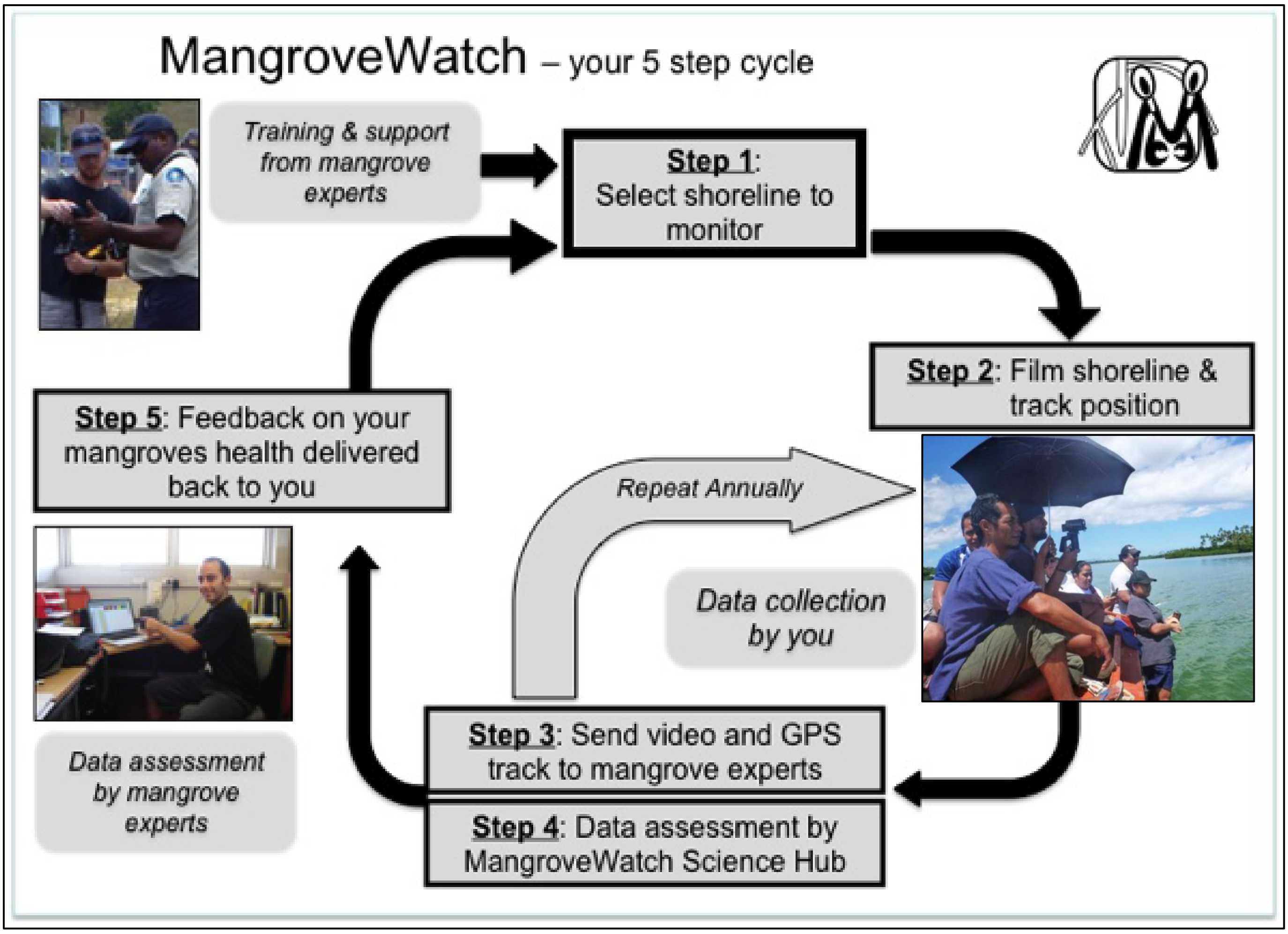

Figure 2.2 The MangroveWatch approach

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, 10 km 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 METHODOLOGY

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 Tonga Technical Working Group surveyed 4.75 km of shoreline fringing mangrove habitat along the Folaha/Nukuhetulu mangrove forest MESCAL demonstration site within Fanga'uta Lagoon, Tongatapu (Figure 3.1).This area represents one of the largest mangrove forest areas in Tongatapu. The area is commonly used for fishing, crabbing, and firewood collection. The Folaha/Nukuhetulu mangrove area is considered to be particularly important for maintaining lagoon water quality, as the lagoon has low tidal exchange and is at risk of sediment and nutrient pollution from land-based runoff. The mangrove fringe is also important for protecting adjacent coastal communities from storm surge during occasional cyclones. The area is considered to have future value as an education and ecotourism resource for Tonga (Anon 2012).

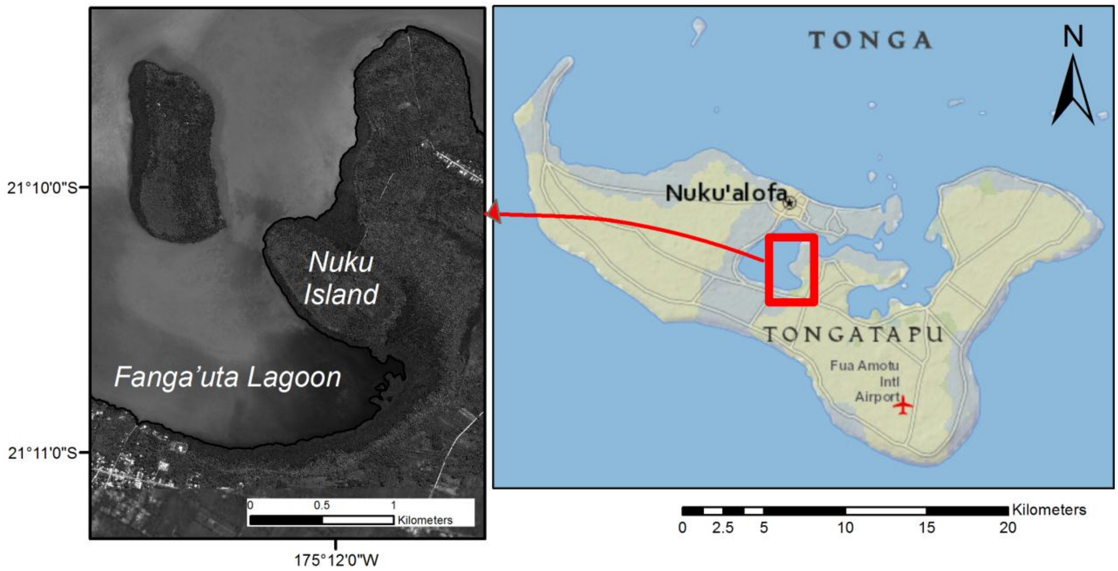

Figure 3.1 Location of MESCAL demonstration site

3.3 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.

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.

3.3.1 Features assessed and assessment criteria

3.3.1.1 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 allows comparison between areas and along shorelines.

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).

Examples of mangrove forest assessed as of biomass scores 2 to 5 are provided in Figure 3.2. Forest of biomass scores of 1 and 2 were not present within the Tonga MESCAL demonstration area.

Table 1 Mangrove biomass assessment criteria

Mangrove Biomass Score	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

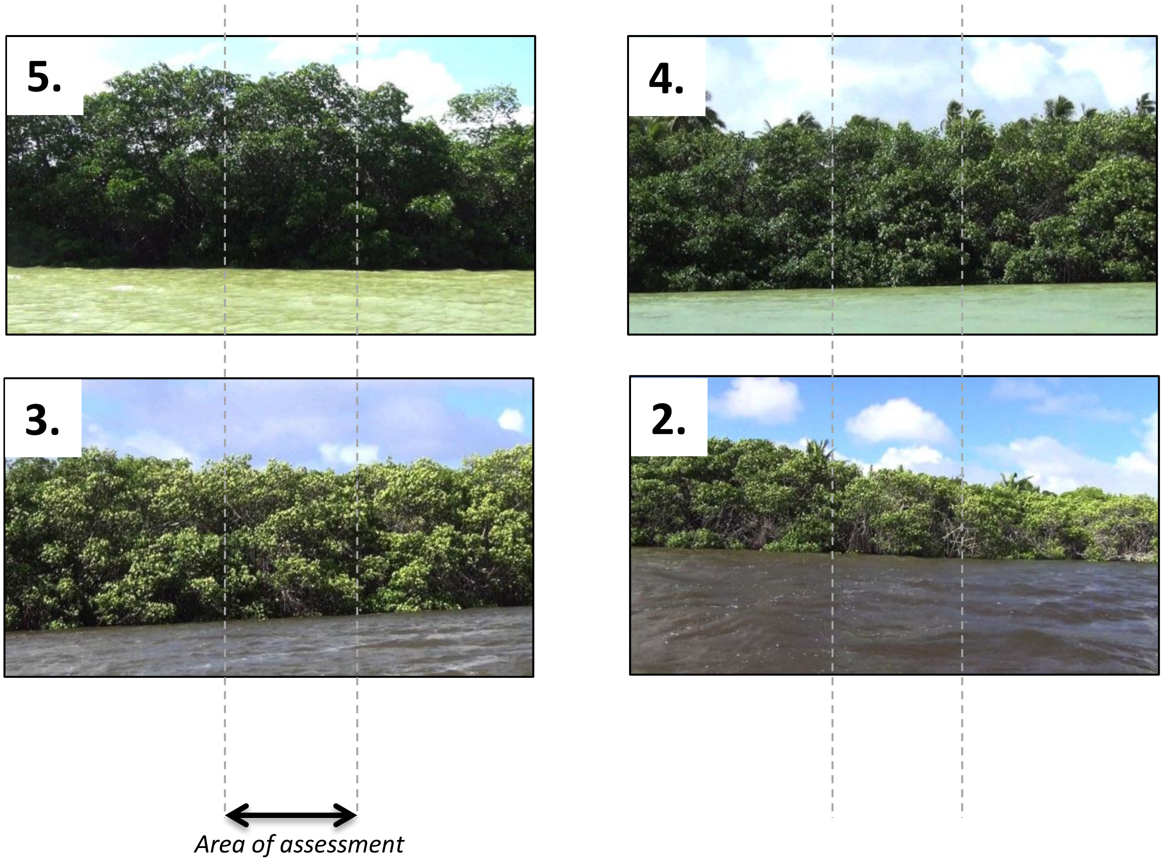

Figure 3.2 Example video stills of mangrove biomass assessment scores

3.3.1.2 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 (Table 2), with 0 being the presence of dead trees. Canopy density describes mean percentage canopy cover for fringing mangroves and the dominant canopy layer ranked from 1 to 5 (Table 2). All classification is based on the visible fringing mangroves intersecting the centre line of the frame. Overall mangrove condition scores were generated by the following equation, giving a total score between 0 (unhealthy) and 5 (healthy);

Mangrove condition score = (dieback score * 2 + canopy score) / 3

Examples of forest assessed as of mangrove condition scores 2 to 5 are provided in Figure 3.3. Forest of mangrove condition scores 1 and 2 were not present within the Tonga MESCAL demonstration area.

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.

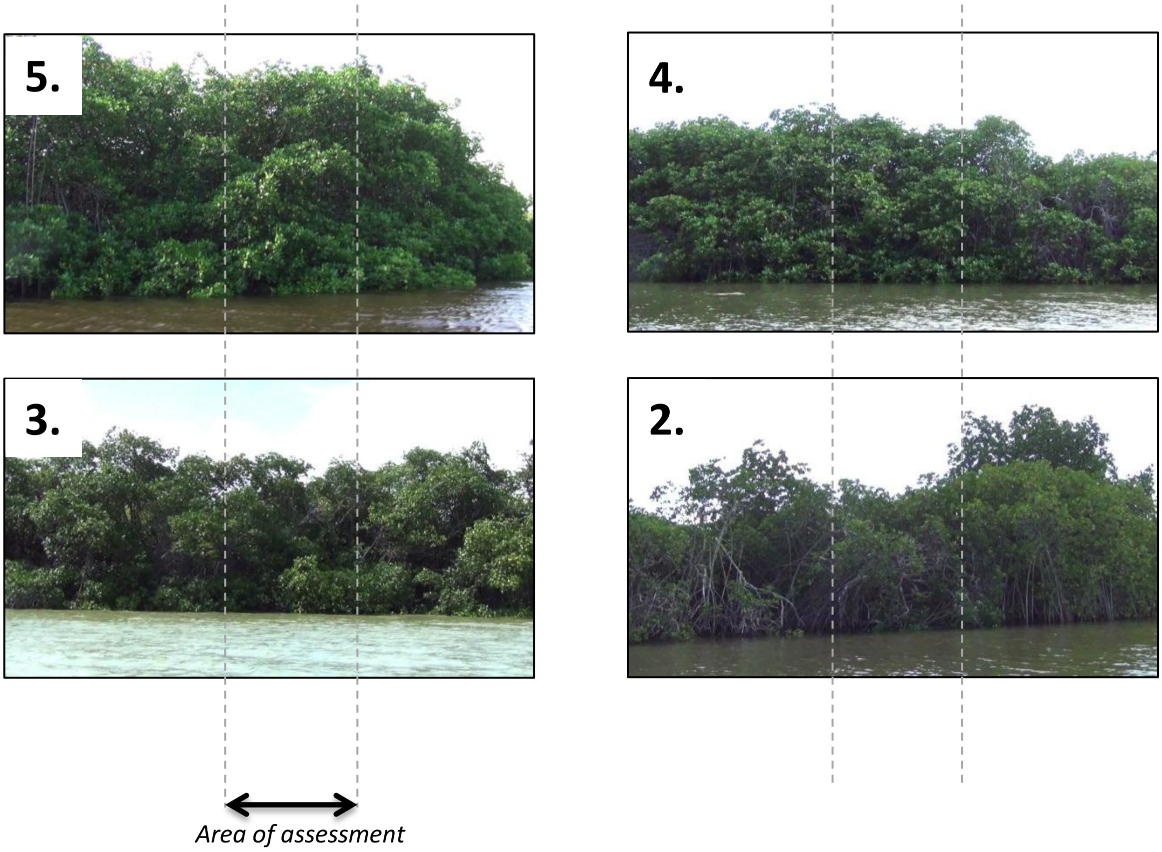

Figure 3.3 Example video stills of mangrove condition assessment scores

3.3.1.3 Mangrove value

Mangrove structural attributes are key factors determining the capacity of fringing mangroves to provide ecosystem services (Alongi 2008, Nagelkerken et al. 2008, McIvor et al. 2012a, McIvor et al. 2012b). 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 3 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 a 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.

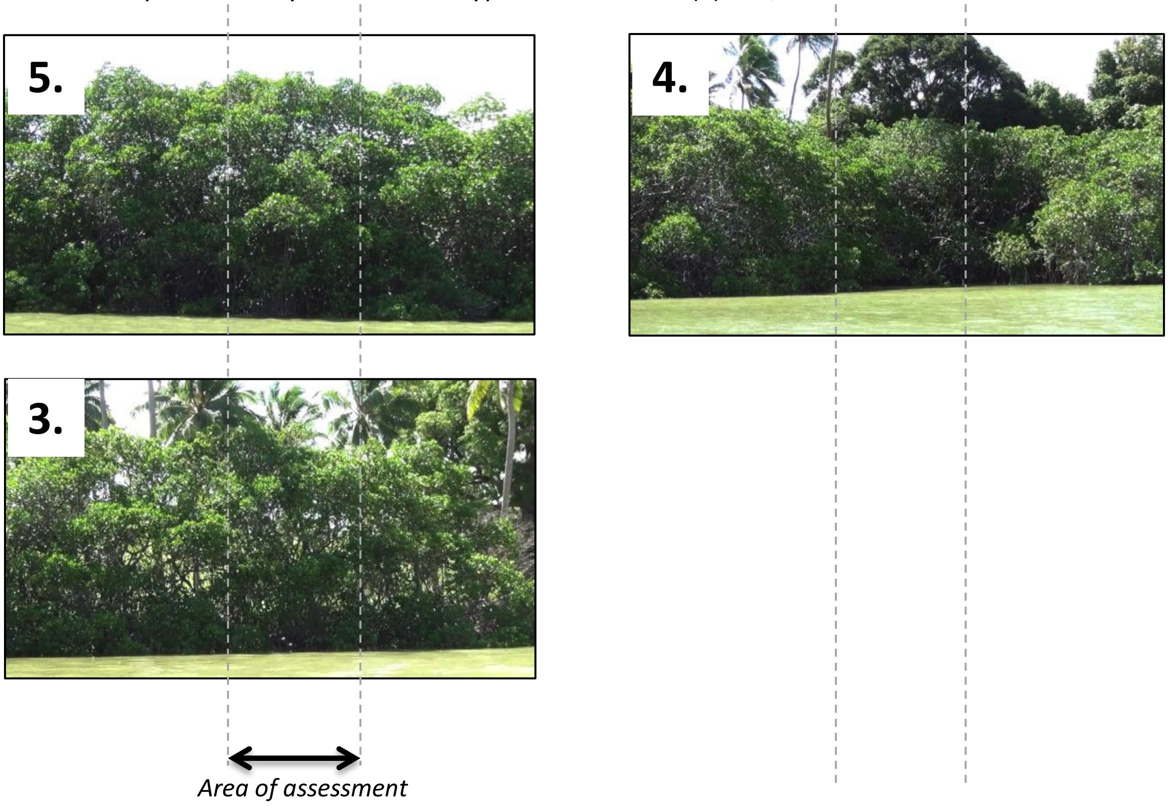

Figure 3.4 Example video stills of mangrove physical value assessment scores

3.3.1.4 Shoreline change and mangrove forest process

Mangrove forest process describes shoreline mangrove habitat identified as retreating, exposed, stable, growing or expanding (see Table 3). Visual indicators were used to classify these conditions, as shown in Figure 3.5. 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

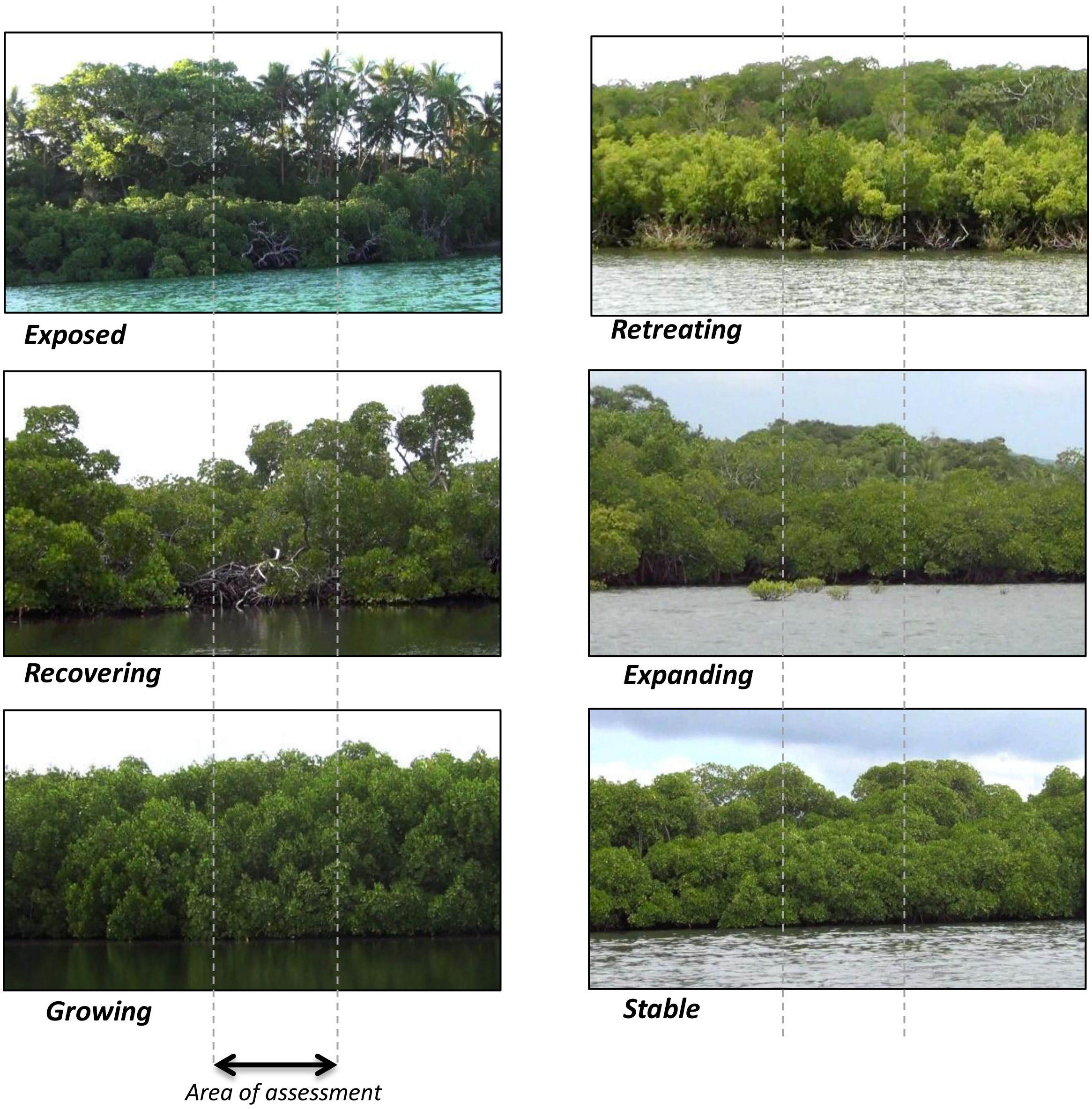

Figure 3.5 Example video stills of mangrove forest process assessment scores

3.3.1.5 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 (Table 4). The percentage of shoreline with human gaps determines the human modification score (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

3.3.1.6 Drivers of Change

Mangrove forests are impacted by both natural and anthropogenic drivers of change. 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). 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.

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 Tonga's 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 Tonga Technical Working Group surveyed 4.75 km of the shoreline of Fangu'uta Lagoon in March 2013. Figure 4.1 provides detail of the GPS track of survey travel and adjacent surveyed shoreline.

Figure 4.1 Shoreline video assessment, Fanga'uta Lagoon

4.2 Forest presence, biomass, physical value and habitat diversity

Mangroves were observed to occupy 4.73 km out of the total 4.75 km representing 99.6% of 10 m shoreline segments assessed. Forest height was relatively moderate across the surveyed shoreline, being estimated as between 5 and 6 meters. The fringing forest is mostly of moderate biomass (66%), with taller fringing mangroves of greater biomass (~8-9 m) present to the north of Nuku Island (Figure 4.2). 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. [1]Relative score as described in methods. [2]Percentage 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]
5.5 ± 0.06	3 ± 0.03 *Moderate*	4.96 ± 0.02 *Closed-continuous*	4.2 ± 0.03 *(60-80% cover)*	89%	4.5 ± 0.03 *Very High*

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

Score	1	2	3	4	5
Height	0	17%	65%	15%	3%
Forest structure	0	0	0	1%	99%
Biomass	0	17%	65%	15%	3%
Physical value	0	0	6%	36%	58%

Mangroves along the Fanga'uta Lagoon shoreline are relatively structurally homogeneous with the majority of mangroves (64%) being closed-continuous, *Rhizophora* dominated fringe forest (
Table 6; Figure 4.3).

The dominant species appears to be *Rhizophora samoensis* (99%), with *R. stylosa* present in more exposed areas (9%; Table 7). The dominance of *R. stylosa* recorded here may be an under-representation due to difficulties in remote identification to species level. *Lumnitzera littorea* and *Excoecaria agallocha* were observed to be common species in landward mangrove stands behind the *Rhizophora* fringe.

Table 7 Fringe mangrove species dominance

Species name	*R. samoensis*	*R. stylosa*	*R. selala*	*L. littorea*	*E. agallocha*
% of shoreline dominated by species	99%	9%	2%	3%	1.5%

Fringing mangroves in Fanga'uta Lagoon have a moderate structural diversity (D=3.1) and habitat type richness (r=22) owing to differences in canopy cover along the shoreline (see Table 9). The most common fringe habitat types are provided in Table 8. A low habitat evenness score (E=0.14) reflects how the presence of remaining factors (stem density, canopy layers, intertidal canopy, aerial root structures) is relatively similar across the surveyed shoreline. Most common is closed continuous, *Rhizophora* dominated fringe forest with inter-tidally submerged canopy and either very high or high canopy cover (77%; Table 8 types 2 and 3).

Table 8 Five most common fringe mangrove habitat 'types' contributing to habitat type richness. [1]Percentage 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	60-80%	Yes	Prop Roots	Fringe Only	48%
2	Closed-Continuous	80-100%	Yes	Prop Roots	Fringe Only	29%
3	Closed-Continuous	60-80%	No	Prop Roots	Fringe Only	5%
4	Closed-Continuous	40-60%	Yes	Prop Roots	Fringe Only	5%
5	Closed-Continuous	40-60%	No	Prop Roots	Fringe Only	3%

Fringing *Rhizophora* 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 very high mean physical value score (4.5 ± 0.03). The value of the fringe with respect to shoreline protection and water quality improvement capacity was diminished in some locations by poor mangrove health and fragmentation (Figure 4.3).

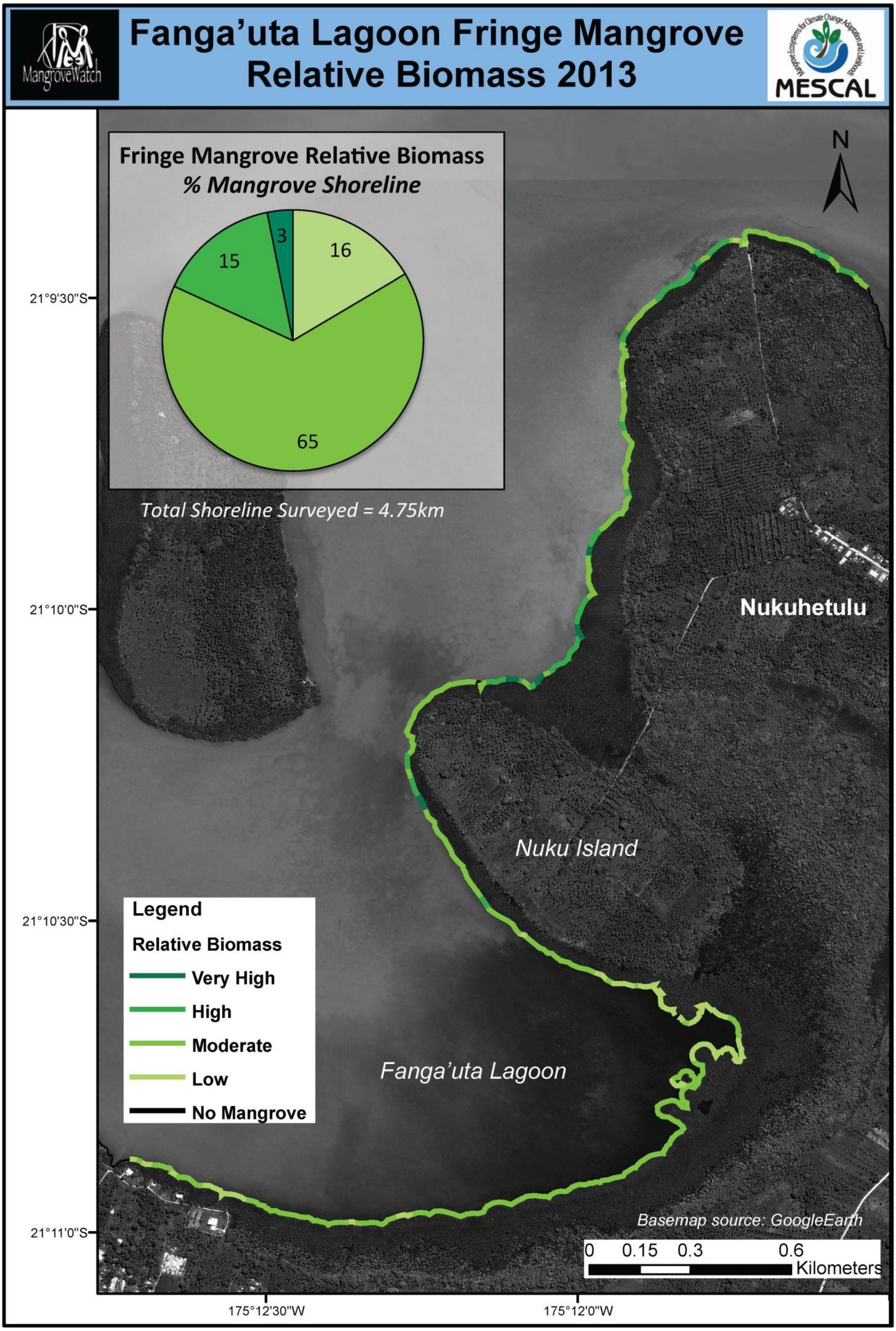

Figure 4.2 Forest biomass, Fanga'uta Lagoon fringe mangroves

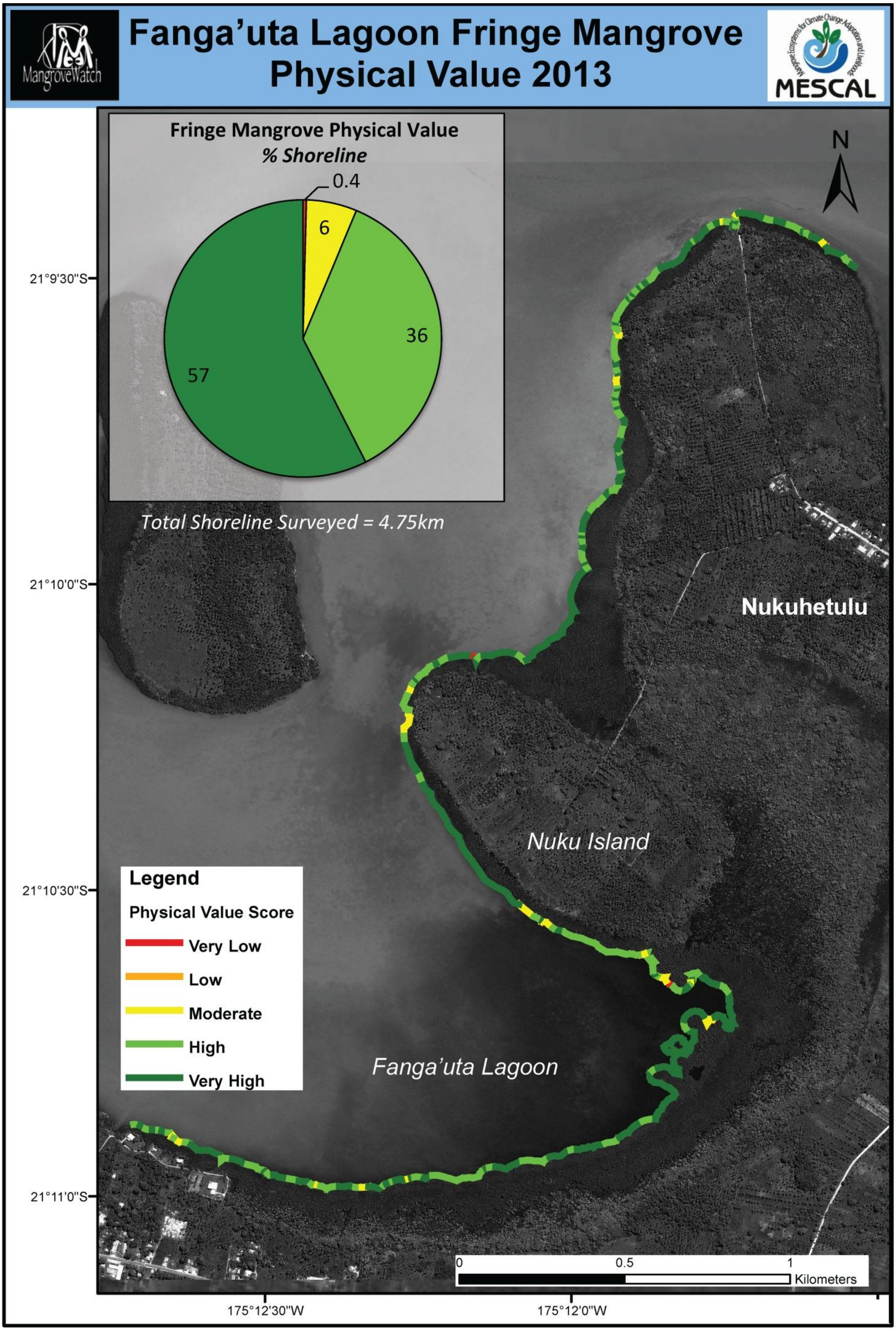

Figure 4.3 Physical value score, Fanga'uta Lagoon fringe mangroves

4.3 Condition of fringe mangrove forest

Most fringing mangroves along the surveyed shoreline are in good health (76%) with a mean mangrove condition score of 4.1 ± 0.04. Twenty-two percent of mangroves were recorded as very healthy, having no visible signs of dieback (Figure 4.4). Twenty-seven percent of mangroves were less than healthy, having noticeable or obvious dieback with the presence of dead trees. Eleven individual dead trees were observed, and 2.3 dead trees were recorded per kilometre of shoreline. The mean canopy cover score was high; 4.2 ± 0.03 (see also Table 8).

Table 9 Shoreline aspect and mangrove health

Score	1	2	3	4	5
Dieback	0	7%	18%	36%	39%
Canopy cover	0	<1%	10%	58%	32%
Mangrove condition	1%	5%	18%	39%	37%

Comments made during video recording suggested that wind damage might be the primary cause of poor mangrove condition in the Lagoon. The relationship between shoreline aspect and mangrove condition was investigated to determine if prevailing winds were related to poor mangrove condition. The majority of mangrove forest is present along the North to West facing shoreline. There was no clear relationship between shoreline aspect and poor mangrove condition. Mangroves on North-East and South-West facing shoreline however, appear to be proportionally healthier than mangroves on other shoreline aspects (
Table 10).

Table 10 Shoreline aspect and mangrove health

Shoreline aspect	Total shoreline (m)	Less than healthy condition	Healthy condition
North	960	23%	77%
North-East	570	11%	86%
North-West	1130	27%	73%
East	10	0%	100%
South-East	40	50%	50%
South	180	56%	44%
South-West	530	11%	89%
West	1250	26%	74%

4.4 Forest process

Fringe mangrove forest was stable along the entire surveyed shoreline (Figure 4.5)

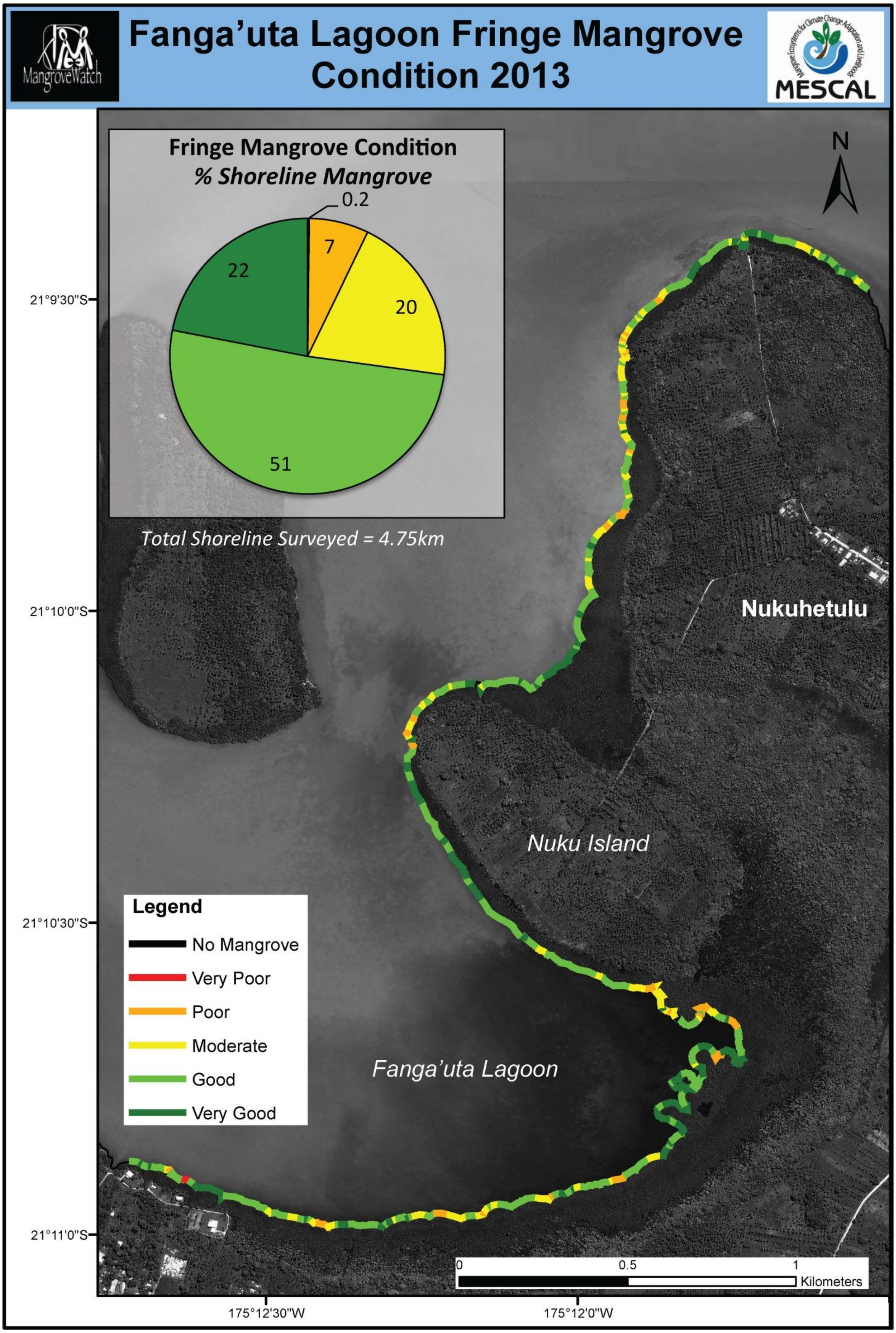

Figure 4.4 Forest condition, Fanga'uta Lagoon fringe mangroves

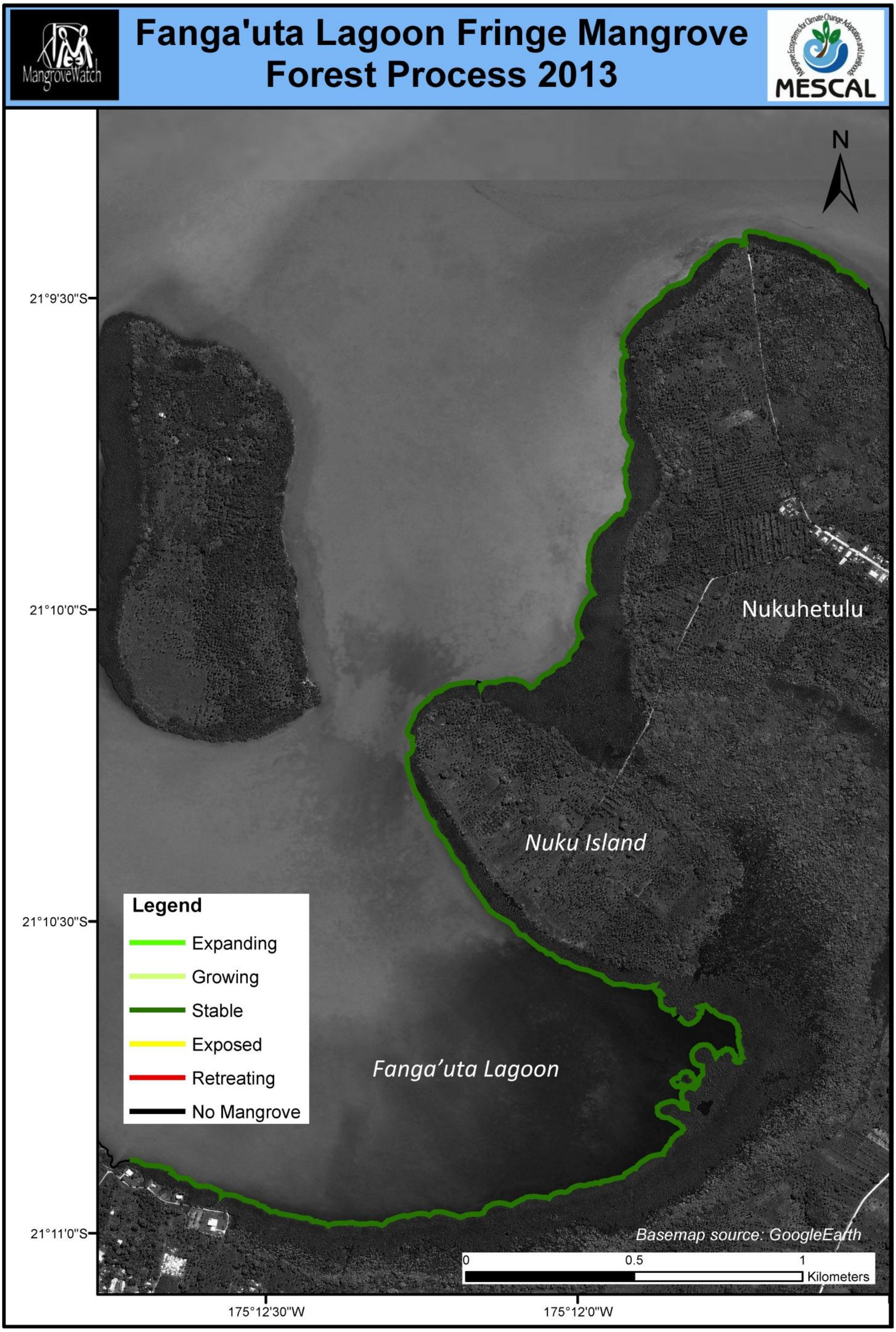

Figure 4.5 Forest process, Fanga'uta Lagoon fringe mangroves

4.5 Fragmentation of fringe mangrove forest

Fringing mangroves of the Folaha/Nukuhetulu mangrove forest are relatively intact, with little obvious fragmentation. Eight unnatural gaps in the fringing forest were observed, equating to 1.7 gaps per kilometre of shoreline. The average length of fringe forest patches was 581 m. All gaps in the fringe were created for access to the shoreline (Figure 4.6).

Figure 4.6 Examples of shoreline access cut through fringing mangroves

4.6 Drivers of change

Natural drivers appear to the dominant driver of fringing mangrove habitat change and disturbance (Table 11; Figure 4.7). Low to moderate level disturbance of mangroves causing mangrove dieback was observed for 27% of mangroves. Ninety meters of mangrove was observed to be affected by light-gaps, most likely caused by lightning strike.

Anthropogenic disturbance to the mangrove fringe is mostly in the form of cutting (60 m) and clearing (170 m) for access channels (Figure 4.6). Two large debris items were noted during the survey. Whilst not currently affecting mangrove condition, large debris such as this can damage mangrove seedlings and cause damage to mangrove forest during storm events.

One hundred and fifty meters of interior forest was observed to be undergoing ecotone shift, with extreme dieback and large-scale tree death occurring. Visual assessment of satellite imagery suggests the dieback is extensive in the interior forest.

Table 11 Drivers of change in fringing mangrove forest

Source	*Driver*	*Shoreline affected (m)*
Anthropogenic	*Access gaps*	80
	Cutting	60
	Clearing	170
Natural	*Light-gap*	90
	Ecotone shift	150

4.7 Other Observations

Fishing nets were observed along 640 m (13.5%) of shoreline.

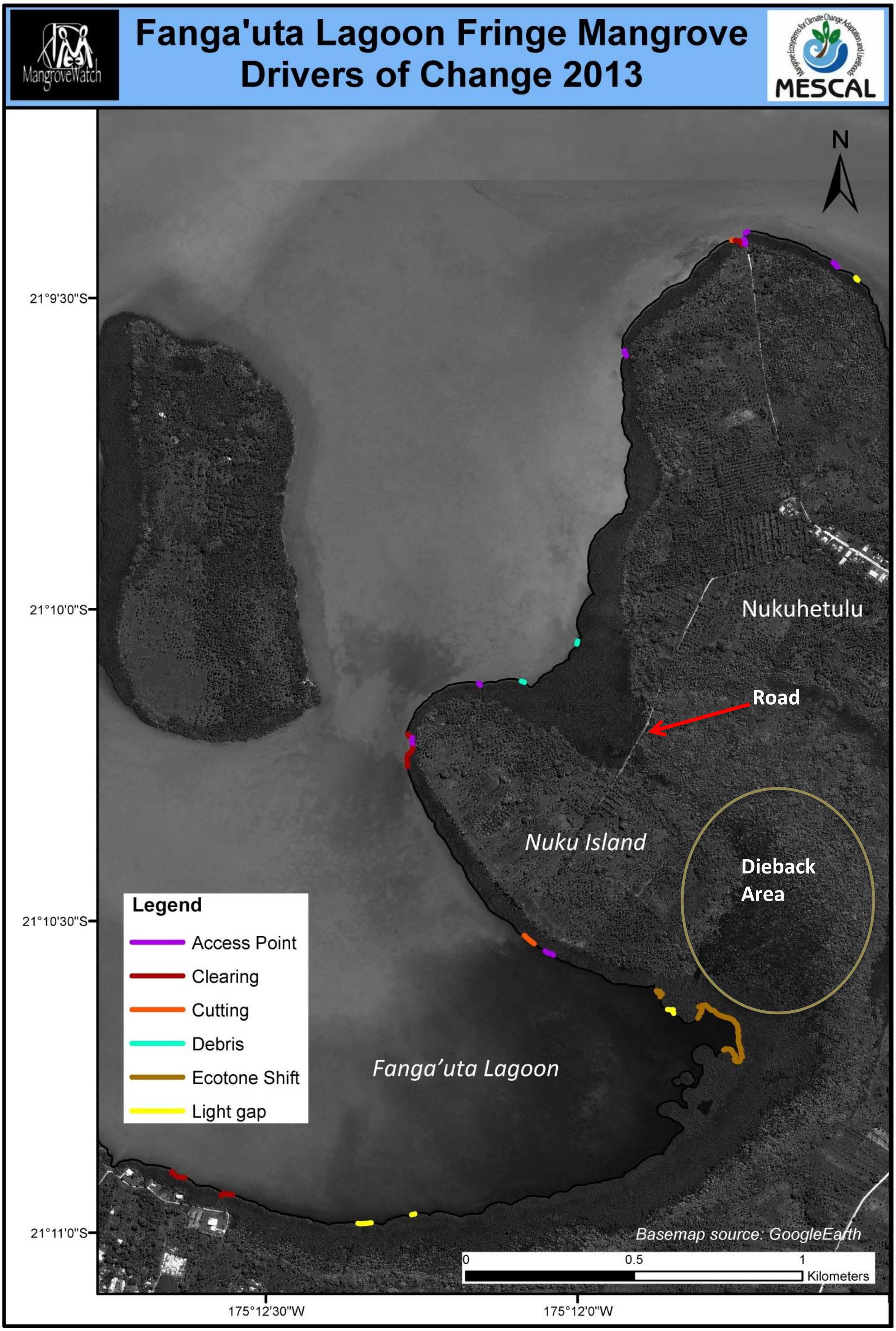

Figure 4.7 Drivers of change, Fanga'uta Lagoon fringe mangroves

5 DISCUSSION

This report provides critical baseline information to inform future management of valuable fringing mangrove habitats in Tonga for the maintenance and improvement of mangrove ecosystem resilience to climate change. Pacific Island Countries and Territories (PICTs) are particularly susceptible to climate change impacts due to their often low elevation and large coastal frontage relative to landmass (SPREP 2012). Mangroves are highly susceptible to changes in sea level and increases in storm intensity due to their location within the tidal zone at the shoreline edge (Lovelock & Ellison 2007, Alongi 2008, Hoegh-Guldberg and Bruno 2010, Knutson et al. 2010). Tropical cyclones are the most destructive force facing 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). 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 chemistry (Smith et al. 1994, Gilman et al. 2008). Shoreline vegetation can provide significant shoreline protection to coastal communities by buffering wave action and reducing the impact of storm surge upon adjacent infrastructure. The capacity of coastal vegetation to adapt to sea level rise and survive storm events is, however, affected by the health and extent of the ecosystems (Alongi 2008). Reductions in extent, structural complexity, and condition of mangrove ecosystem 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 (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 (McIvor et al. 2012a, McIvor 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 4.74 km of fringing mangrove forest Folaha/Nukuhetulu at the MESCAL demonstration site within Fanga'uta Lagoon, Tongatapu, Tonga. From this data, informed management actions can be taken to address anthropogenic pressures currently identified as negatively impacting the health and extent of mangrove forests within the surveyed area.

The protected embayment of Fanga'uta Lagoon provides stable and suitable conditions for mangrove growth. Consequently, the fringing mangroves surveyed along Folaha/Nukuhetulu demonstration site have high ecosystem value. Continuous, closed canopy, *Rhizophora samoensis* dominated mangrove stands comprise the majority of the mangrove fringe. Although structurally homogenous across the shoreline landscape, these mangroves have high structural complexity and form a near continuous barrier with a high capacity to provide ecosystem services such as shoreline protection, fish habitat and water quality improvement. The high fish habitat value of the mangroves in the survey area is apparent with the presence of fishing nets in areas of high mangrove biomass.

Very little direct anthropogenic disturbance was observed along the shoreline area, with only minor fragmentation of the fringe related to clearing for water access. A relatively recent access path appears to have been made near Nukuhetulu Village.

Surveyed mangroves were overall healthy, but a high proportion (36%) appeared to be experiencing low level dieback and more than half (58%) had 60-80% canopy cover. This broadscale, low level impact suggests the presence of a background stressor affecting mangrove condition or a press disturbance such as recent dry conditions. Comments made during the survey regarding the presence of wind damage affecting mangroves. An examination of the relationship between shoreline aspect and condition showed no clear pattern relating to mangrove condition and aspect, and the majority of mangroves face away from the prevailing south-easterly winds. However, recent cyclone activity in the region may have impacted mangroves in Fanga'uta Lagoon. If this is the case, then these mangroves potentially have low resilience to cyclone damage, with no recovery observed during the survey. Additionally, a large area of inner forest experiencing ecotone shift die-off was observed during the survey. Further examination of this area in Google Earth revealed it to be extensive. It is possible the large dieback area is associated with the construction of a road connecting Nuku Island to Tongatapu. Where tidal flow is affected, construction within mangroves can have a significant impact on mangrove condition, and often leads to large scale mangrove loss (Harris et al. 2010). If altered hydrology is responsible for the large-scale dieback it is likely to also be affecting fringe mangroves, and may be a contributing factor to reduced mangrove condition documented in the current shoreline assessment. The large-scale dieback area represents the most significant mangrove management issue in the survey area.

Conclusions

The mangroves of the surveyed area in Fanga'uta lagoon have high structural complexity and high ecosystem service potential. Further investigation is required to establish the cause of reduced mangrove condition along the mangrove fringe. A combination of both natural (cyclones) and anthropogenic (road construction) factors may be affecting mangrove condition. If the bund wall is altering hydrology to adjacent mangrove areas, efforts should be undertaken to restore tidal flow as soon as possible.

The data presented here applies specifically to the demonstrations sites surveyed, but the issues reported are likely indicative of general trends in mangrove forest management issues for mangroves throughout Tonga and 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.

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