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JAMES COOK UNIVERSITY
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# MESCAL

## MangroveWatch assessment of shoreline mangroves in Vanuatu

**Jock Mackenzie, Norman C Duke, Apanie Wood**

**Report No. 13/50**

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Pacific Mangroves Initiative

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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 Vanuatu 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 2012 shoreline video assessment MangroveWatch surveys undertaken by MESCAL Vanuatu 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 Vanuatu 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 Crab Bay and Eratap, Vanuatu.

5) A key outcome of these initial MangroveWatch surveys is a long-term visual baseline of mangrove extent, structure and condition along 14 km of Crab Bay and Eratap Bay shorelines 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 results of this survey show the fringing mangroves of Crab Bay, Malekula to be in relatively good condition, with high ecosystem service value. Comparatively, fringing mangroves of Eratap Lagoon, Efate, are damaged by coastal development and are in poorer condition, with ecosystem service values compromised by cutting and clearing of some mangrove areas and habitat fragmentation. The very high condition and natural recovery documented in Crab Bay indicate these mangroves have high climate change adaptation and resilience capacity. Mangroves of Eratap exhibit very low rates of natural recovery from disturbances, making them particularly susceptible to climate change impacts.

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.

# TABLE OF CONTENTS

# 2 INTRODUCTION

In September 2012 MESCAL Vanuatu Technical Working Group and associates undertook a survey of fringing mangrove habitats in Crab Bay and Eratap MESCAL demonstration sites using the MangroveWatch Shoreline Video Assessment Method (SVAM). This report details the results of these surveys, 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 Vanuatu MESCAL MangroveWatching in Crab Bay, Malekula**

## 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 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.*

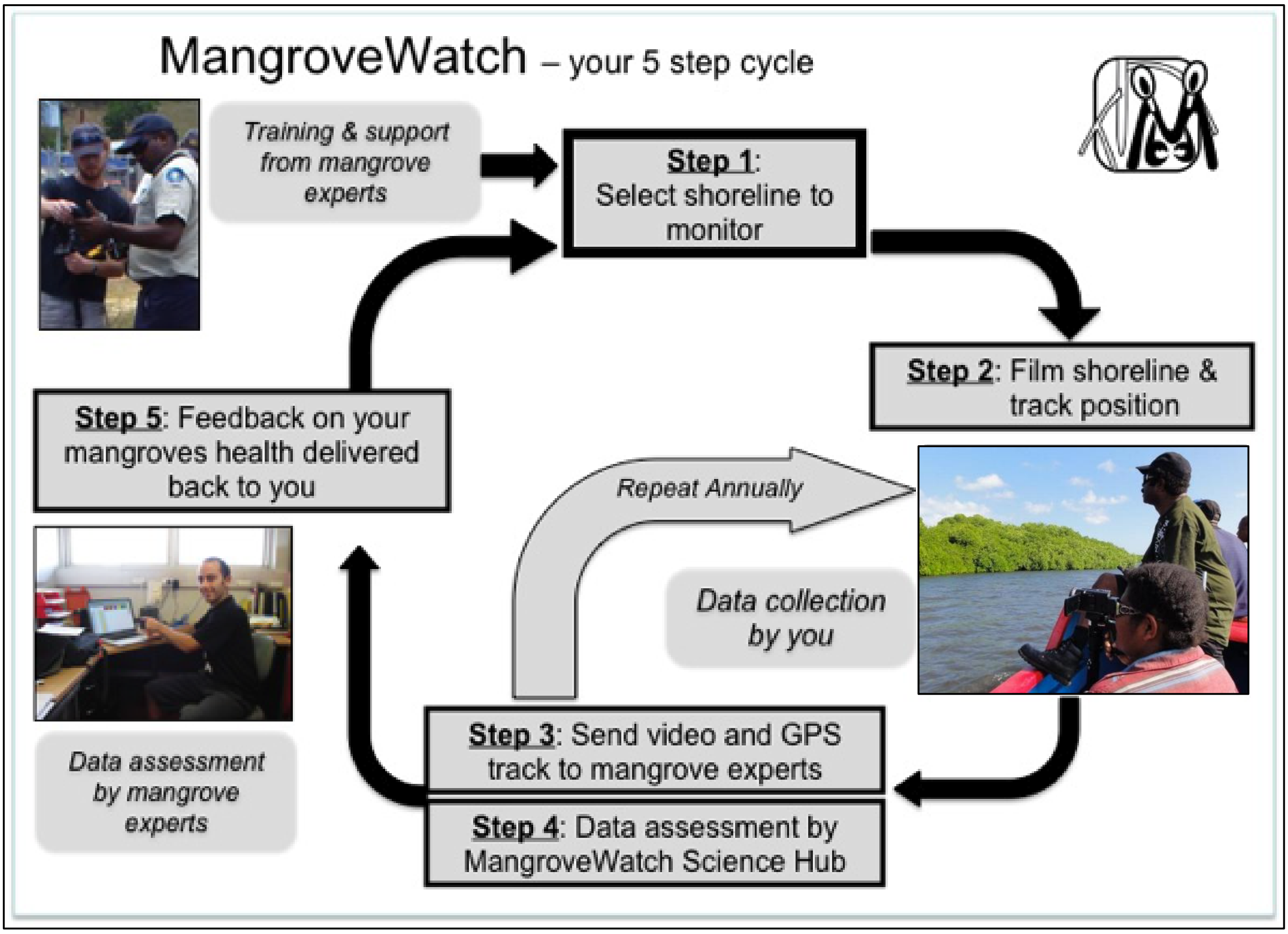


Figure 2.2 The MangroveWatch approach

## 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, 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 REPORT FORMAT

There are two MESCAL demonstration sites in Vanuatu; Crab Bay, Makekula, and Eratap, Efate. Due to the geographic isolation of these sites and differences in ecosystem condition and pressures upon mangrove forests, the results of the shoreline assessments are presented separately in the report (Chapters 5 & 6). The methods, however, apply to both sites (Chapter 4).

# 4 METHODS

## 4.1 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.

## 4.2 Shoreline Video Assessment Method (SVAM) survey locations

### 4.2.1 Demonstration site one: Crab Bay, Malekula

The MESCAL Vanuatu Technical Working Group surveyed fringing mangrove habitat along Crab Bay shoreline, Malekula (Figure 4.1). Crab Bay is one of two MESCAL demonstration areas in Vanuatu. The site has previously been used as a demonstration area for the International Waters program, directed by the Secretariat for the Pacific Region Environment Programme (SPREP). Two tabu areas, where fishing is restricted, are in place on the Eastern and Western headlands of the bay. Local communities initiated the tabu to protect fish resources. The central bay remains open to harvesting. The Crab Bay mangrove area is considered by local communities to be important for maintaining fisheries (SPREP 2005). Mangrove products are a source of economic income to some local communities, as well as being used as fire wood and for house and fence posts (SPREP 2005).

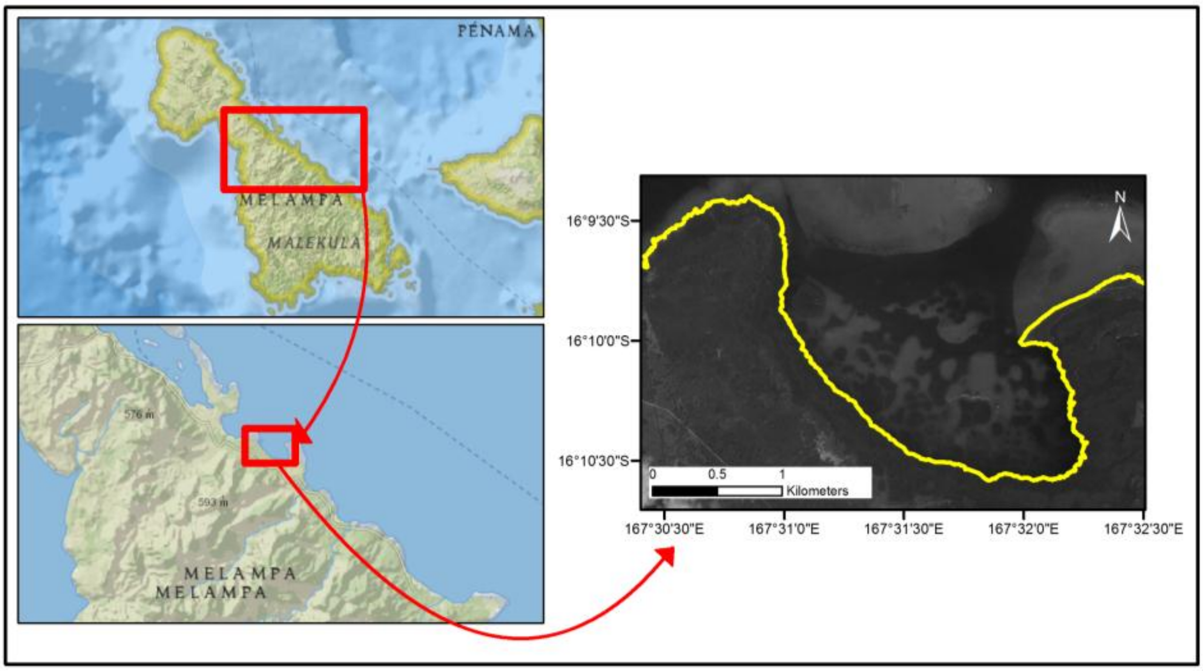


Figure 4.1 Location of MESCAL demonstration site at Crab Bay, Malekula.

### 4.2.2 Demonstration site two: Eratap, Efate

The second Vanuatu MESCAL demonstration site is located at Eratap, in south eastern Efate (Figure 4.2). Due to its close proximity to Port Vila, Eratap is subject to coastal development pressure from the tourism industry. A number of small islands provide some protection to the southern and central shoreline. An enclosed lagoon is located to the north of the site. The area has no history of environmental project activities, so limited baseline environmental data is available. The site is known to support a range of marine species including seagrass, turtles and dugong, as well as a number of commercially targeted fish species.

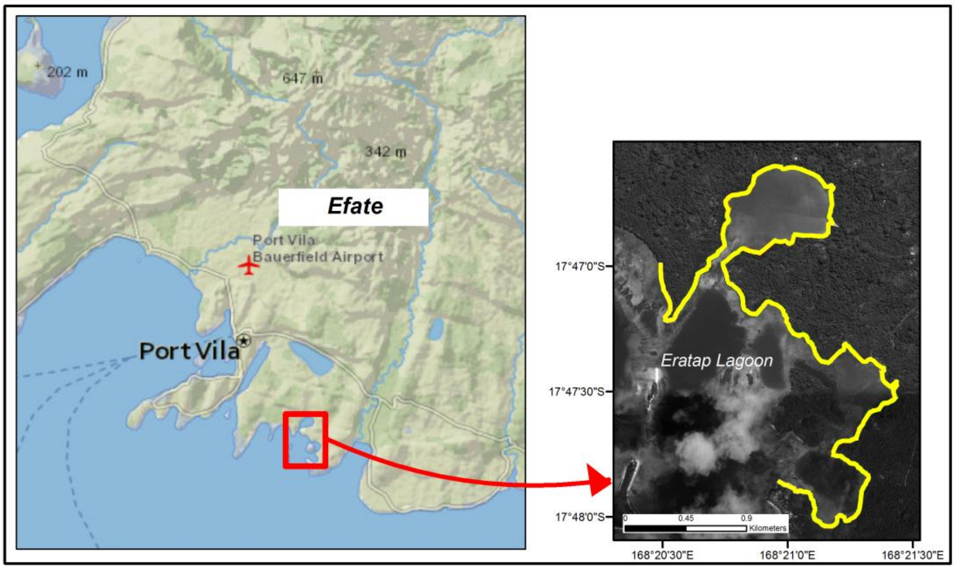


Figure 4.2 Location of MESCAL demonstration site at Eratap, Efate

## 4.3 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 at JCU. 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.

### 4.3.1 Features assessed and assessment criteria

#### *4.3.1.1 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 4.3.

**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 |

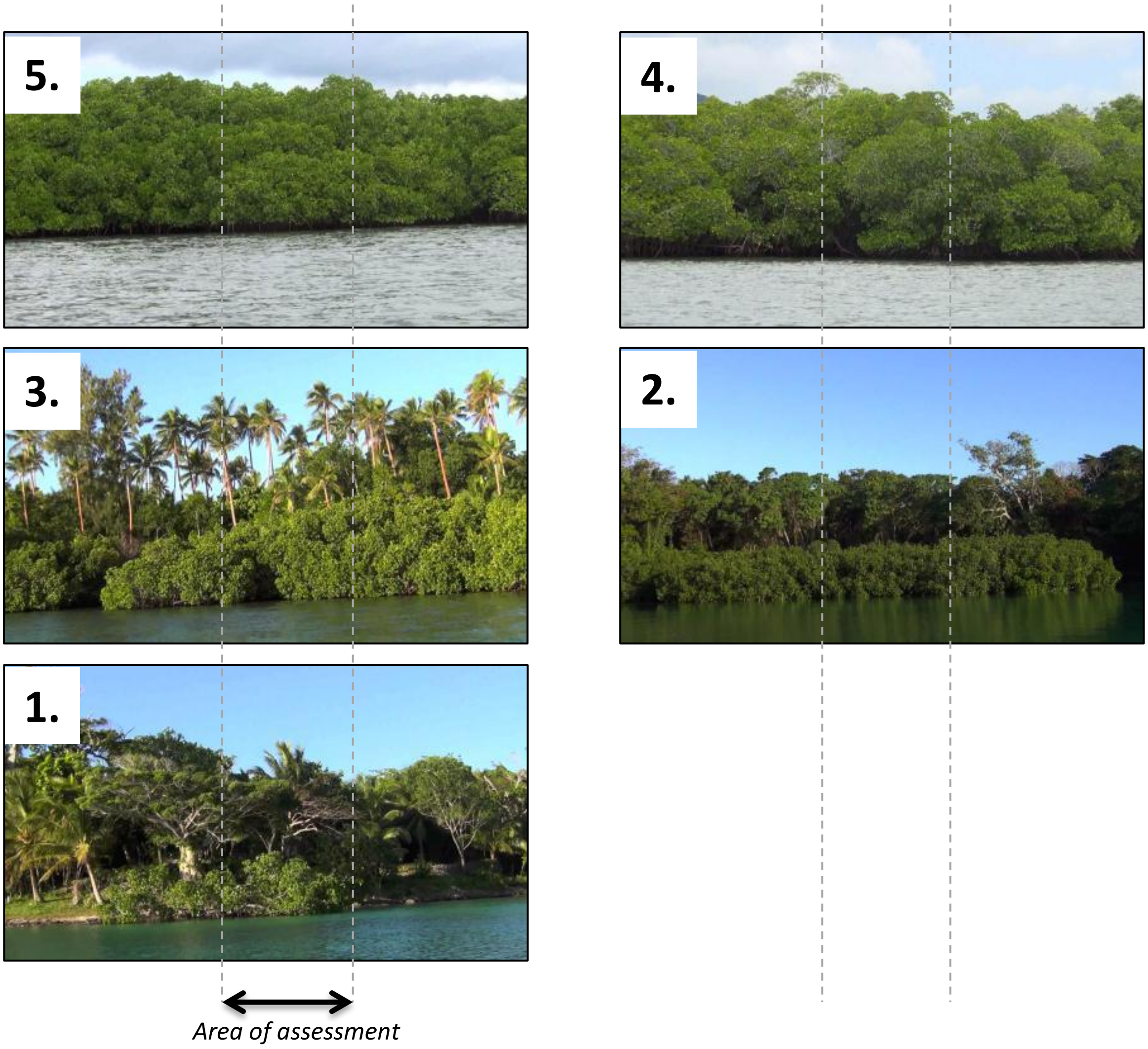


Figure 4.3 Example video stills of mangrove biomass assessment scores

#### *4.3.1.2 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, with 0 being the presence of dead trees. Examples of mangrove forest conditions scores are provided in
Figure 4.4. 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);

**Mangrove condition score = (dieback score * 2 + 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. |

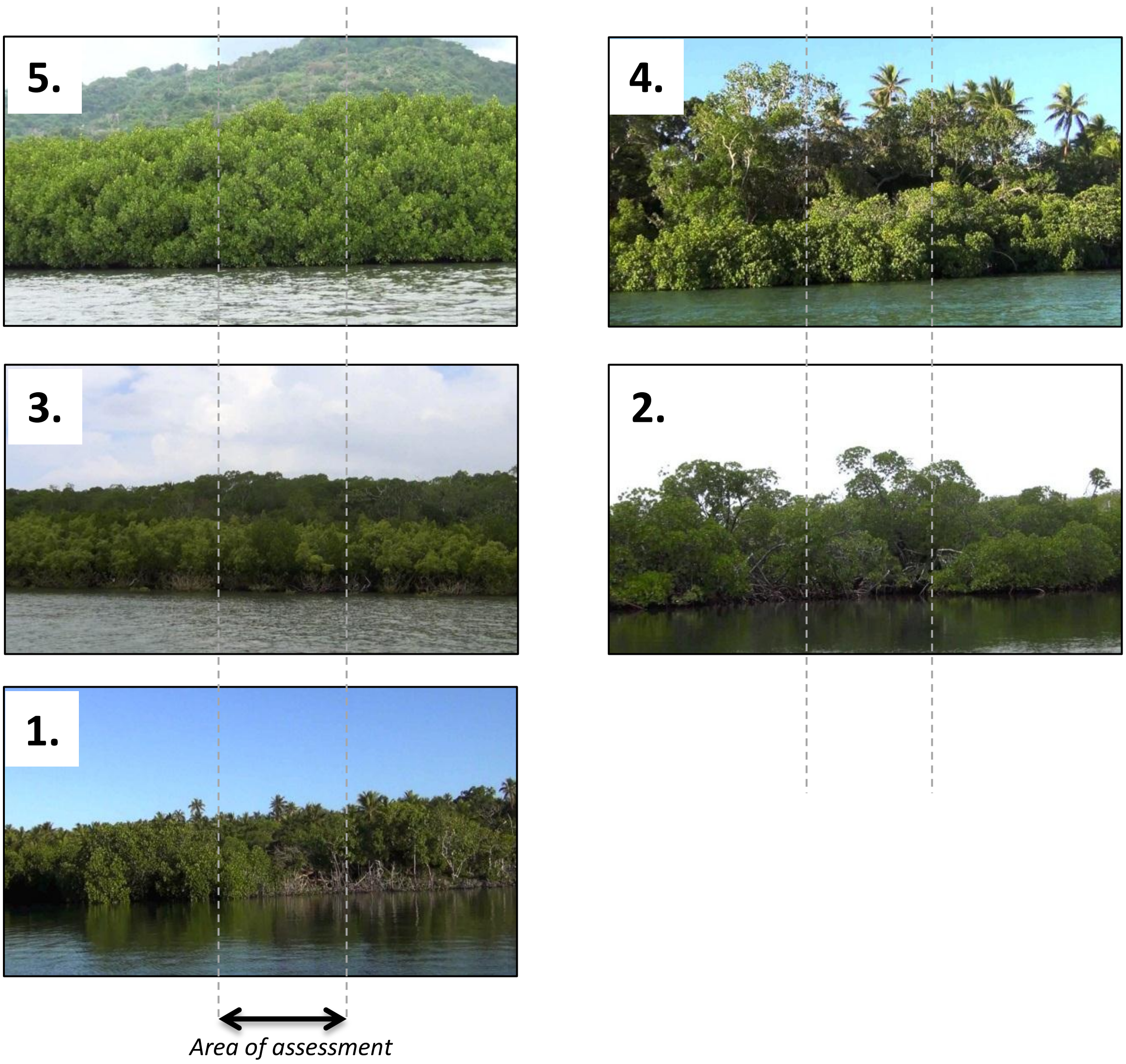


**Figure 4.4 Example video stills of mangrove condition assessment scores**

#### *4.3.1.3 Mangrove value*

Mangrove structural attributes are key factors determining the capacity of fringing mangroves to provide ecosystem services (McIvor et al. 2012a, McIvor 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 3 to 5 are provided in Figure 4.5.

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.

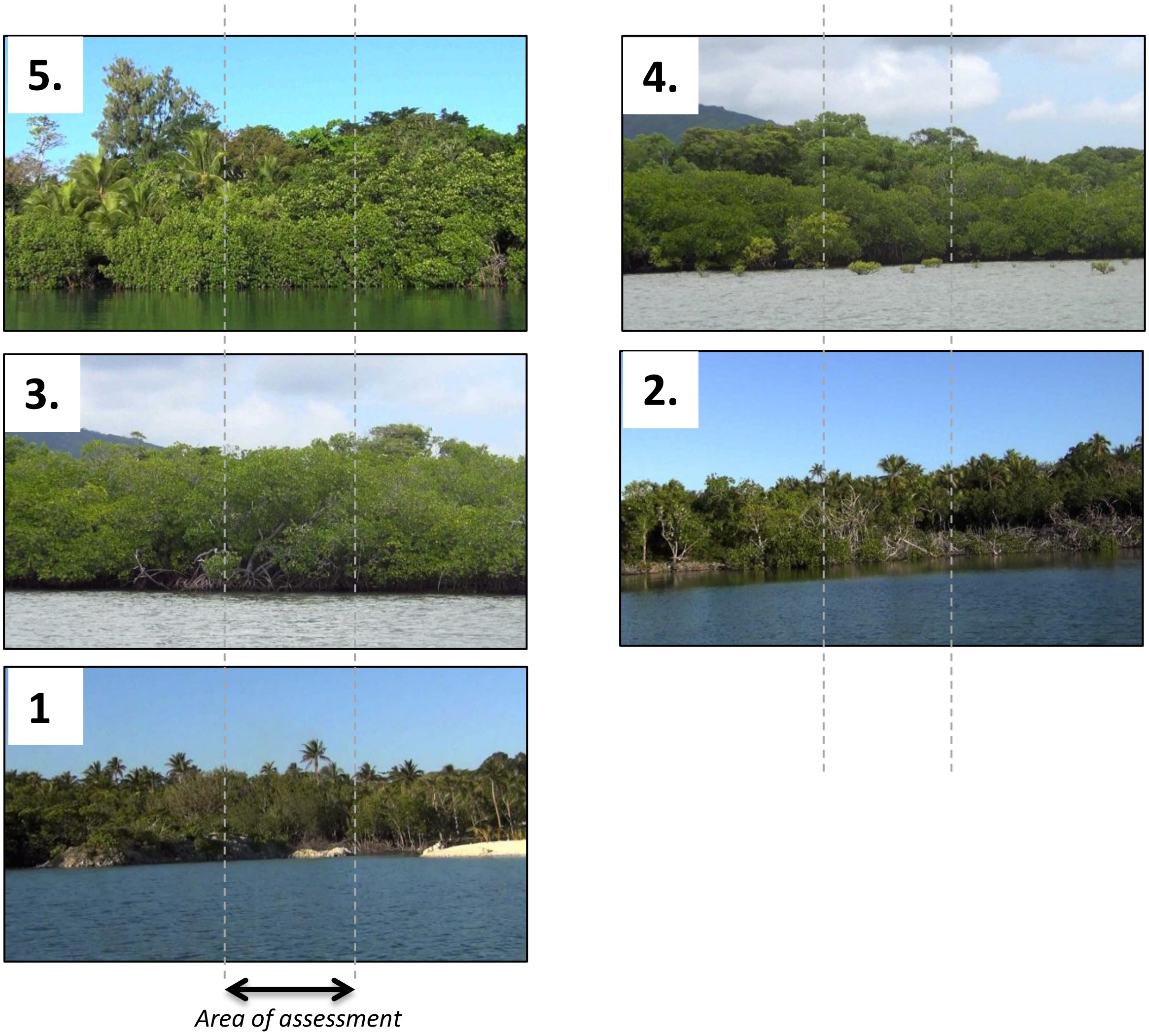


Figure 4.5 Example video stills of mangrove physical value assessment scores

#### 4.3.1.4 Shoreline change and mangrove forest process

Mangrove forest process describes shoreline mangrove habitat identified as retreating, exposed, stable, growing or expanding (Table 3). Visual indicators were used to classify these conditions, as shown in Figure 4.6. 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$^{o}$ 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 |

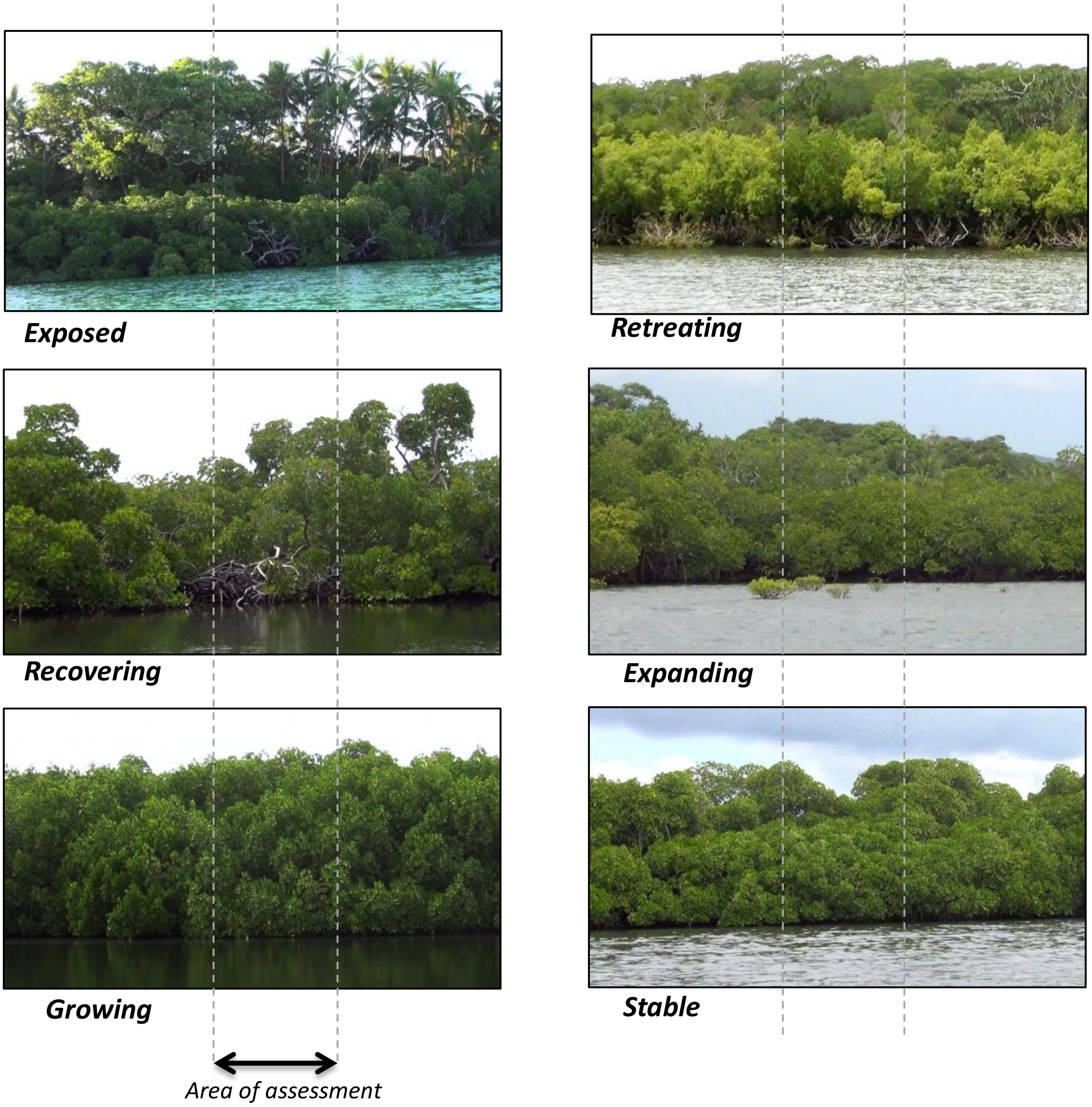


Figure 4.6 Example video stills of mangrove forest process assessment

#### *4.3.1.5 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, 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 |

#### *4.3.1.6 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 Vanuatu's MESCAL demonstration areas, such as the presence of access paths, cutting, mangrove removal for coastal development and root burial.

# 5 CRAB BAY RESULTS

## 5.1 Survey area covered

The MESCAL Vanuatu Technical Working Group surveyed 7.22 km of the shoreline of Crab Bay on 21st September 2012. Figure 5.1 provides detail of the GPS track of survey travel and adjacent surveyed shoreline.

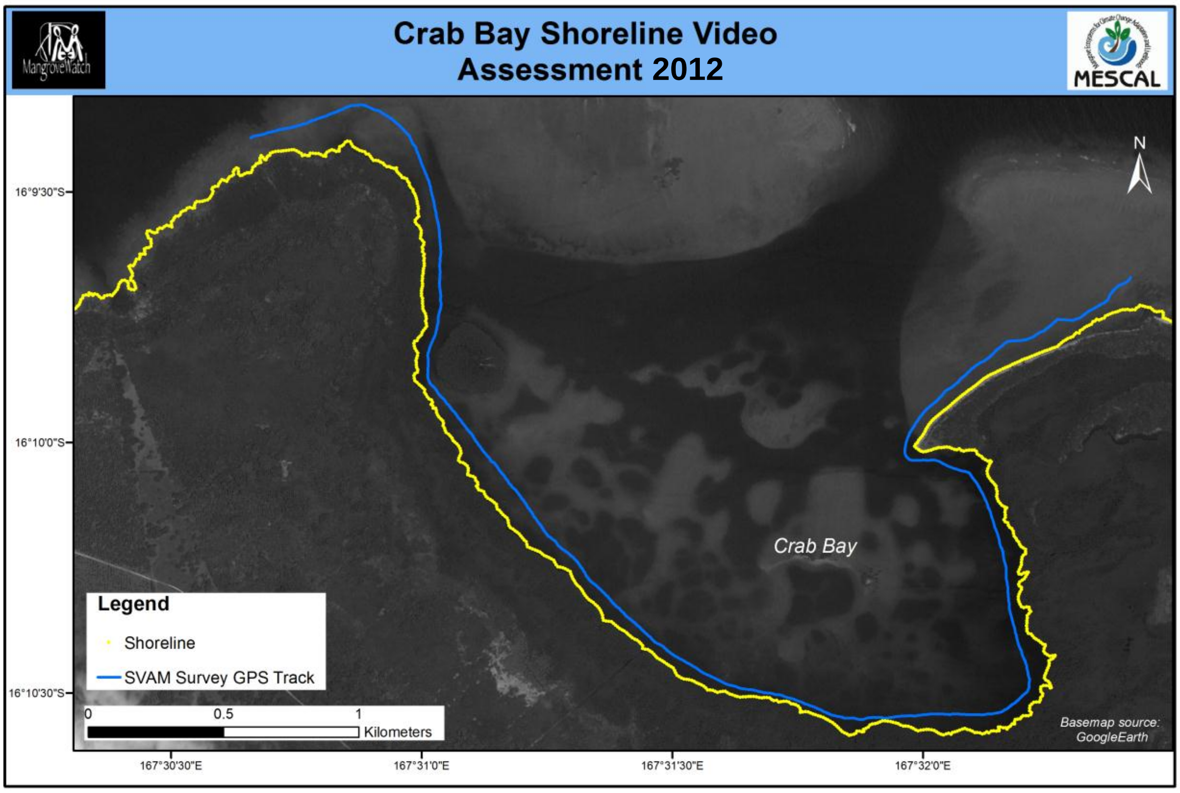


Figure 5.1 Shoreline video assessment, Crab Bay

## 5.2 Forest presence, biomass, physical value and habitat diversity

Mangroves were observed to occupy 6.37 km out of the total 7.72 km representing 88.2% of 10 m shoreline segments assessed. Forest height was relatively moderate across the surveyed shoreline, being estimated as 5 meters. The fringing forest is mostly of moderate to high relative biomass (86%), with mangroves inside the bay area having the greatest biomass (Figure 5.2). Forest biomass was lowest to the Eastern and Western ends of the survey area, where the survey included shoreline at the outer edge of the protective bay area. 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 5.3 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 ± 0.03 | 3.3 ± 0.03 | 4.8 ± 0.02<br>*Closed-continuous* | 4.7 ± 0.02<br>*(80-100% cover)* | 72% | 4.6 ± 0.02<br>*Very high* |

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

| *Score* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ***Height*** | <1% | 4% | 44% | 49% | 3% |
| ***Forest structure*** | <1% | <1% | 2% | 10% | 87% |
| ***Biomass*** | 1% | 11% | 46% | 40% | 1% |
| ***Physical value*** | <1% | 2% | 3% | 22% | 72% |

Mangroves along the Crab Bay shoreline are relatively structurally homogeneous with the majority of mangroves (87%) being closed-continuous, *Rhizophora* dominated fringe forest
Table 6; Figure 5.3).

The dominant species appears to be *Rhizophora stylosa* (96%), with *R. apiculata* often present (and co-dominant) along the shoreline (68%; Table 7). *R. mucronata* was also present, but in lower densities. *Avicennia marina* was present in depositional areas at both the outer limits of the survey area. *Sonneratia alba* was also infrequently present as an upper canopy species extending into the inner forest.

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

| Species name | *A. marina* | *R. apiculata* | *R. stylosa* | *R. mucronata* | *S. alba* |
|---|---|---|---|---|---|
| ***% of shoreline dominated by species*** | 8% | 68% | 96% | 11% | 4% |

Fringing mangroves in Crab Bay have moderate structural diversity (D=3.2) and habitat type richness (r=35) owing to differences in canopy cover along the shoreline (see Table 9). The most common fringe habitat types are provided in Table 8. A very low habitat evenness score (E=0.09) reflects how the presence of remaining factors (stem density, canopy layers, intertidal canopy, aerial root structures) are relatively similar across the surveyed shoreline. The most common structural attribute association is closed continuous, *Rhizophora* dominated fringe forest with inter-tidally submerged canopy and either very high canopy cover (52%; 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 | 80-100% | Yes | Prop Roots | Fringe Only | 52% |
| 2 | Closed-Continuous | 80-100% | Yes | Prop Roots | Fringe & Upper Canopy | 14% |
| 3 | Open-Continuous | 60-80% | No | Prop Roots | Fringe Only | 6% |
| 4 | Closed-Continuous | 60-80% | No | Prop Roots | Fringe Only | 5% |
| 5 | Closed-Continuous | 80-100% | No | Prop Roots | Fringe Only | 4% |

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 (4.6 ± 0.02). 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 5.3).

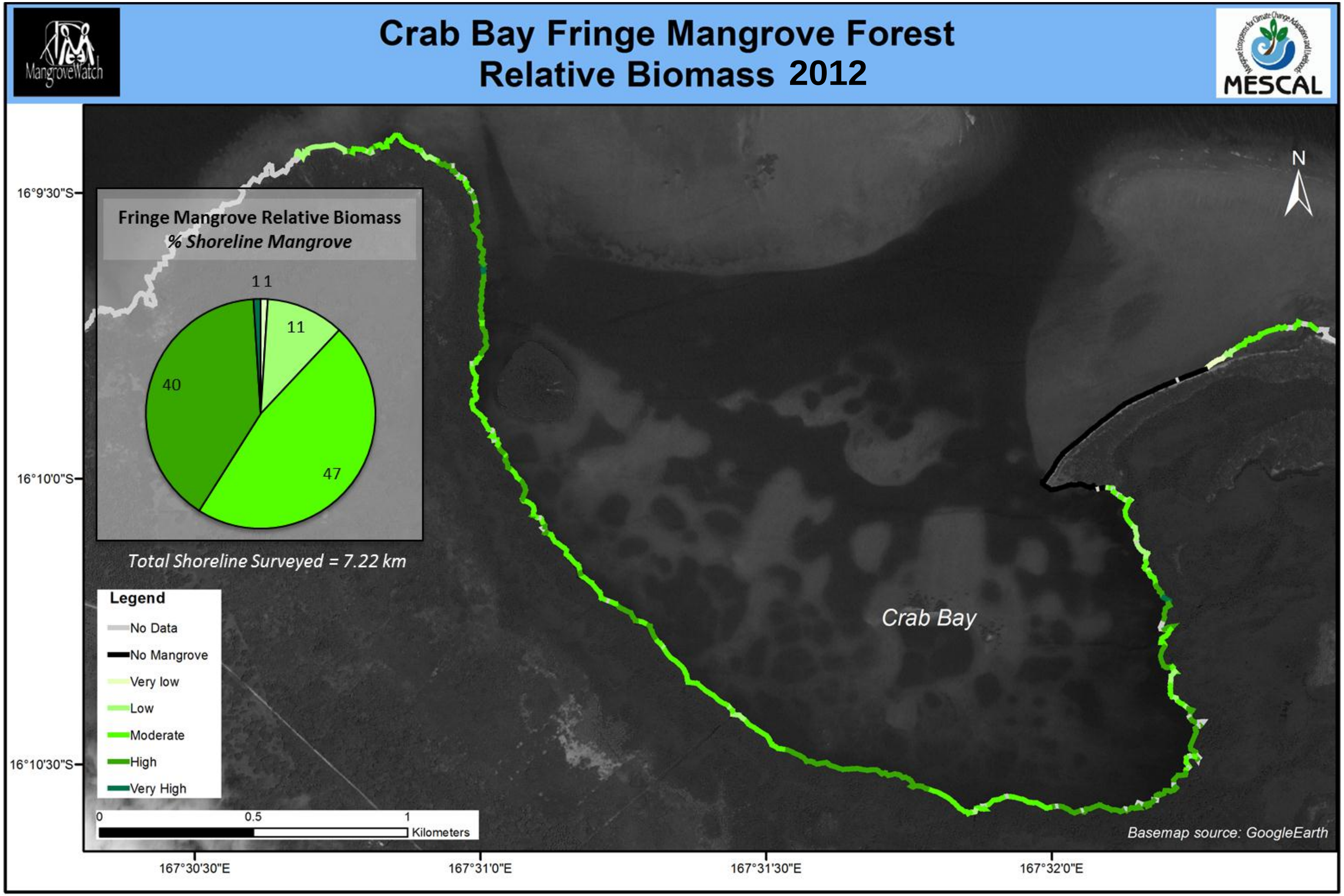


**Figure 5.2 Forest biomass, Crab Bay fringe mangroves**

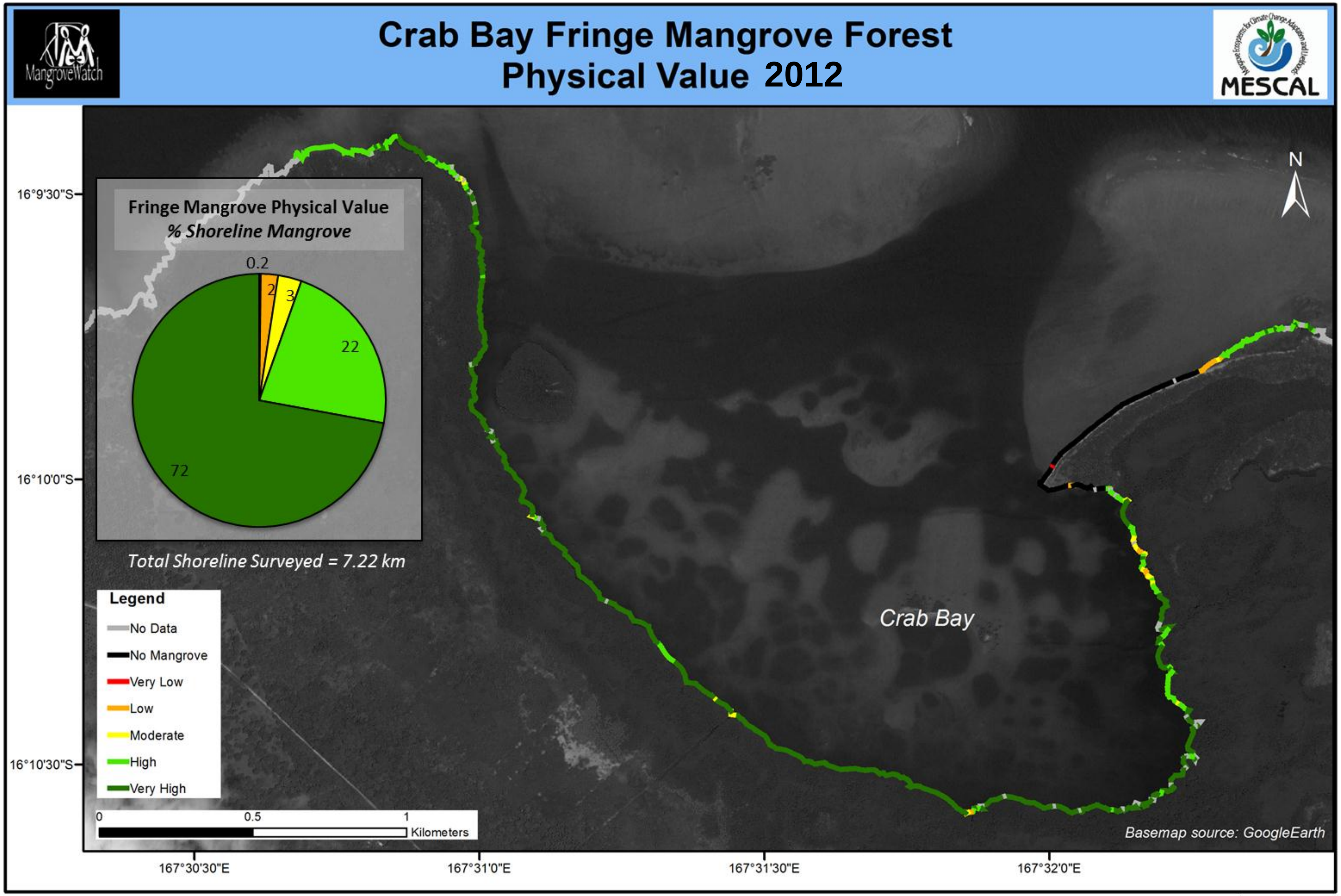


Figure 5.3 Physical value score, Crab Bay fringe mangroves

## 5.3 Condition of fringe mangrove forest

The majority of fringing mangroves along the surveyed shoreline are in very good or good health (90%) with a mean mangrove condition score of 4.6 ± 0.03. Seventy-five percent of mangroves were recorded as very healthy, having no visible signs of dieback (Table 9; Figure 5.4). Less than 2% of fringe mangroves were in poor condition. However, 12% of mangrove shoreline was observed as having noticeable or obvious dieback. Eleven individual dead trees were observed; 2.3 dead trees recorded per kilometre of shoreline. The mean canopy cover score was high; 4.2 ± 0.03 (see also Table 8).

**Table 9 Mangrove health score distribution**

| *Score* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ***Dieback*** | <1% | 5% | 6% | 15% | 75% |
| ***Canopy cover*** | <1% | <1% | 2% | 21% | 77% |
| ***Mangrove condition*** | <1% | 1% | 8% | 15% | 75% |

## 5.4 Forest process

Within Crab Bay proper, fringing mangrove forest is stable, growing or expanding. Fringe mangrove forest is stable along 40% of the surveyed shoreline, and exhibits clear signs of growth along almost half of the shoreline (Figure 5.5). Where the survey extended beyond the bay area, mangroves become exposed to wind and wave action. This is evident at the Eastern and Western ends of the surveyed area.

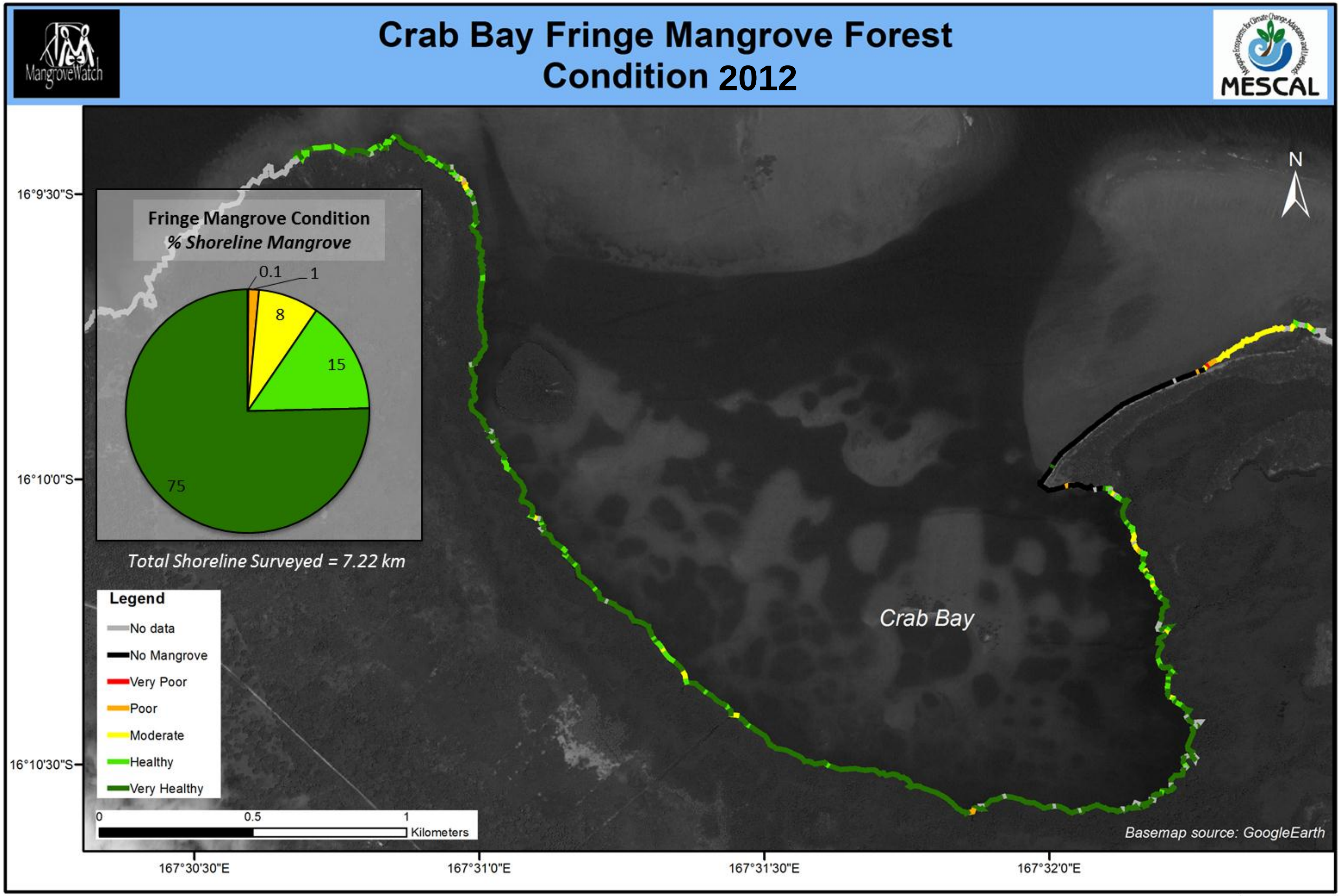


**Figure 5.4 Forest condition, Crab Bay fringe mangroves**

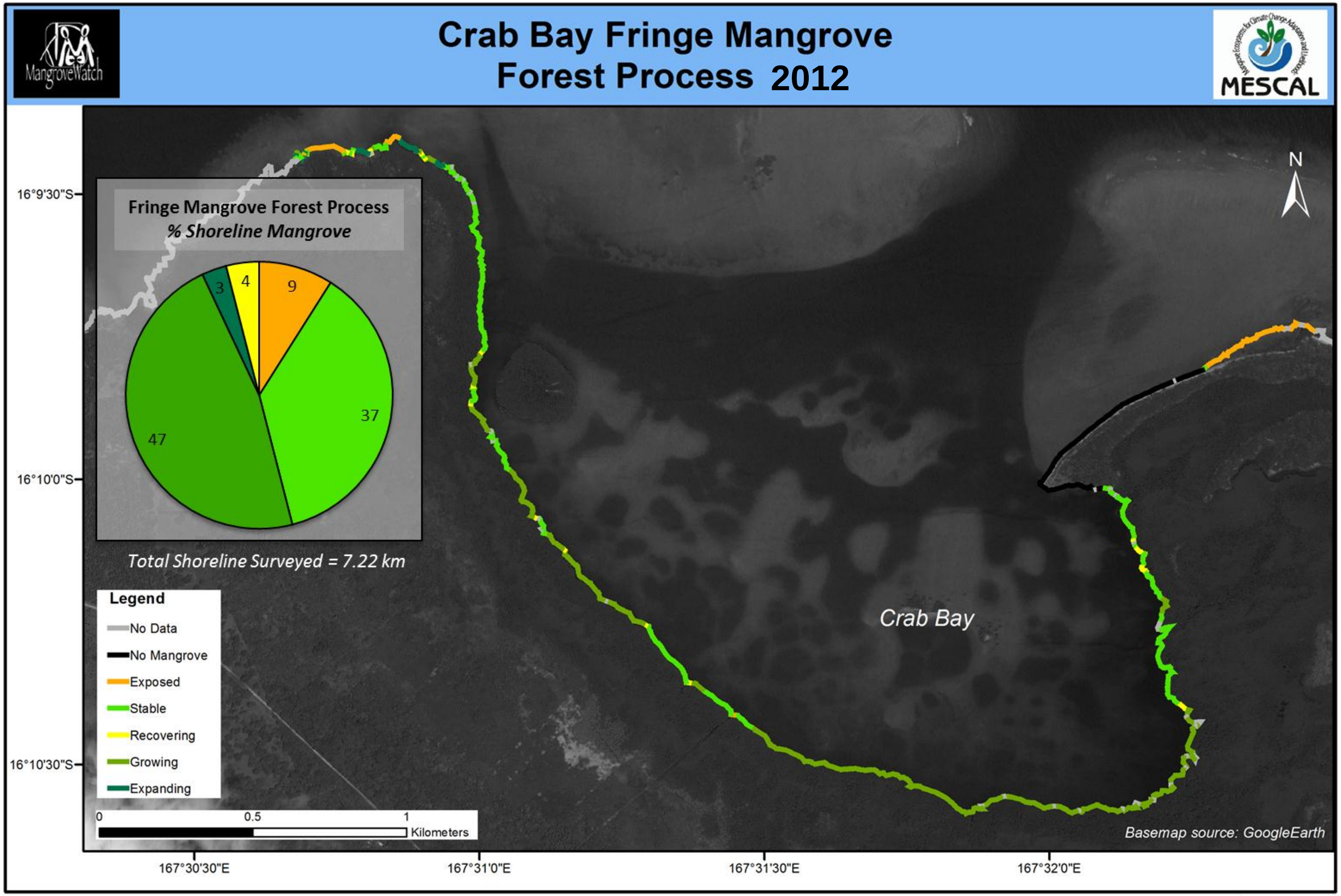


**Figure 5.5 Forest process, Crab Bay fringe mangroves**

## 5.5 Fragmentation of fringe mangrove forest

Fringing mangroves of Crab Bay are relatively in-tact with little obvious fragmentation. Five unnatural gaps in the fringing forest were observed (out of a total of 9 gaps), equating to 1.2 gaps per kilometre of shoreline. This is a very low rate of fragmentation. The average length of fringe forest patches was 631 m showing high connectivity and structural integrity. All unnatural gaps in the fringe were created for access to the shoreline or as a result of mangrove cutting (Figure 5.6).

## 5.6 Drivers of change

Mangroves in Crab Bay are exposed to low levels of natural and anthropogenic disturbance (Table 10; Figure 5.7), reflected by the general healthy condition of the fringing forest. Direct disturbances resulting in canopy dieback was identified in only 2% of fringing mangroves along the shoreline. However, unattributed disturbances are affecting mangrove condition as indicated by the level of dieback and reduced mangrove condition along an additional 8% of shoreline (Table 9; Figure 5.4).

Natural drivers include exposure to wind, wave and currents which are affecting a small amount of mangroves growing outside the area of Crab Bay proper. Three light gaps, most likely caused by lightning, strike are present along 50 m of shoreline.

Figure 5.6 Lightning strike damage (left) and a gap formed for shoreline access (right) in Crab Bay fringing mangroves

Inside the bay some cutting (80 m) and clearing (130 m) is evident, and what appear to be unnaturally formed gaps in the forest fringe are present in some areas (100 m). These are likely access trails for local communities.

Table 10 Drivers of change in fringing mangrove forest

| *Source* | *Driver* | *Shoreline affected (m)* |
|---|---|---|
| ***Anthropogenic*** | *Unnatural gaps* | 100 |
| | *Cutting* | 80 |
| | *Clearing* | 130 |
| ***Natural*** | *Light-gap* | 50 |
| | *Waves, wind, current damage* | 600 |

## 5.7 Other Observations

Shoreline erosion affecting non-mangrove shoreline habitats is present along the eastern outer bay shoreline.

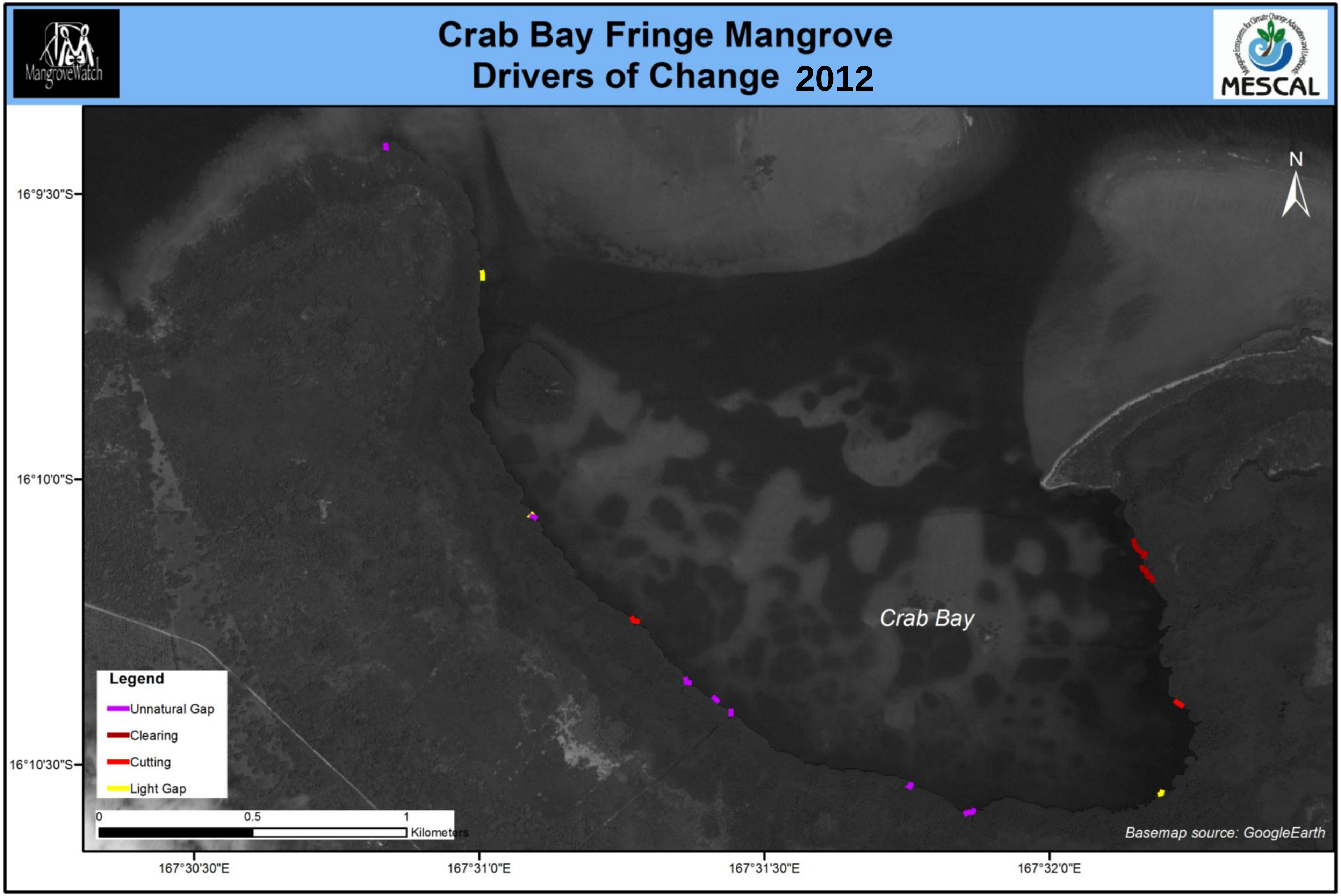


Figure 5.7 Drivers of change, Crab Bay fringe mangrove

# 6 ERATAP RESULTS

## 6.1 Survey area covered

The MESCAL Vanuatu Technical Working Group surveyed 6.65 km of the shoreline of Eratap on 27th September 2012. Figure 6.1 provides detail of the GPS track of survey travel and adjacent surveyed shoreline.

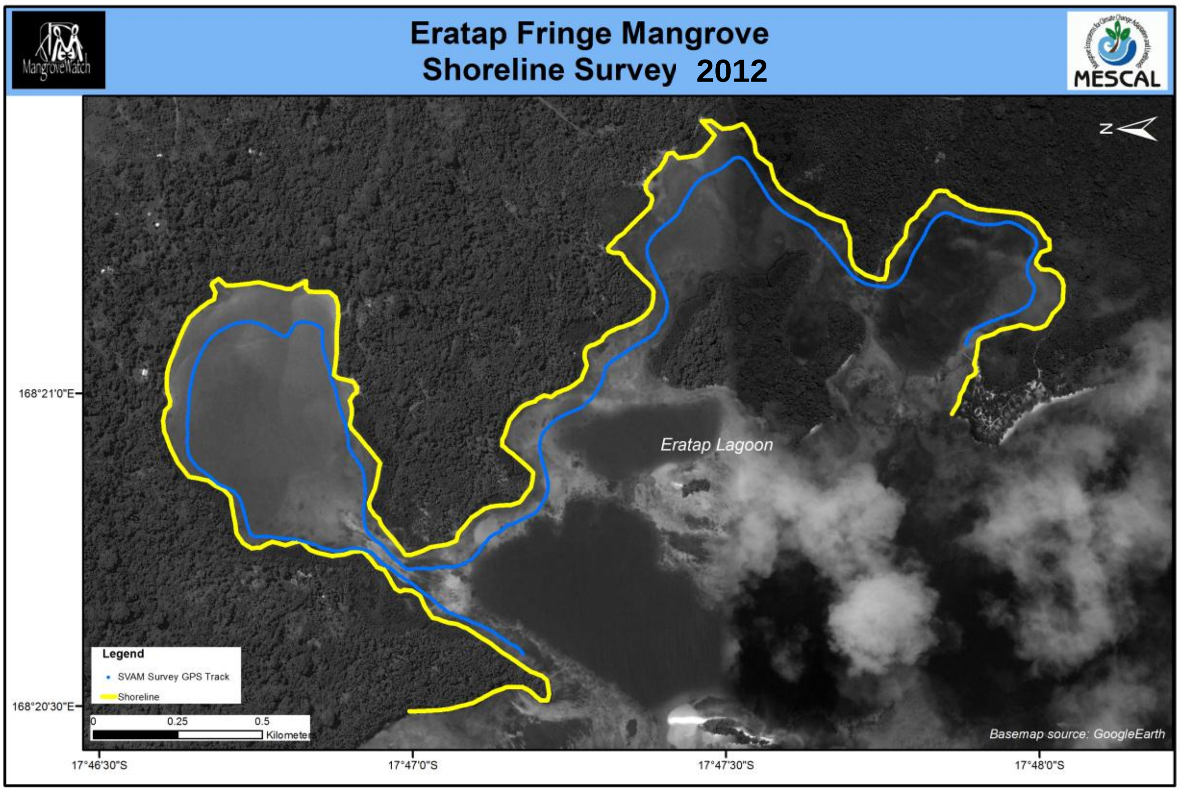


Figure 6.1 Shoreline video assessment, Eratap

## 6.2 Forest presence, biomass, physical value and habitat diversity

Mangroves were observed to occupy 5.71 km out of the total 6.85 km of shoreline representing 83% of 10 m shoreline segments assessed. Mean mangrove percent cover for shoreline segments was 79%, including non-mangrove areas. Forest height was relatively moderate across the surveyed shoreline, being estimated as approximately 5 m. The fringing forest is mostly of moderate to high biomass (67%; Figure 6.2). Mean mangrove forest height, structure score and biomass scores are provided in Table 11 and Table 6 provides a breakdown for the assessed forest structure, height, biomass and physical value scores. Figure 6.3 shows the distribution of physical value scores along the surveyed shoreline.

**Table 11 Summary of Eratap 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] |
|---|---|---|---|---|---|
| 5.04 ± 0.04<br>*Moderate* | 2.9 ± 0.04<br>*Moderate* | 4.5 ± 0.04<br>*Closed-continuous* | 4.4 ± 0.03<br>*60-80% cover* | 34% | 4.1 ± 0.03<br>*High* |

**Table 12 Percentage of surveyed shoreline classified as falling within each forest structure score**

| *Score* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ***Height*** | 4% | 15% | 37% | 41% | 3% |
| ***Forest structure*** | 2% | 3% | 5% | 25% | 65% |
| ***Biomass*** | 9% | 23% | 36% | 31% | 1% |
| ***Physical value*** | <1% | 6% | 12% | 21% | 58% |

Mangroves along the Eratap Lagoon shoreline are relatively structurally homogeneous. The dominant species appears to be *Rhizophora stylosa* (69%), with *R. apiculata* often present (and co-dominant) along the shoreline (43%; Table 13). *Avicennia marina* was present in more marine areas. *Sonneratia alba* was present in isolated stands within the lagoon. *Ceriops tagal* was observed where the upper inter-tidal zone was near the shoreline edge, often occurring as small shrubs.

**Table 13 Fringe mangrove species dominance. Note; percentages add to >100% where species are co-dominant**

| Species name | *A. marina* | *R. apiculata* | *R. stylosa* | *S. alba* | *C. tagal* |
|---|---|---|---|---|---|
| ***% of shoreline dominated by species*** | 8% | 43% | 69% | 10% | 3% |

Fringing mangroves in Eratap Lagoon have high structural diversity (D=6.64) and habitat type richness (r=47) owing to variation in canopy cover along the shoreline related to habitat condition (see Table 15). The most common fringe habitat types are provided in Table 14. A very low habitat evenness score (E=0.14) reflects how the presence of remaining factors (stem density, canopy layers, intertidal canopy, aerial root structures) are relatively similar across the surveyed shoreline. The most common structural attribute association is closed continuous, *Rhizophora* dominated fringe forest with inter-tidally submerged canopy and either very high canopy (34%; Table 14 types 1 and 2).

**Table 14 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 | 80-100% | No | Prop Roots | Fringe Only | 34% |
| 2 | Closed-Continuous | 60-80% | Yes | Prop Roots | Fringe Only | 10% |
| 3 | Open-Continuous | 80-100% | No | Prop Roots | Fringe Only | 9% |
| 4 | Closed-Continuous | 60-80% | Yes | Prop Roots | Fringe Only | 9% |
| 5 | Open-Continuous | 60-80% | Yes | Prop Roots | Fringe Only | 7% |

Fringing *Rhizophora* forest generally has very high structural complexity that is beneficial to mangrove shoreline protection and stabilisation capacity and water quality improvement. As such the fringing mangroves surveyed have an overall high mean physical value score (4.1 ± 0.05). 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 5.3).

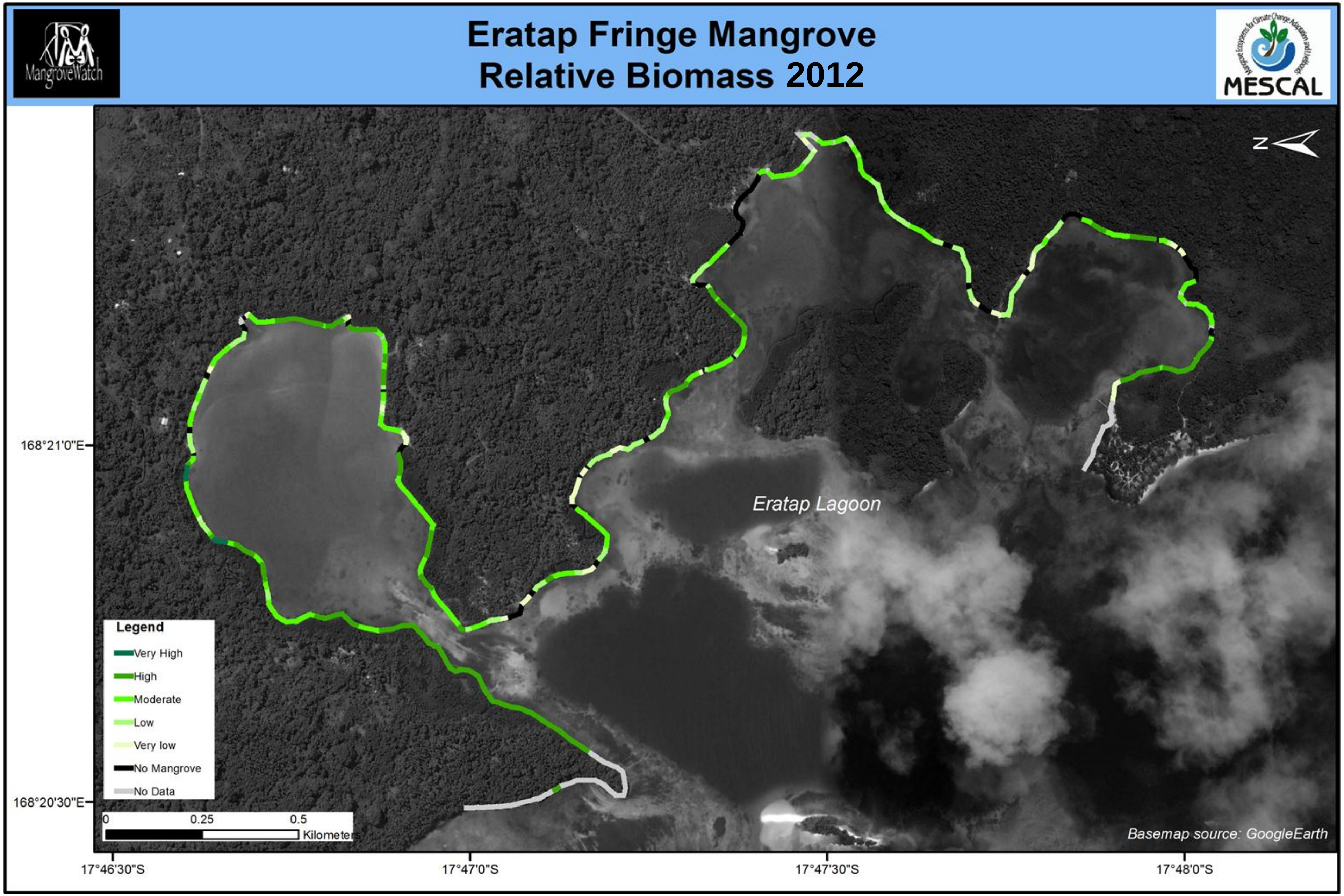


**Figure 6.2 Forest biomass, Eratap fringe mangroves**

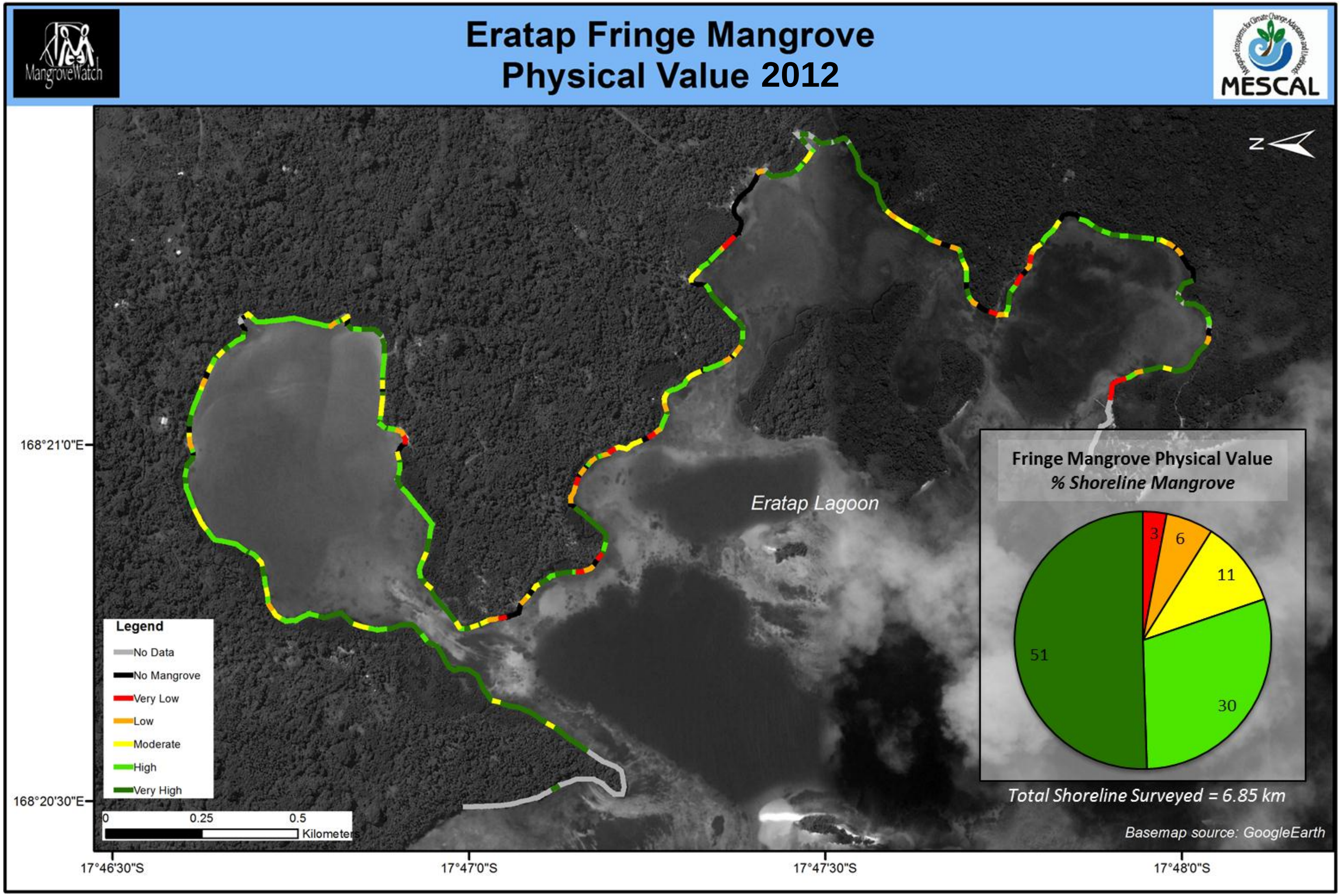


**Figure 6.3 Physical value score, Eratap fringe mangroves**

## 6.3 Condition of fringe mangrove forest

The majority of fringing mangroves along the surveyed shoreline are in very good or good health (78%) with a mean mangrove condition score of 4.2 ± 0.04. Forty-eight percent of mangroves were recorded as very healthy, having no visible signs of dieback (Table 15; Figure 6.4). Twenty-two percent of fringe mangroves were less than healthy having either low canopy cover, dieback or experiencing cutting. Dieback was obvious in fringe mangroves along 35% of the shoreline, giving an overall low dieback mean score (4 ±0.05). Fifteen individual dead trees were observed, occupying 2.6% of the shoreline, with 2.6 dead trees per km. The mean canopy cover score was high; 4.4 ± 0.03 (60-80% cover; see also Table 15), showing that mangrove fringe forests have relatively open, yet continuous, canopies in Eratap Lagoon.

**Table 15 Mangrove health score distribution**

| *Score* | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ***Dieback*** | 3% | 7% | 25% | 19% | 48% |
| ***Canopy cover*** | <1% | <1% | 8% | 39% | 52% |
| ***Mangrove condition*** | 2% | 3% | 17% | 25% | 53% |

## 6.4 Forest process

Eratap fringing mangroves are generally stable (85%), however on just over 10% of the shoreline fringe mangroves are either exposed (5.8%) or retreating (5.4%). Expanding mangrove forest is present along 2.8% of the shoreline (Figure 6.5). Very little shoreline mangrove showed signs of new growth (0.7%). Retreating and exposed mangrove were mostly present within the small embayment at the northern end of the lagoon.

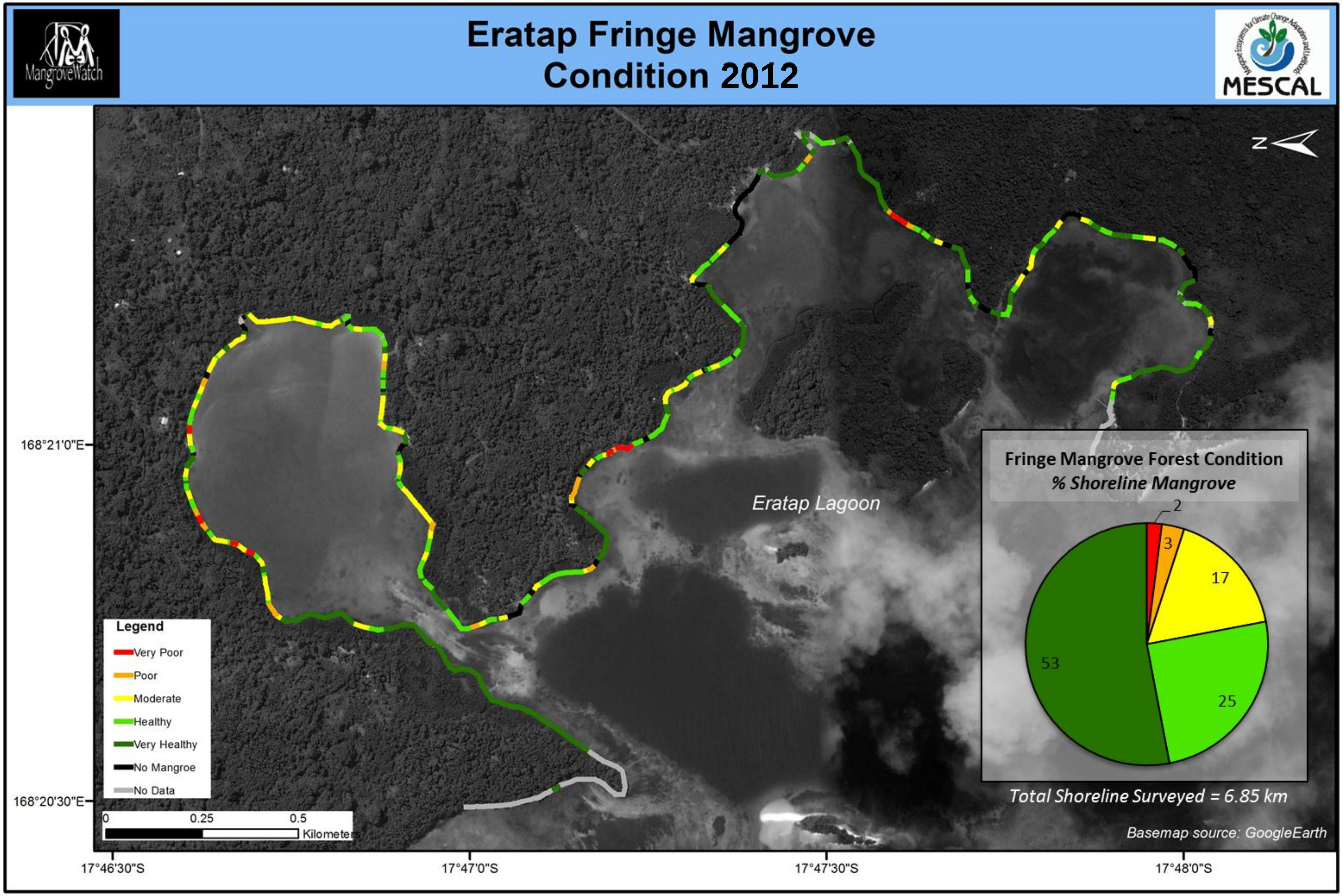


**Figure 6.4 Forest condition, Eratap fringe mangroves**

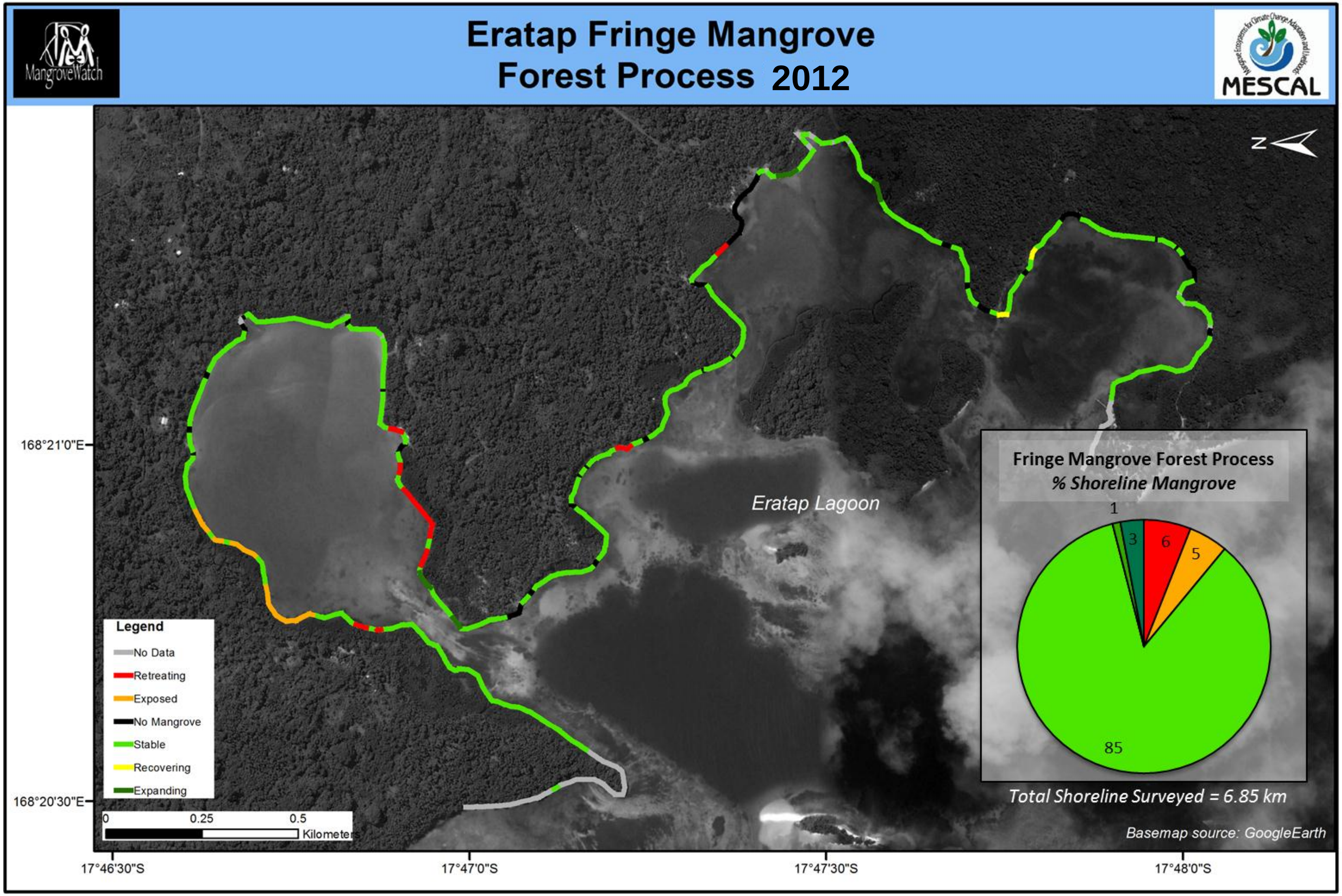


**Figure 6.5 Forest process, Eratap fringe mangroves**

## 6.5 Fragmentation of fringe mangrove forest

Fringing mangroves of Eratap Lagoon are fragmented with 50 gaps in the mangrove fringe observed equating to 7.3 gaps per kilometre of shoreline. Half (25) of the forest gaps can be attributed to recent or historic coastal development and mangrove clearing. The average length of fringe forest patches was 100 m.

## 6.6 Drivers of change

Mangroves in Eratap Lagoon are exposed to high levels of anthropogenic disturbance (Table 10; Figure 6.7), which is reflected by the level of fragmentation and high proportion of mangroves with less than healthy condition. The primary anthropogenic driver of mangrove habitat degradation is coastal development related to recent and historical clearing (670 m) and cutting (450 m). The construction of Aquana Beach resort has resulted in the loss of approximately 220 m of mangrove. Sand deposited during construction is impacting 40 m of adjacent mangrove due to root burial (Figure 6.6).

Natural drivers of change are also affecting Eratap Lagoon fringing mangroves. The primary natural driver appears to be wind, wave and currents, causing shoreline exposure and mangrove retreat along 640 m of shoreline (Figure 6.5).

**Table 16 Drivers of change in fringing mangrove forest**

| *Source* | *Driver* | *Shoreline affected (m)* |
|---|---|---|
| ***Anthropogenic*** | *Unnatural gaps* | 590 |
| | *Cutting* | 450 |
| | *Clearing* | 670 |
| | *Root Burial* | 40 |
| ***Natural*** | *Light-gap* | 10 |
| | *Waves, wind, current damage* | 640 |

**Figure 6.6 Drivers of change in Eratap fringing mangroves: Cutting (top left), clearing for a new coastal development (top right), and root burial causing mangrove dieback adjacent to resort development (bottom)**

## 6.7 Other Observations

The Eratap Lagoon is shoreline is mostly raised coral reef platform with a sharp delineation between terrestrial and intertidal habitats and limited intertidal zone width available for mangrove colonisation.

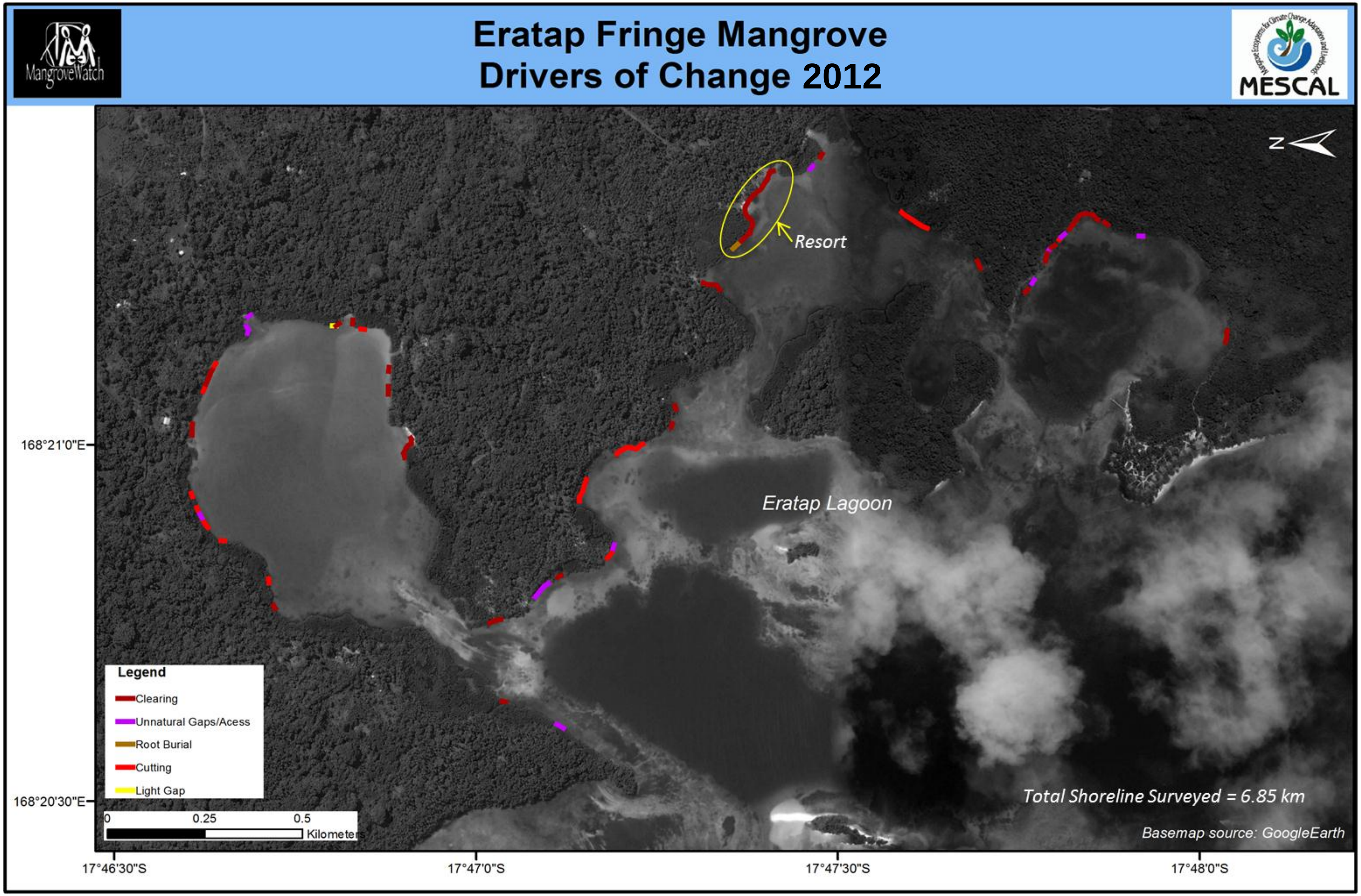


**Figure 6.7 Drivers of change, Eratap fringe mangrove**

# 7 DISCUSSION

This report provides critical baseline information to inform future management of valuable fringing mangrove habitats in Vanuatu 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 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). 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). Shoreline vegetation can provide significant shoreline protection to coastal communities by buffering wave action and reducing the impact of storm surge upon adjacent infrastructure (McIvor et al. 2012a, McIvor et al. 2012b). 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 (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 7.22 km of fringing mangrove forest of Crab Bay, Malekula, and 6.85 km of fringing mangrove forest of Eratap, Efate; the two MESCAL demonstration sites in Vanuatu. 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 assessment of two distinct areas in Vanuatu provides capacity for comparison between the demonstration sites and enables a more holistic view of mangrove forest structure, condition and threats throughout Vanuatu that can inform future mangrove management. The results presented here show that mangrove forest structure is relatively similar at Crab Bay and Eratap Lagoon. However, there are key differences in structural integrity between the two sites relating to ecosystem service provision and resilience capacity. These differences are for the most part due to adjacent human population densities, the proximity of the sites to urban centres, and coastal geomorphology. Crab Bay shoreline is of relatively low-relief with a gradual intertidal slope allowing for expansive tidal wetland areas. In comparison, much of the Eratap lagoon shoreline is raised coral reef platform, with sharp delineation between terrestrial and intertidal habitats and limited intertidal margins suitable for mangrove colonisation. Eratap Lagoon is 6 km from the capital Port

Vila, an area of high population density, whereas Crab Bay is more isolated and surrounded by small villages and low-intensity landuse.

Comparisons of mangrove structure between the two survey locations show that fringing mangroves within Eratap Lagoon generally have lower stem density, more open canopies and less intertidal canopy compared to fringing mangroves in Crab Bay. In Crab Bay the canopy was on average a closed continuous structure, with high canopy cover and a high proportion of intertidal canopy present. These variations in forest structure are likely a result of differences in coastal geomorphology between the sites, but may also relate to greater anthropogenic pressure experienced at Eratap

High levels of cutting, clearing and habitat fragmentation were observed at Eratap compared to Crab Bay. In Crab Bay the average length of a continuous mangrove fringe (between gaps) was 631 m. In Eratap this distance was only 100 m. These differences in fragmentation are probably due to both greater demand for wood resources relating to proximity of the site to Port Vila, and generally elevated population density on Efate compared with Malekula. The close proximity of Eratap to Port Vila also increases coastal development pressure, e.g. for resort developments.

Fringing mangrove habitat in Eratap Lagoon was in poorer health than in Crab Bay. The hard coral platform substrate of Eratap Lagoon would very likely influence mangrove growth and condition. Additionally, Eratap mangrove condition is partly related to greater exposure to climatic variations (wind, waves and currents) of this site compared with the protected interior of Crab Bay, and the intensified effect these have on the fragmented mangrove forest at Eratap.

Habitat fragmentation is known to negatively affect ecosystem health and resilience {McLeod and Salm 2006}. The capacity of mangrove stands to provide ecosystem services are also negatively impacted by reductions in forest density and condition (Victor et al. 2004, McIvor et al. 2012a, McIvor et al. 2012b). Mangroves in Eratap Lagoon received a lower fringing mangrove physical value score compared with Crab Bay mangroves. As a result, it is likely that Eratap Lagoon mangroves have lower capacity to buffer wind, waves and storm surges and maintain good lagoon water quality. Additionally, in some circumstances habitat fragmentation may actually exacerbate damaging waves and storm surges; increasing risk of habitat loss and damage to coastal infrastructure (McIvor et al. 2012b).

Habitat fragmentation reduces connectivity, having likely negative impacts on value of the mangroves as fish habitat (Sheaves 2005). As such, despite Eratap Lagoon exhibiting higher mangrove structural complexity and habitat diversity, it is likely that the habitat value of Crab Bay mangroves is the higher of the two demonstration sites due to the low rates of fragmentation at this site. Additionally, habitat value is positively influenced by high mangrove productivity. Healthy mangroves have higher rates of productivity, which in turn influences fisheries productivity (Twilley 1988, Barbier and Strand 1998). Crab Bay mangroves are healthier than those in Eratap Lagoon; likely resulting in higher productivity and habitat value in Crab Bay mangroves.

Both Eratap Lagoon and Crab Bay are experiencing some degree of mangrove loss and exposure associated with shoreline erosion. In Crab Bay exposed mangrove areas, which represent potential loss, are offset in part by areas of mangrove expansion. In Eratap lagoon there is both greater extent of mangrove retreat and exposure, and little mangrove expansion occurring. Consequently, there is a greater net loss of mangrove fringe in Eratap Lagoon.

Whilst some areas in Crab Bay have experienced natural and anthropogenic damage, recovery and regrowth in areas previously damaged shows that Crab Bay has high resilience capacity. Mangroves in Crab Bay were observed to be increasing in biomass through forest growth, a further indicator of the health of mangroves in this area. Comparatively, in Eratap Lagoon no recovery of the fringing mangroves was observed, and little evidence of forest growth were identified. These forest processes indicate what may be a lower resilience capacity of mangroves in Eratap Lagoon compared with Crab Bay mangroves.

The coastal geomorphology of Eratap Lagoon is a limited intertidal zone abutting a sharp increase in relief (an elevated step), meaning mangroves are mostly restricted to a narrow shoreline fringe. The absence of extensive mangrove areas in Eratap Lagoon elevates the importance of the mangrove fringe for coastal defence, water quality improvement and habitat provision compared to areas that have basin forest mangroves behind the fringe such as occurs in Crab Bay. Additionally, the stepped physical profile means that mangroves of Eratap Lagoon are highly at risk of sea level rise impacts, as both accretion capacity and landward encroachment is likely to be low (Lovelock and Ellison 2007). Identification and implementation of management actions that build the resilience and adaptation capacity of Eratap mangroves are of great importance at this site, particularly given the documented low rates of natural mangrove recovery and regrowth. The current study has identified relatively high levels of anthropogenic disturbance within Eratap fringing mangroves. Actions which work to limit or reduce further anthropogenic disturbances will have likely positive outcomes for climate change adaptation capacity and resilience of mangroves in Eratap Lagoon.

**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. The information presented here provides a baseline from which to assess future habitat change 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. Fringing mangrove habitat with reduced structural integrity or in poor condition due to natural or anthropogenic disturbance should be considered management priorities to improve habitat value and resilience. Specifically, fringing mangroves in Eratap Lagoon require greater protection from anthropogenic fragmentation, clearing and cutting in order to maintain ecosystem values and climate change resilience capacity. Additionally, restoration of damaged areas may be required to assist timely habitat recovery, particularly given the lack of observed natural recovery in Eratap Lagoon.

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 Vanuatu 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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