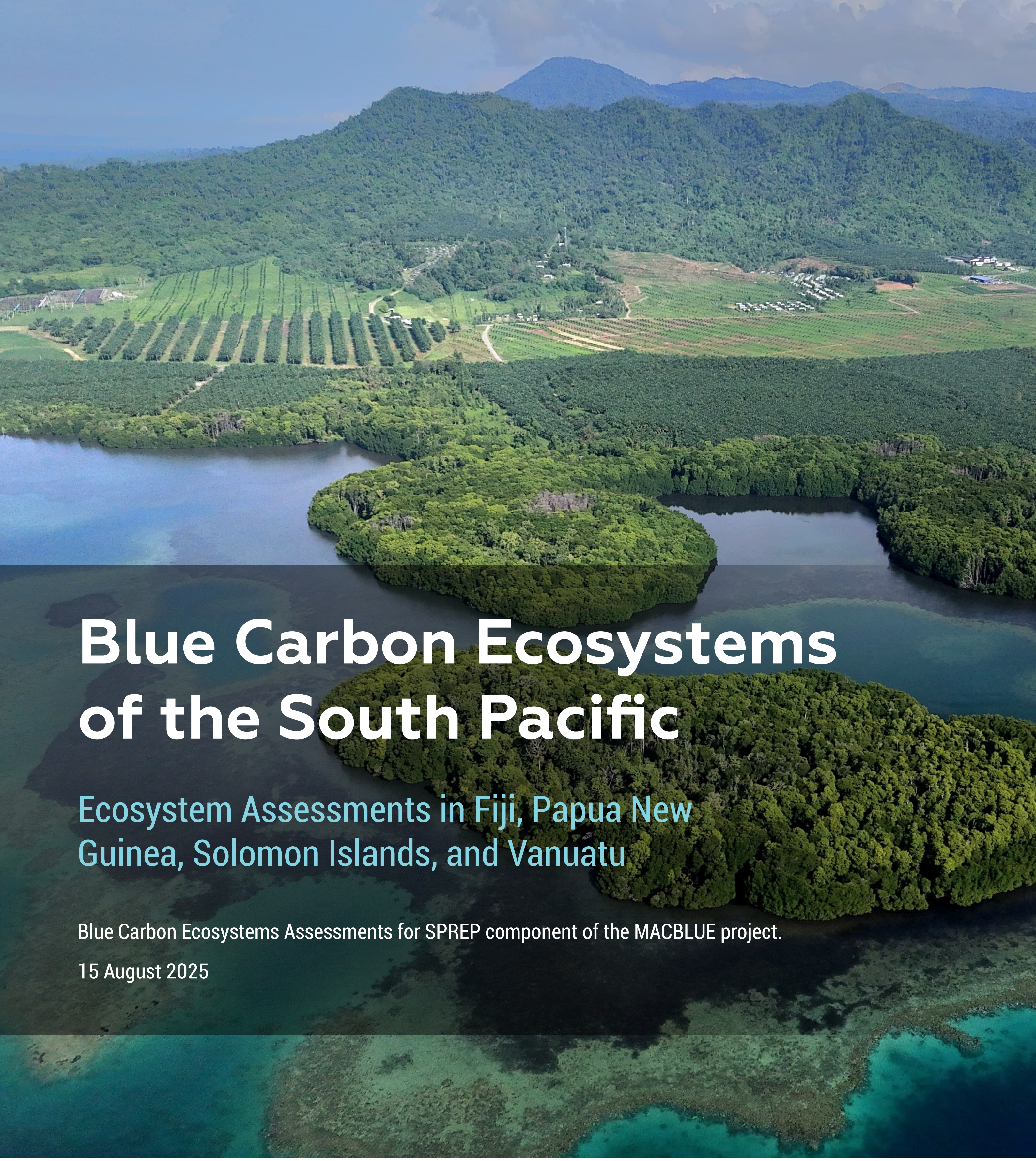

Blue Carbon Ecosystems of the South Pacific

Ecosystem Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu

Blue Carbon Ecosystems Assessments for SPREP component of the MACBLUE project.

15 August 2025

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All photos: Unless otherwise acknowledged, all photographs taken by Alluvium Group

Disclaimer
This report was prepared by EcoFutures Consulting Australia Pty Ltd for SPREP under the contract titled ‘Blue Carbon Ecosystems Assessments for the SPREP component of the MACBLUE Project.’

Executive Summary

About the project

The project contributes to the Secretariat of the Pacific Regional Environment Programme (SPREP)'s component of the Management and Conservation of Blue Carbon Ecosystems (or MACBLUE) project, aiming to "*contribute to human and technical capacity to the mapping, management and rehabilitation of coastal ecosystems."* The MACBLUE project is a joint effort between the Deutsche Gesellschaft fur International Zusammenarbeit (GIZ), The Pacific Community (SPC) and SPREP. Its aim is to *"strengthen coastal biodiversity conservation and management through protection and rehabilitation incentives for coastal carbon sinks in Pacific Island countries."* The project requires blue carbon assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu.

The data collected will allow inventories of associated natural capital and will support government partners to better develop and implement conservation, management, and rehabilitation efforts. Good quality mapping and assessment data is essential for developing informed conservation and rehabilitation plans. This project seeks specifically to:

- Verify satellite mapping,
- Assess carbon sequestration rates in seagrass and mangrove habitats,
- Evaluate coastal blue carbon habitats,
- And to train and build capacity in each of the countries.

Scope of this report

This report forms one part of a series of Seagrass and Mangrove (SaM) Ecosystem Assessment Reports for Stage 3 of the project titled *"Consultancy services to conduct Blue Carbon Ecosystems Assessments for SPREP component of the MACBLUE project"*. This report is specific to fieldwork assessments conducted in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu for this project. It includes:

- A summary of existing information relevant to this assessment in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu
- The methods for site selection and fieldwork implemented in this study
- The results of the seagrass, mangrove, biodiversity, and threat assessments conducted in-country
- A summary of the findings, conclusions, and limitations of this study.

Foreword

Blue carbon ecosystems, including mangrove and seagrass ecosystems, are known for the critical services they provide, as habitats and nurseries for marine life, coastal protection, food security, water quality, eco-tourism and as important as carbon sinks, all of which have sustained our Pacific people for generations. Despite their importance, rapid habitat loss is increasing driven predominantly by climate change and data on drivers, rate of loss, and vulnerabilities remain insufficient.

With the aim of reducing that knowledge gap, the Secretariat of the Pacific Regional Environment Programme (SPREP), through the Management of Blue Carbon Ecosystems in Pacific Island Countries (MACBLUE) project, conducted a standardised rapid biodiversity and threat assessment for seagrass and mangroves in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu.

The methodology enabled a broader spatial coverage with a total of 131sites assessed across the four countries, providing an extensive ecological overview and analysis across diverse environment and settings.

It gives me great pleasure to present the culmination of the study - the Blue Carbon Ecosystem Assessment report. The report describes in detail the study sites, field survey methods, and results.

Overall, the assessment findings indicate that despite the existing pressures on these ecosystems, mangrove forests remain resilient in most locations while seagrass meadows thrived as habitat/feeding grounds for a large range of marine species, including dugongs in Papua New Guinea and Vanuatu. While impacts from cyclones were instantaneously notable in certain areas, many of the threats identified were anthropogenic in nature (man-made).

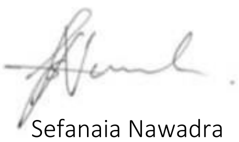
Furthermore, this report documents the distribution of seagrass and mangrove species and highlights priority areas for management. As Pacific countries and territories continue to lead the global discussion on climate action and nature-based solutions, this report provides substantive contributions for strategic actions and interventions.

The MACBLUE project is implemented by SPREP in partnership with Deutsche Gesellschaft fur International Zusammenarbeit (GIZ) and the Pacific Community (SPC), and we acknowledge the German Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV)- through its International Climate Initiative (IKI) for funding this project.

On behalf of SPREP, I extend our appreciation to Alluvium International Group for leading the implementation of the study in collaboration with our key government partners in the four countries, whose collective efforts have made this project and study a success.

We are sincerely grateful for the support of the local communities across the 131 sites assessed who, through Free, Prior and Informed Consent (FPIC), generously shared their lands, waters, and knowledge to make this study possible.

It is our hope that the information generated through this report will not only support national and regional strategies but will also inspire continued investment, innovation, and strengthen partnerships to protect and restore the blue carbon ecosystems for the people of our Blue Pacific continent.



Sefanaia Nawadra

Director General SPREP

Acknowledgements

We gratefully acknowledge the many individuals, communities, and organizations who made this blue carbon assessment project possible across Fiji, Papua New Guinea, Solomon Islands, and Vanuatu.

We extend our special thanks to the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for their generous funding and support, which made this work possible.

This work was made possible through the generous support and collaboration of local communities, who welcomed us onto their lands and waters. We respectfully recognize the importance of the Free, Prior and Informed Consent (FPIC) process, which was followed in all locations. Communities were notified prior to our arrival, and permissions were formally granted by village chiefs, provincial administrators, and local leaders. Their trust and hospitality were essential to the success of this project.

Across the project, Turang Teuea and Paul Maxwell led project management, with field assessments coordinated by Emily Saeck and Erin Thompson. Field assessments were led by a dedicated team of botanists and ecologists, including Ana Backstrom, Emily Saeck, Erin Thompson, Rohan Khot, Chrissi Charles, Paul Maxwell, Patrick Pikacha, Simon Albert, Alistair Grinham, Fernanda Adame, and Nicholas Grundy. Blue carbon expert advice and oversight were provided by Cath Lovelock, Fernanda Adame, Simon Albert, Patrick Pikacha, and Alistair Grinham. Mapping support was led by Aakash Malik and Erin Thompson, in collaboration with SPC and GIZ. Charlotte Warfield and Erin Thompson led the big job of data management and analysis.

Field assessments in each country required the support of teams of local experts and field support, as summarised here. We hope we have not left anyone out.

Fiji

Local Expert Advice: Helen Sykes, Milika Sobey, Paula Tuvura

Fieldwork Coordination: Manasa Vulu, Vasiti Vosabalavu Naikoyadau, Shyam Lodhia, Turang Teuea

Fieldwork Support: Nick Metherall, Shyam Lodhia, Semi Lawevuso, Paula Tuvura, Mereoni Taga, Kalesi Tuitui Nadalo, Etuate Serevi, Vasiti Vosabalavu Naikoyadau, Mr Henry Miller, Mr Tom, Miss Sala, Mr Ben

We extend our sincere thanks to the village heads (Turaga ni Koro), provincial and national government offices who granted permission and supported this research, including:

- Ministry of iTaukei Affairs
- Roko Tui and Assistant Roko Tui, Rewa Provincial Office
- Turaga ni Koro for Nakadrudru, Galoa Island, and Tavea
- Tui Labasa Ratu Jone Qomate
- Turaga ni Koro for Mali Island
- Solomone Qilatabu and Joji Lalabalav for Ovalau Island and Lomaiviti Province
- Mr Asaeli Tamanitokula – Bua Province
- Mr Manasa Vula – Cakaudrove Province
- Ms Vasiti Vosabalavu Naikoyadau – Macuata Province

- Maria Dali – Rewa Province

Papua New Guinea

Local Expert Advice: Phelameya Haiveta, Patrick Pikacha, Japheth Gai, Marika Seden

Fieldwork Coordination and Community Liaison: Phelameya Haiveta, Japheth Gai, Akanisi Lomaloma, Gideon Bogosia, Gerard Avoa, Benjamin Keni, Marika Seden, Tiana Reimann, Artie Jacobson, Dainah Gigiba, Lulu Osembo

Fieldwork Support: Tiana Reimann, Marika Seden, Isaac Rounds, Priscilla Pep, Paul Taro, Ray Barrette, Seawomen of Melanesia, Artie Jacobson, INLOC Ranger Program, Tobby Jinga, Nembo Oro, Marzena Marinjembi, Japheth Gai, Turang Teuea

We extend our sincere thanks to the community leaders, provincial administrations and national authorities who granted permission and supported this research, including:

- Climate Change and Development Authority
- Conservation and Environment Protection Authority
- National Research Institute
- Village Headman, Old Mawatta
- Village Headman, Lavatbura
- Youth President, Maiwara Village
- Bautama Seventh Day Adventist Church
- Lulu Osembo – Milne Bay Province
- Benjamin Keni – Central Province / Hiri District
- Dianah Gigiba – South Fly District
- Gideon Bogosia – New Ireland Province
- Desmond Mondo Poka Vaghelo – West New Britain Province

Solomon Islands

Local Expert Advice: Myknee Sirikolo, Veira Pulekera, Simon Albert

Fieldwork Coordination, Fieldwork Support and Community/Provincial Liaison: Sammy Airahui, Myknee Sirikolo, Veira Pulekera

We extend our sincere thanks to resources owners, provincial governments, community chief and leaders, rangers and National Government participated in this study in four Provinces, with relevant permits under MECDM & Provincial Government. Among those we wish to acknowledge include:

- Ministry of Environment, Climate Change, Disaster Management and Meteorology
- Environment and Conservation Department
- Climate Change Division
- Ministry of Forestry and Research
- Ministry of Fisheries and Marine Resources
- Village Chief, Takwa

- Village Chief, Michi
- Village Chief, Chumbikopi
- Village Chief, Nazareth
- Village Chief, Baolo
- Malaita Province
- Santa Isabel Province
- Western Province
- Guadalcanal Province

Vanuatu

Local Expert Advice: Rolenas Tavue Baereleo, Dean Launder, Milika Sobey

Field Coordination and Community Liaison: Moses Amos, Clay Sara, Malili Malisa

We extend our sincere thanks to the community leaders, provincial and National Government offices who granted permission and supported this research, including:

- Department of Environmental Protection and Conservation
- Chief, Malokillikilli
- Chief, Paonangisu
- Chief, Peskarus
- Mayor, Sanma Province
- Town Clerk and Deputy Town Clerk, Luganville
- Malampa Province

We are deeply grateful to all who contributed their time, expertise, and hospitality. This project would not have been possible without your support.

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GLOSSARY

DBH	Diameter at Breast Height
FPIC	Free, Prior, and Informed Consent
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Corporation for International Cooperation)
MACBLUE	Management and Conservation of the Blue Carbon Ecosystems
NGO	Non-Governmental Organisation
PNG	Papua New Guinea
SaM	Seagrass and Mangrove
SE	Standard Error
SPC	The Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
TECs	Total Ecosystem Carbon stocks

1 Introduction

1.1 Background

1.1.1 Seagrass and mangroves are valuable coastal ecosystems for Pacific Island Nations

Blue Carbon Ecosystems (BCEs), such as Seagrass and Mangrove (SaM) ecosystems, provide substantial ecological, economic, and social benefits, significantly supporting the lives and livelihoods of Pacific Island Nations.

SaMs capture and store carbon, acting as highly effective carbon sinks and play a crucial role in climate change mitigation. These systems, despite being much smaller in size than terrestrial forests, sequester carbon at a much greater rate. When these systems are degraded or removed, a large amount of carbon is emitted back into the atmosphere, where it can contribute to climate change.

Ecologically, these habitats serve as critical nurseries for numerous marine species, enhancing biodiversity and supporting fisheries that are vital for food security. Mangroves, with their complex root systems, stabilise coastlines, reduce erosion, and protect against storm surges and tsunamis. Economically, these ecosystems support artisanal and commercial fisheries, providing livelihoods for coastal communities. Additionally, they attract ecotourism, which generates income and promotes conservation efforts. Socially, mangroves and seagrasses contribute to the cultural heritage of Pacific communities, offering resources for traditional practices and medicines.

The protection and restoration of these BCEs not only protect carbon stores that help mitigate climate change but are also essential for the sustainable development and resilience of Pacific Island nations.

1.1.2 Rapid assessment across four Pacific Island Nations: Fiji, Papua New Guinea, Solomon Islands, and Vanuatu

Understanding the unique characteristics and vulnerabilities of SaM ecosystems across the Pacific Island Nations is critical for their management and protection, particularly in the context of land development, climate change, and sea-level rise. Many previous studies have focused on assessments at the scale of individual sites and locations; however, no prior study has sought to compare carbon stocks, ecological characteristics, and threats using a standardised method across four Pacific Island Nations (Fiji, Papua New Guinea, Solomon Islands, and Vanuatu). This is due to logistical difficulties and the vast geographic spread of the islands, which can hinder extensive research efforts.

This project aims to fill this gap by applying rapid assessment methods for evaluating the carbon stocks, ecological characteristics, condition, biodiversity, and threats to SaM ecosystems. Rapid assessment methods are advantageous because they enable researchers to cover larger spatial areas efficiently, providing a comprehensive overview of ecosystems across diverse locations. This broad spatial coverage facilitates comparative analyses, helping to identify patterns and trends that may not be apparent in smaller-scale studies. Additionally, these methods allow for the quick identification of high-priority areas for further research, restoration, and protection efforts, ensuring that resources are allocated effectively to the most critical sites.

1.2 Purpose of this document

This document was developed to present the results of an ecosystem assessment for mangroves and seagrass communities of four Pacific Island nations – Fiji, Papua New Guinea (PNG), Solomon Islands, and Vanuatu.

This document fulfills the task “Prepare SaM Ecosystem reports” for the project titled *“Consultancy services to conduct Blue Carbon Ecosystems Assessments for SPREP component of the MACBLUE project”*. The document presents the results of a field-based threat assessment and biodiversity assessment, incorporating the findings of a rapid field assessment and data analysis for each.

For each country this report presents:

- A review of existing literature on seagrass and mangrove ecological conditions for the country
- Description of field survey locations and methods
- Seagrass and mangrove habitat maps for each country and survey location
- Results of the field seagrass and mangrove condition assessment at each study location
- Results of the field rapid biodiversity assessment at each study location
- Results of the field rapid threat assessment at each study location.

1.3 About the project

The project contributes to SPREP's component of the MACBLUE project, aiming to *"contribute to human and technical capacity to the mapping, management and rehabilitation of coastal ecosystems."* The Management and Conservation of Blue Carbon Ecosystems (or MACBLUE) is a joint effort between the Deutsche Gesellschaft fur International Zusammenarbeit (GIZ), The Pacific Community (SPC) and The Secretariat for the Pacific Regional Environment Programme (SPREP). Its aim is to *"strengthen coastal biodiversity conservation and management through protection and rehabilitation incentives for coastal carbon sinks in Pacific Island countries."* The project requires blue carbon assessments in Fiji, Papua New Guinea, Solomon Islands and Vanuatu.

The data collected will allow inventories of associated natural capital and will support government partners to better develop and implement conservation, management, and rehabilitation efforts. Good quality mapping and assessment data is essential for developing informed conservation and rehabilitation plans. This project seeks specifically to:

- Verify satellite mapping
- Assess carbon sequestration rates in SaM ecosystems
- Evaluate coastal BCEs
- And to train and build capacity in each of the countries.

2 Method

2.1 Summary

For each country, four to eight representative locations, with known seagrass and mangrove presence, were selected for carbon stock and ecological assessment. At each of these location the following ecological assessment methods were applied to two to eight sites:

1. Seagrass ecosystem rapid biodiversity assessment
2. Mangrove ecosystem rapid biodiversity assessment
3. Rapid threat assessment

The fieldwork survey methods implemented for this project were developed based on the following resources:

- *Coastal Blue Carbon: Methods for assessing carbon stocks and emissions*
- *Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses* (Howard et al. 2014[1])
- *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetland* (Hiraishi et al. 2014[2])
- *Coastal Wetlands in National Greenhouse Gas Inventories: Advice on reporting emissions and removal from management of Blue Carbon ecosystems* (Green et al. 2013[3])
- *Manual for mangrove monitoring in the Pacific Islands region* (Ellison et al. 2012[4])
- *Intertidal Spot-checks: Quick guide to collecting intertidal field validation data for seagrass mapping* (McKenzie and Yoshida, 2023[5])
- *Subtidal Spot-checks: Quick guide to mapping subtidal seagrass using drop-camera (*McKenzie and Yoshida, 2024[6])
- *Guidelines for Undertaking Rapid Biodiversity Assessments in Terrestrial and Marine Environments in the Pacific,* (Patrick et al. 2014[7])

The full fieldwork survey methodology is described in detail in *Blue Carbon Ecosystems Assessment for Carbon Stock, Biodiversity and Threats: Training and Field Manual* (Alluvium International and EcoFutures 2024[8]).

---

[1] Howard, J., Hoyt, S., Isensee, K., Telszewski, M., Pidgeon, E. (eds.) (2014). *Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses.* Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.
[2] Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). (2014). Published: IPCC, Switzerland 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/
[3] Green, Carly., Lovelock, Catherine E., Sasmito, Sigit., Hagger, Valerie. and Crooks, Stephen. (2021). Coastal Wetlands in National Greenhouse Gas Inventories: Advice on reporting emissions and removal from management of Blue Carbon ecosystems. Published by Australian Aid, University of Queensland, Environmental Accounting Services, Silvestrum Climate Associates.
[4] Ellison, Joanna., Jungblut, Vainuupo., Anderson, P., and Slaven, Christian. (2012). Manual for Mangrove Monitoring in the Pacific Islands Region. Published by Secretariat of the Pacific Regional Environment Programme (SPREP).
[5] McKenzie and Yoshida, (2023), Intertidal Spotchecks: Quick guide to collecting intertidal field validation data for seagrass mapping. Seagrass-Watch HQ. Clifton Beach, Queensland, Australia
[6] McKenzie and Yoshida, (2024). Subtidal spot-check: Quick guide to mapping subtidal seagrass using drop-camera. Seagrass-Watch HQ. Clifton Beach, Queensland, Australia
[7] Patrick, B., McClellan, R., Martin, T., Tocher, M., Borkin, K., & Smith, D. (2014). Guidelines for Undertaking Rapid Biodiversity Assessments in Terrestrial and Marine Environments in the Pacific. Apia, Samoa: SPREP, Wildlands, Australian Aid
[8] Alluvium International and EcoFutures. 2025. Blue Carbon Ecosystems Assessment for Carbon Stock, Biodiversity and Threats: Training and Field Manual (Version 21 Feb 2025). Prepared for SPREP.

2.2 Site selection

Prior to commencing field work, sites were identified and selected in stage 2 of this project (Alluvium International and EcoFutures 2024[9]) based on a framework of site prioritisation criteria. This framework was informed by project logistics, stakeholder input, and existing protocols/guidelines for carbon assessments.

A key priority for site selection process was to ensure that all habitat types, geomorphological settings, and land-use conversion levels (as described in Table 1) were representatively sampled across all countries. For the ecological assessment presented in this report, 'intact' sites were used to characterise ecosystems, and 'degraded' and 'converted' sites were used to assess key threats and impacts.

Caveat: While sites were chosen to capture variability across different settings, they were not randomly selected and therefore do not constitute a statistically representative sample. Site selection was strongly influenced by practical considerations, including accessibility, safety, and landholder permissions. This limitation should be considered when interpreting results, particularly when extrapolating findings to broader regional or national scales.

Table 1. Sampling design variables.

Variable	Categories
Habitat type	Seagrass Mangroves
Geomorphology	Riverine Tidal creek Open coast Calcareous Island Lagoon
Land-use conversion	Intact Degraded Converted

2.2.1 Geomorphology

Global studies of mangrove soil carbon have found that mangrove soil carbon significantly varies between geomorphological settings (e.g., river delta, lagoon, estuary). This is because in each setting different processes dominate and influence the soil chemistry and mangrove ecosystem, such as tides, river discharge, temperature, precipitation, and evapotranspiration. As such, to ensure variation in mangrove soil carbon is appropriately represented by this study, the geomorphic setting has been considered in sampling design. In each country, sites were selected to ensure sampling across all categories shown in Table 1.

2.2.2 Land-use conversion

Prioritising conservation and restoration efforts for blue carbon habitats requires an understanding of 1) avoided carbon emissions due to prevention of loss; and 2) gained carbon stocks due to restoration. Different types of land-use conversions are related to different carbon emission predictions. Specifically, they have been found to vary between land-use changes due to: (a) conversion to commodities, such as agriculture or aquaculture; (b) coastal erosion; (c) clearing; (d) extreme climatic events; and (e) conversion to human settlements. As such, sampling across a gradient of land-use conversion levels has been included in sampling design (Table 1). This approach will ensure the data collected from this study allows land-use drivers for carbon stocks to be integrated into Nationally Determined Contributions to the Paris Agreement and support each country's ability to predict and prioritise conservation and management.

[9] Alluvium International and EcoFutures. 2024. STAGE 2 – Priority Sites Identification Report. Blue Carbon Ecosystems Assessments for SPREP component of the MACBLUE project. Prepared for SPREP.

2.3 Site prioritisation framework

Logistics and safety concerns were equally significant criteria for site selection. Given this, priority was given to sites where:

- Seagrass and mangroves were confirmed present.
- Sites representing two or more categories were present in the surrounding area.
- Accessibility to location and associated sites was high.
- Safety risk to field team was low.
- Likelihood of community consent to visit and sample was high.

Table 2 provides a description of the criteria that were used to select priority sites. Combinations of priority locations were then compared. Table 3 provides a description of the criteria used to assess various combinations of sites.

Table 2. Criteria used to rank and select short list of priority sites.

Category	Criteria for individual sites	Description
Habitat	Mangroves present	Sites where both seagrass and mangrove are present are preferred from a logistics perspective. Sites with relatively large habitat extents are preferred as they represent significant carbon stocks for each country.
	Seagrass present	As above.
	Endemic species present	Sites where endemic species are present are relatively unique and unlikely to represented by existing allometric that do not represent their unique carbon stocks; as such understanding carbon stocks in these habitats are key to more accurate national carbon stock assessments.
Access & safety	Travel cost to access site	Sites that minimise travel costs are favoured, reducing budget costs and allowing more sites to be surveyed.
	Travel time between sites	Sites that minimise travel time are favoured, allowing more sites to be surveyed.
	Travel mode between sites	Sites that have fewer, easier and safer modes of transport are favoured, allowing more sites to be surveyed.
	Access at site	Sites where access is not complex are favoured, as this reduces survey time and allows more sites to be surveyed.
	Hazards at site	Sites where risks to field staff safety are lowest are favoured. Hazards may include saltwater crocodiles, aggressive dogs, hostile individuals from local community, or regions with high criminal activity.
Community engagement	Community	Sites must have a community that is aware, engaged and welcoming of the project on their land.
	NGO	Ideally sites have an NGO actively working with the local community.
	FPIC (free prior informed consent)	Ideally an FPIC process has been formally completed.
National priorities	Local management site	The MACBLUE project will identify one Local Management Site per country. These sites are a priority for carbon stock assessment.

Category	Criteria for individual sites	Description
	National priority	Sites that have been identified as a priority by the MACBLUE NSC.
	Conservation value	Sites of high conservation significance.
Other considerations	Existing data/projects/baselines	Sites that have been extensively studied for carbon stocks in mangroves and seagrass will be a low priority compared to sites with no baseline. Sites that have a baseline only and/or limited previous studies will be prioritised.
	Permit	Sites where research permits are unlikely to gain approval within the project timeframes have low priority.

Table 3. Criteria used to rank and establish best combination of the priority sites

Category	Criteria for site combinations	Description
Representativeness	Floristically representative	Balanced representation of dominant floristic types across sites is required (rather than a suite of sites that are floristically very similar).
	Climate vulnerability	Range of climate vulnerabilities represented across sites (rather than all sites that are vulnerable to the same climate risks).
	Land use management	Dominant land-use practices represented across the suite of sites selected.
Logistics	Total time lost to travel between sites	Relatively short distances between sites resulting in low to no days lost to travel, will be favoured over large distances between sites, with multiple flights/long boat rides required, result in many days lost to travel.
	Total travel cost to access all sites	Total travel costs to access sites needs to be minimised / fit within budget allocation.

2.4 Field survey methods

2.4.1 Seagrass ecosystem rapid biodiversity assessment

Where crocodile risk is low, intertidal and subtidal seagrass sites was surveyed on foot during low tide. At greater depths, a boat was used for subtidal plots. Where crocodile risk was high, all seagrass sites were sampled by boat and underwater camera with a grab sampler to collect seagrass specimens.

A minimum of three plots were sampled per site, to ensure that variation was captured at each site. Plots were selected with the aim of accurately representing the site (e.g., geomorphology, flora, fauna, and degradation-level present).

At intertidal areas, plots were accessed on foot. Plots were first measured out (1 x 5 m; Figure 1) and at the centre of the plot, a photograph was taken of a 1 x 1m quadrat, and the coordinates were recorded. The percentage cover of seagrass species, coral, macroalgae, sand, mud, rubble and rock were recorded. The species and count of any fauna present was noted. A sediment core was also taken at the centre of the plot. The threats listed in Cadier et al. (2024[10]) were recorded.

Submerged seagrass plots were accessed by boat. At these plots, underwater cameras were lowered to the seafloor to observe an area approximately 1 x 5m. Soil cores were taken using with sediment corers if water was shallow and if unsafe, only surface sediment was taken using a grab sampler. Biodiversity and threats were assessed in the same way as intertidal areas.

[10] Charles Cadier, Julieanne Blake, Mike Ronan, Maria Zann, Arnon Accad, Daniela Ceccarelli, Mary Chang, Guillermo Diaz-Pulido, Sabine Dittmann, Christopher Doropoulos, Caitlin Fleck, Paul Groves, Valerie Hagger, Catherine E. Lovelock, Taryn McPherson, Megan I. Saunders, Nathan J. Waltham, Maria Fernanda Adame. (2024). A standard condition and threat indicator framework for benthic marine and estuarine condition assessment. Ecological Indicators. 162 (2024) 111988. https://doi.org/10.1016/j.ecolind.2024.111988

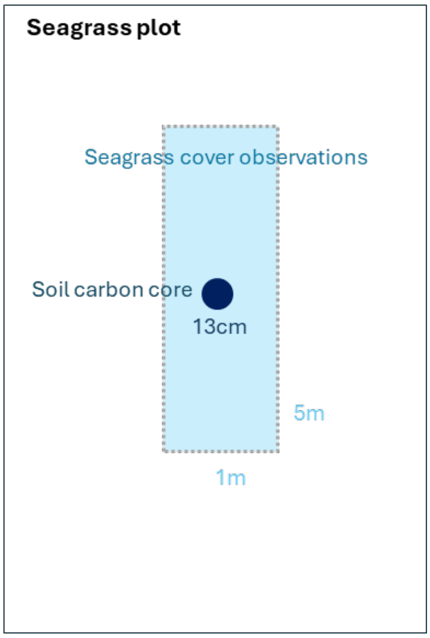

Figure 1. Representation of plot layout, showing core at centre of each plot (note there are 3 plots per site).

2.4.2 Mangrove ecosystem rapid biodiversity assessment

A minimum of three plots were sampled per site, to ensure that variation was captured at each site. Plots were selected with the aim of accurately representing the characteristics of the site (e.g., geomorphology, flora, fauna and degradation level present). Plots were measured as shown in Figure 2 and at the centre of the plot, a photograph was taken, and the coordinates were recorded. At the centre of each plot, a soil core was taken. Within a 2-10 m radius of the centre (depending on density of mangrove trees), the species and diameter at breast height (DBH) of all mangroves were recorded. Within a 1 m radius of the centre, the number and height of seedlings/saplings was recorded. The species and count of any fauna present was also noted. The canopy cover and disturbance impact were also recorded (Table 4).

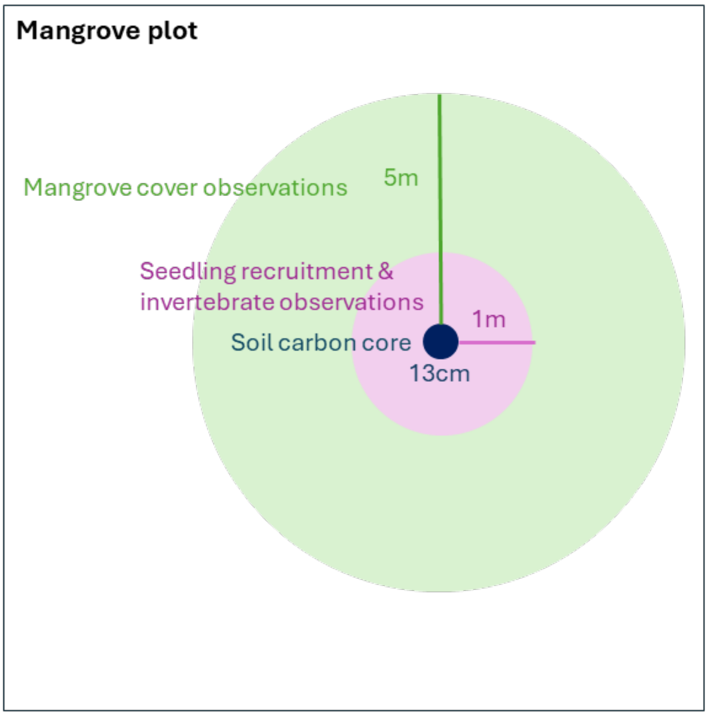

Figure 2. Representation of plot layout, showing core at centre of each plot and different plot dimensions for mangrove (note there are 3 plots per site). Mangrove plot size can vary between 2 and 10m radius if mangrove density requires it. Ensure plot radius is recorded.

Table 4. Guide to canopy cover estimates

Code	Impact	% Canopy Cover	Example
0	No Impact	96-100	Even canopy of trees. No gaps. No evidence of human interference.
1	Slight Impact	76-95	Canopy of trees fairly continuous but some gaps. Some regrowth. Isolated cutting/stripping of trees or some evidence of pig digging up saplings.
2	Moderate Impact	51-75	Broken canopy of trees with lower regrowth and recruitment areas. Some trees cut and stripped.
3	Rather High Impact	31-50	Tree canopy is uneven, the majority of the area is not showing regrowth and there is bare mud.
4	High Impact	11-30	Only a few trees remain at canopy height. Extensive clearance and some recruitment, large areas of bare mud.
5	Severe Impact	0-10	Extensive clearance to bare mud, little recruitment, few trees remain alive.

2.4.3 Rapid threat assessment

Threats to the health of the ecosystem were rated (0 to 5) at both the site scale (i.e. “habitat scale”, up to 1000 m) and landscape/seascape scale (i.e. within 1-5 km from site), where relevant. An existing framework for measuring these threats was used, and a list of the threat indicators assessed are listed in Table 5. Threat ratings were made using information from discussions with the local community, general observations or images from drone footage. Refer to Appendix F (MarECAT) of Cadier et al. 2024 for full descriptions of threat indicators and ratings framework.

Table 5. Threat indicators for seagrass and mangrove sites. Modified from Cadier et al. (2024[11]). Where HS = habitat scale (<1000m from site), LS/SS = landscape/seascape scale (1–5 km from the edge of the site).

Threat indicator		Relevant assessment scale	Example
T1	Major hydrological modifications	LS/SS	Dams. May result in erosion – uneven mud surfaces or little scarps/cliffs.
T2	Minor hydrological modifications	HS	Tidal gates. May result in erosion – uneven mud surfaces or little scarps/cliffs.
T3	Inflow from land activities	HS	Stormwater, sewage, water releases from activities such as mining
T4	Sediment resuspension	HS	Sediment resuspension may be caused by dredging, sand and gravel extraction, or beach nourishment activities
T5	Land Use	LS/SS	Human Land Use, including infrastructure including agriculture, garbage dumps, developments. Mining activities such as sand collections.
T6	Sea Use	LS/SS and HSS	Boating activities and aquaculture
T7	Native habitat conversion	LS/SS and HSS	Direct removal of riparian or shoreline habitat and activities that disturb or damage habitat areas, such as coastal urbanisation.
T8	Species collection or harvesting	LS/SS and HSS	Extensive cutting or bark stripping (for tannins/dyes). Commercial, subsistence or recreational fishing, bait collection and aquarium fish collection
T9	Non-preferred species	LS/SS and HSS	Non-preferred species, including exotic (weeds or pests) or native species
T10	Extreme events	LS/SS and HSS	Marine heatwaves, cyclones

[11] Charles Cadier, Julieanne Blake, Mike Ronan, Maria Zann, Arnon Accad, Daniela Ceccarelli, Mary Chang, Guillermo Diaz-Pulido, Sabine Dittmann, Christopher Doropoulos, Caitlin Fleck, Paul Groves, Valerie Hagger, Catherine E. Lovelock, Taryn McPherson, Megan I. Saunders, Nathan J. Waltham, Maria Fernanda Adame. (2024). A standard condition and threat indicator framework for benthic marine and estuarine condition assessment. Ecological Indicators. 162 (2024) 111988. https://doi.org/10.1016/j.ecolind.2024.111988

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3 Seagrass and mangroves of Fiji

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3.1 Seagrass past studies

Previous studies of seagrass across Fiji were synthesised in a national scale study by McKenzie & Yoshida (2020) [12] that compiled species and spatial data from previous studies, citizen science data and field surveys. The study analysed data from across the country and confirmed, with relatively high confidence, Fijian seagrass species, mapped seagrass extent, and trends in condition over time. Prior to the McKenzie & Yoshida (2020) study, the majority of seagrass studies had been relatively site specific (or at a more global scale) with limited analysis at a national scale. There are several long-term seagrass-watch monitoring sites located predominantly on the island of Viti Levu, which commenced around 2002, that are used to determine changes in condition and response to threats over time.[12].

Fijian seagrass meadows are reported to grow in a range of habitats. They grow in the intertidal and shallow subtidal waters of protected and soft bottom ecosystems, including bays, lagoons, as well as backreef areas surrounding nearshore reefs and offshore islands.[12] Meadows are found to grow in depths of up to 25m and in different substrata, including fine muddy sand, coarse sand, sandy-rubble, and large boulders with sandy patches. Seagrass extent in Fiji is estimated at 59.19 ha, based on McKenzie & Yoshida (2020), with the most extensive meadows being found in sheltered bays, broad fringing reefs, and shallow lagoons bordered by barrier reefs.[13]

There are six seagrass species from three families found in Fiji, *Halophila decipiens, Halophila ovalis, Halophila ovalis subspecies bullosa, Halodule pinifolia, Halodule uninervis*, *Rupia maritima* and *Syringodium isoetifolium.*[14] [15] Most species have an Indo-Pacific distribution, except *Halophila ovalis* subspecies *bullosa*, which is endemic to Fiji, Tonga, and Samoa. On foreshore sandbanks close to the main islands, *Halodule pinifolia* seagrass meadows typically grow immediately offshore, forming patchy or intermixed meadows with other species. Denser patches of *Syringodium isoetifolium* seagrass are typically found on the shallow sub-tidal reefs and lagoons. *Halophila ovalis* forms patchy and intermixed meadows. It tolerates fine mud sediments so and can often be found in areas unsuitable for other species[13]. *Halophila decipiens* is a recent addition to the seagrass species list in Fiji. It occurs in waters greater than six-metre depth and has

[12] McKenzie, L.J., & Yoshida, R.L. (2007). Seagrass-Watch: Guidelines for Monitoring Seagrass Habitats in the Fiji Islands. Proceedings of a training workshop, Corpus Christi Teachers College, Laucala Bay, Suva, Fiji, 16th June 2007. Seagrass-Watch HQ Cairns.
[13] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. *Marine pollution bulletin*, *160*, 111636.
[14] Skelton, P.A. and G. South. Seagrass biodiversity of the Fiji and Samoa Islands, South Pacific. New Zealand Journal of Marine and Freshwater Research, 2006, Vol. 40: 345-356
[15] L. McKenzie, R. Yoshida 2020 Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events, Marine Pollution Bulletin, Volume 160.

only been found in sparse patches along the reef channels of Cakaulevu Reef in northern Vanua Levu.[13] *Ruppia maritima* occurs in estuarine habitats in Viti Levu in the Rewa, Penang, and Sigatoka Rivers.[13]

The current condition of seagrass meadows in Fiji is generally stable and resilient.[16] Over a decade of monitoring has shown that these ecosystems are composed predominantly of opportunistic species, which have a moderate resistance to stress and a high capacity for recovery. Despite fluctuations in abundance at some sites, no long-term declines have been observed. The presence of persistent seed banks, particularly for *Halodule* species, supports the resilience of these meadows. This stability is evident even in the face of significant disturbances, such as tropical cyclones, indicating a robust ability to recover and maintain ecological functions.

While overall relatively stable through time, the condition of seagrass meadows varies between islands and specific locations, as a result of the varying levels of pressures each area is exposed to. For instance, seagrass meadows in Laucala Bay (Suva) are impacted by nutrient enrichment from sewage and runoff, leading to higher epiphyte cover. In contrast, meadows in more remote areas like Rotuma are less affected by anthropogenic activities. [17]

The most significant threat to seagrass in the Fiji Islands is poor water quality in the nearshore coastal zone. This is primarily from sediment and nutrient runoff from catchment modifications, with inshore meadows tending to be most affected.[18] [19] Sediments are delivered down the larger river systems (e.g., Rewa) during flood periods, which can smother seagrass and decrease the light availability within the plume-impacted areas. Nutrients from catchment run-off and from domestic and industrial wastewater often leads to a proliferation of macroalgae which can out-compete seagrass for space and epiphytic algae (e.g. algae growing on the seagrass leaves) which can decrease the light available for photosynthesis. Sykes and Morris (2009)[20] reported that the main impacts on seagrass beds over the past few years have been from coastal and over-water developments, mainly for tourism and residential properties that cause sedimentation from inadequately controlled construction activities, and from increased boat traffic. Similarly, Sykes and Reddy (2007)[21] reported that channel blasting, lagoon dredging, and over-water construction have destroyed some seagrass beds. These threats not only impact seagrass meadows but also have a follow-on effect on the ecosystem services that meadows provide to the local community.

Seagrasses play a crucial role in Fiji's coastal ecosystems by contributing to nutrient recycling, which helps maintain coastal water quality, supporting a high level of biodiversity, and providing habitat for species that are vital to fisheries and cultural practices.[18] Additionally, they stabilize sediments against coastal erosion and sequester carbon, thereby offering significant ecological, biodiversity, and coastal protection benefits.

Seagrasses support habitat for some nationally and internationally significant and threatened species, for example Fiji's seagrass meadows provide foraging habitat for over half of the adult green turtles in the central South Pacific (*Chelonia mydas*).[22] Notably, where seagrasses, mangroves, and coral reefs exist in proximity, a greater species richness and abundance of fish species is found compared with areas where these habitats are isolated.[23]

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[16] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. *Marine pollution bulletin*, *160*, 111636.

[17] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. *Marine pollution bulletin*, *160*, 111636.

[18] Singh, S., 2019. Importance of seagrasses: a review for Fiji Islands. International Journal of Conservation Science 10, 587–602.

[19] Sykes, H (2021). Overview Navua Estuary Habitats, Marine Ecology Consulting. 25pp

[20] H. Sykes, C. Morris (2009), Status of Coral Reefs in the Fiji Islands, Southwest Pacific Status of Coral Reefs Report 2007 (Editor: C. Whippy-Morris), CRISP, Secretariat of the Pacific Regional Environment Program, Noumea.

[21] H.R. Sykes, C. Reddy (2007), Assessment of Marine resources for proposed development "Vunabaka Bay" Malolo Island, Mamanuca Islands, Fiji. November 2007, Marine Ecology Consulting Fiji www.marineecologyfiji.com

[22] Craig, P., Parker, D., Brainard, R., Rice, M., & Balazs, G. (2004). Migrations of green turtles in the central South Pacific. Biological Conservation, 116(3), 433-438.

[23] Olds A., R. Connolly, K. Pitt, S. Pittman, P. Maxwell, C. Huijbers, B. Moore, S. Albert, D. Rissik, R. Babcock, T. Schlacher (2015) Quantifying the conservation value of seascape connectivity: a global synthesis. Global Ecology and Biogeography 25(1):3-15.

3.2 Mangrove past studies

A cornerstone for understanding Fiji's mangrove ecosystems is the "Mangrove Management Plan for Fiji" by Dr Dick Watling.[24] This plan, initially developed in 1985-86 and updated in 2013, provides insights into the management and conservation of mangrove ecosystems in Fiji based on Dr Watling's extensive work and observations over nearly 40 years. A more recent study, published in a series of papers by Cameron et. al. (2021),[25] [26] provides a recent analysis of mangrove extent and loss in Fiji. This study also undertook mangrove ecosystem assessments across four contrasting regions around Viti Levu in 2019, focusing on forest structure and carbon stocks. Based on these and other past studies, the mangroves of the island of Viti Levu, and some parts of Vanua Levu, are relatively well understood, with less data available for the remaining regions of the Fijian archipelago.

The reported extent of mangroves varies between studies and estimates range between 33,000 ha to 65,243 ha.[27] [28] The most recent estimate by Cameron et. al. (2021) [28] places the total area of mangroves in the Fijian archipelago at approximately 65,243 ha. The majority of these mangroves are found along the coastlines of the two largest islands, Viti Levu and Vanua Levu, with 31,509 ha and 29,938 ha respectively.[20] The largest continuous mangrove areas are in the Rewa Delta (7,110 ha) and Ba Delta (5,540 ha) on Viti Levu, followed by the Labasa Delta (1,545 ha) on Vanua Levu. Additionally, there are some coral atoll islands offshore from Vanua Levu with significant mangrove coverage. Overall, Fiji and the Solomon Islands (64,200 ha) are considered some of the largest mangrove resources in the Pacific islands after Papua New Guinea (372,770 ha).

Fijian mangroves are comprised of seven main species and several associated plants. The seven species can be effectively split into three broad functional groupings, Red Mangrove “Tiri” (*Rhizophora stylosa* and *R. samoensis*), Black Mangrove “Dogo” (*Bruguiera gymnorriza*) and White Mangrove (*Xylocarpus granatum)* (Figure 3)[29].

[24] Watling, D. (2013) Mangrove Management Plan 2013, Report for Mangrove Eco Systems for Climate Change Adaptation and Livelihood project Project (MESCAL). Department of the Environment (DoEnv).
[25] Cameron, C., Kennedy, B., Tuiwawa, S., Goldwater, N., Soapi, K., & Lovelock, C. E. (2021). High variance in community structure and ecosystem carbon stocks of Fijian mangroves driven by differences in geomorphology and climate. *Environmental Research*, *192*, 110213.
[26] Cameron, C., Maharaj, A., Kennedy, B., Tuiwawa, S., Goldwater, N., Soapi, K., & Lovelock, C. E. (2021). Landcover change in mangroves of Fiji: Implications for climate change mitigation and adaptation in the Pacific. Environmental Challenges, 2, 100018.
[27] Watling, D. 2013. The Mangrove Management Plan of Fiji. National Mangrove Management Committee. Department of Environment.
[28] Cameron, C., Maharaj, A., Kennedy, B., Tuiwawa, S., Goldwater, N., Soapi, K., & Lovelock, C. E. (2021). Landcover change in mangroves of Fiji: Implications for climate change mitigation and adaptation in the Pacific. Environmental Challenges, 2, 100018.
[29] Sykes, H (2021). Overview Navua Estuary Habitats, Marine Ecology Consulting. 25pp

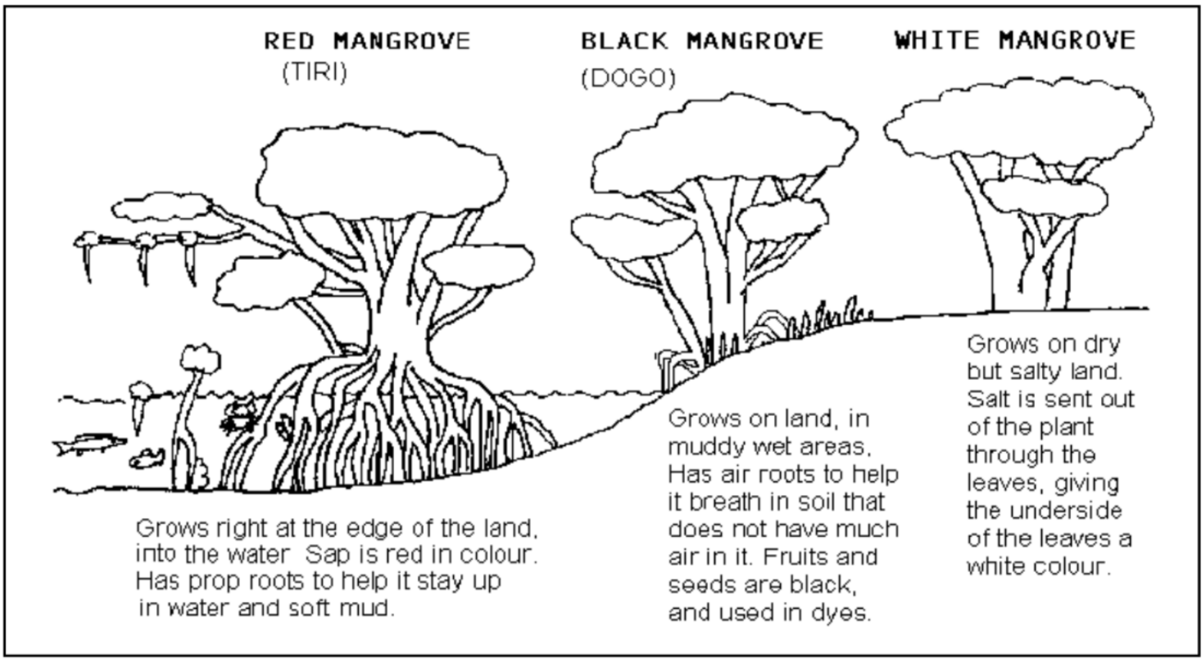

Figure 3. The seven mangrove species found in Fiji can be grouped into three broad functional groupings that form the typical structure of mangrove forests in Fiji (Figure courtesy of Helen Sykes).

Red Mangroves grow at the water's edge, with "prop" roots that stabilise trees in soft mud and wave zones. In Fiji there are two species of trees which live in this manner, and one sterile hybrid when both species are present:

- *Rhizophora stylosa* (*R. stylosa*) "Tiri tabua" – usually directly fronting the sea
- *Rhizophora samoensis* (*R. samoensis*) "Tiri wai" – usually closer to rivers
- the Hybrid *Rhizophora selela* (*R. selala*) – taller trees found in mixed forest

Black Mangroves (known as "Dogo" in Fijian) are usually found behind Red Mangroves, in muddy areas that flood at high tide. They may have "prop", or "elbow" roots that stick up out of the mud, sometimes both. In Fiji there is only one species Black Mangrove:

- *Bruguieria gymnorrhiza* (*B. gymnorrhiza*) "Dogo"

White Mangroves are very salt-tolerant trees that grow on dry land immediately behind the wetter intertidal mangrove areas, and can survive occasional salt-water inundation, and salty soil. In Fiji there are four species of trees which live in this environment:

- *Lumnitzera littorea* (*L. littorea*) "Sagali"
- *Heritiera littoralis* (*H. littoralis*) "Kedra viv na yalewa kalou"
- *Excoecaria agallocha* (*E. agallocha*) – Milky Mangrove "Sinu gaga"
- *Xylocarpus granatum* (*X. granatum*) – the Puzzlenut tree "Dabi"

Mangrove Associates are plants often found in the same area as the White Mangrove, but also in non-mangrove areas such as beaches. In Fiji these include:

- *Acrostichum aureum* - Mangrove Fern
- *Hibiscus tiliaceus* - Beach Hibiscus "Vau"
- *Hernandia nymphaeifolia* - Chinese Lantern "Evuevu"
- *Barringtonia asiatica* - Poisonfish tree "Vuturakaraka"

- *Pandanus pyriformis* – Screwpine "Vauvau"

Fiji's mangroves are under significant threat from land reclamation for agriculture, clearing for construction and development, and harvesting for wood fuel. [30] [31] Comparing historical and contemporary datasets, Cameron et. al. (2021) estimated that since 1896 Fiji has lost 5,447 ha of mangrove habitat (7.7% of the original extent). [32] A historical loss of 4,313 ha of mangroves between 1896 and 1986 was primarily the result of conversion to sugarcane plantations. [33] Since then, Tropical Cyclones have been the dominant cause of mangrove cover loss (especially in Ra, Ba, and Bua Provinces), while other threats such as tourism development, coastal reclamation, disposal of dredging spoil, and harvesting) have also contributed a significantly, albeit to a lesser extent. [32]

The effects of climate change, particularly associated with sea level rise and coastal erosion, are a major threat to Fiji's mangrove forests. The vulnerability of different mangrove forests to climate change factors depends on their aspect, pre-existing condition, and the presence of effective management. [34]

Mangroves in Fiji, like elsewhere across the South Pacific, support a large array of marine and estuarine organisms, including crabs, fish, prawns, mangrove lobsters, sharks, rays, eels, and a host of other invertebrates. The forests also host a range of terrestrial animals, including birds, flying foxes, mammals, and insects. Additionally, mangroves provide a range of ecosystem services for Fiji's communities, including serving as a food source, construction material, firewood, and coastal protection. Mangroves play a crucial role in protecting coastlines from sea level rise and increased major weather events by acting as natural buffers against storm surges, high winds, and flooding. Their dense root systems stabilise sediments and prevent coastal erosion, safeguarding shorelines and infrastructure. Awareness of these significant ecosystem services provided by mangroves to the communities and economy of Fiji, especially in the context of a changing climate, is increasingly being recognised in the country's conservation planning.

3.3 Fiji study sites

Seagrass meadows and mangrove forests were surveyed across three major islands in Fiji, including Vanua Levu, Viti Levu and Ovalau. The survey locations for both mangroves and seagrass are shown in Figure 4, including: Rewa, Ovalau-Moturiki, and Vanua Levu. A total of 20 mangrove sites and 10 seagrass sites were surveyed across a diversity of geomorphological settings in order to capture representative data for these dynamic ecosystems. Locations and sites are shown in detail in Figure 5 to Figure 9.

[30] Lal P. 2003. Economic valuation of mangroves and decision-making in the Pacific. Ocean & Coastal Management 46: 823–844. https://doi.org/10.1016/S0964-5691(03)00062-0

[31] Veitayaki J, Waqalevu V, Rollings N. 2017. Mangroves in small island development states in the Pacific: an overview of a highly important and seriously threatened resource. In: DasGupta R, Shaw R (eds), Participatory mangrove management in a changing climate: perspectives from the Asia-Pacific (Disaster Risk Reduction series). Tokyo: Springer.

[32] Cameron, C., Maharaj, A., Kennedy, B., Tuiwawa, S., Goldwater, N., Soapi, K., & Lovelock, C. E. (2021). Landcover change in mangroves of Fiji: Implications for climate change mitigation and adaptation in the Pacific. Environmental Challenges, 2, 100018.

[33] Lal, P. N. (1990). Conservation or conversion of mangroves in Fiji: An ecological economic analysis. Environment Policy Institute, East-West Centre. Occasional Paper No. 11. Honolulu, Hawaii.

[34] Ellison, J.C. 2015. Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecol Manage* 23, 115–137.

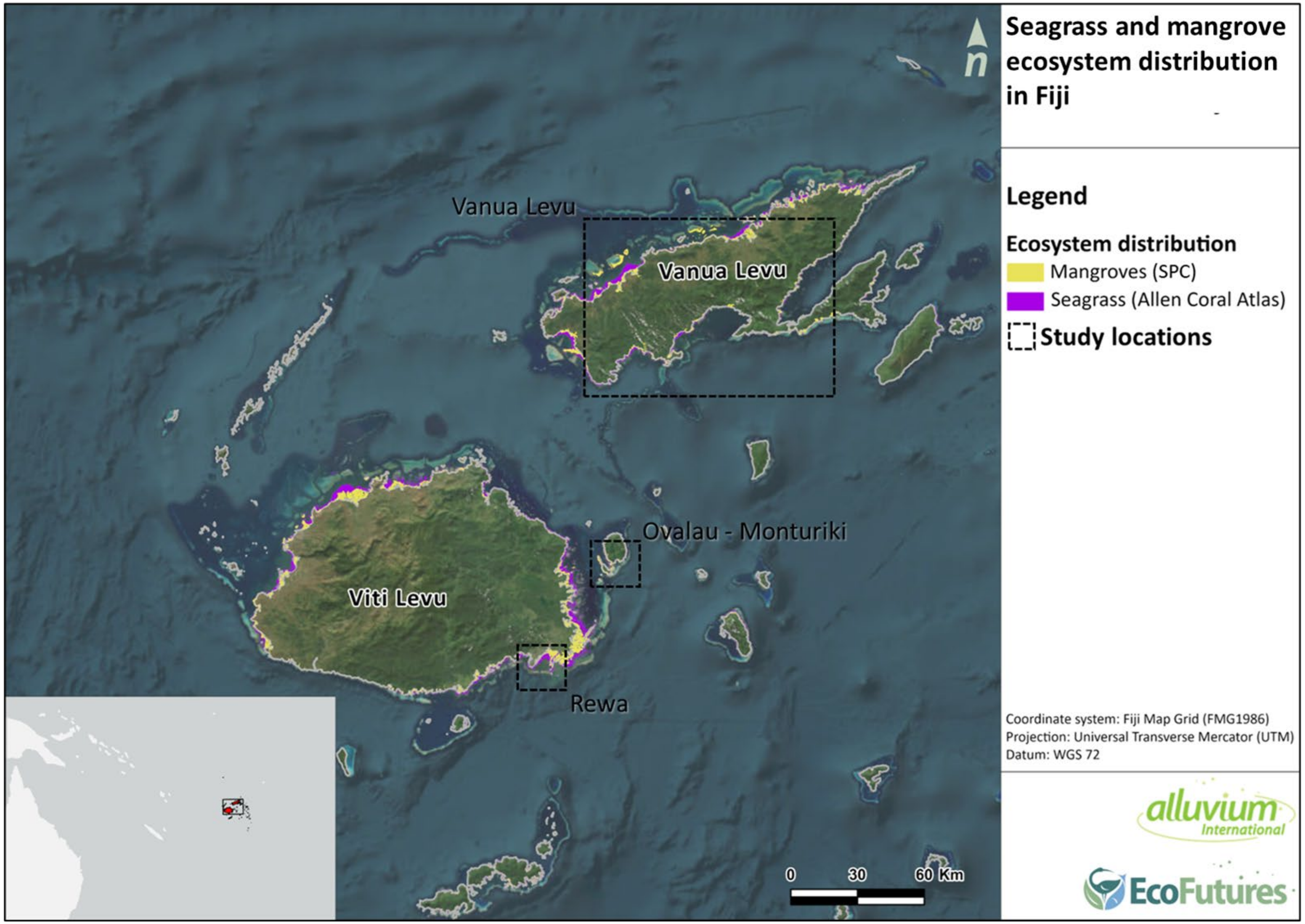

Figure 4. Seagrass and mangrove ecosystem distribution and assessment locations in Fiji. For the purpose of this study, several study sites across three study locations were grouped for analysis, specifically: Rewa, Ovalau-Moturiki, and Vanua Levu. The location of individual study sites are shown in the Figures below.

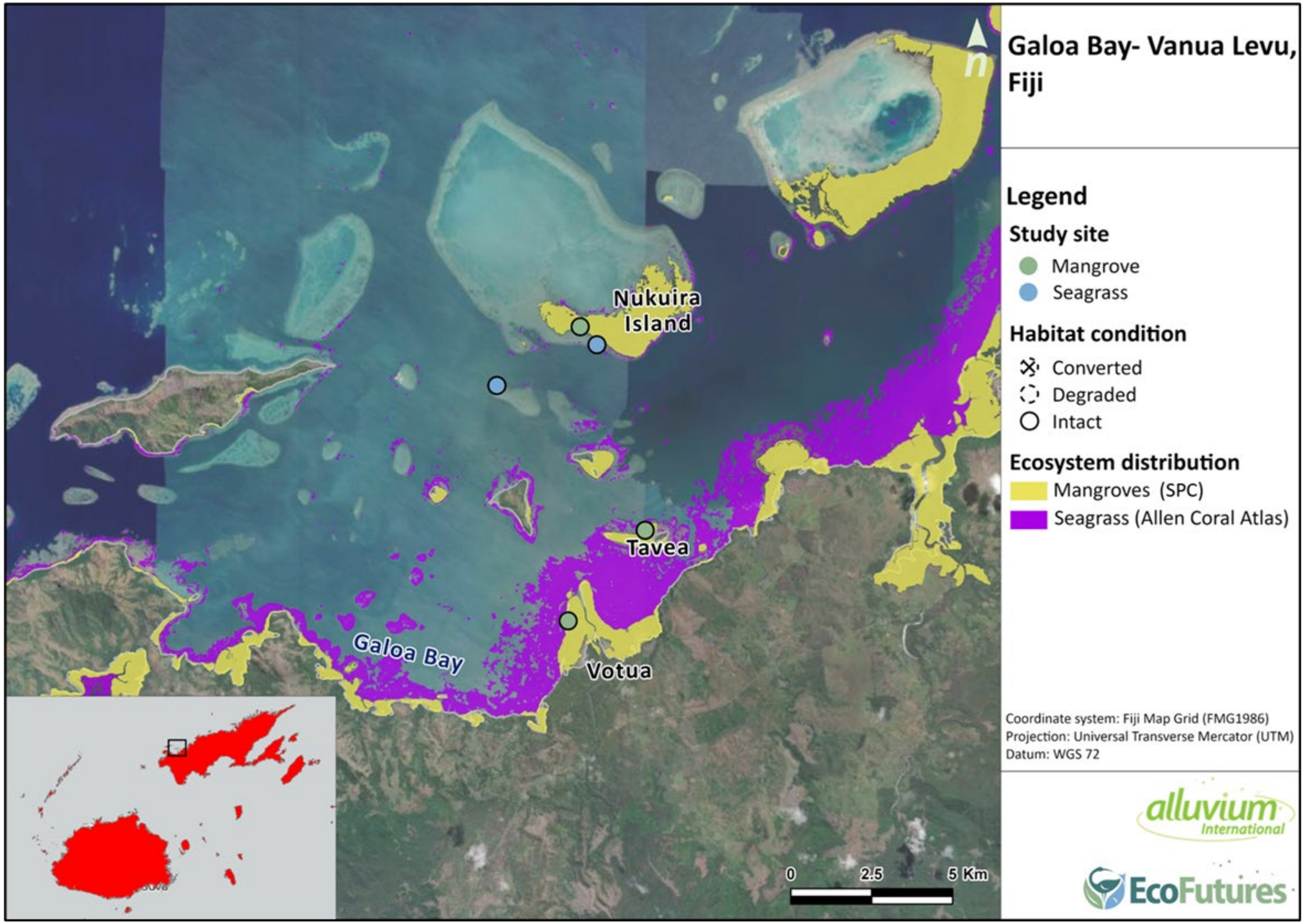

Figure 5. Seagrass and mangrove ecosystem distribution and survey sites at Galoa Bay, Vanua Levu. At this location there were three (3) intact mangrove sites, two (2) intact seagrass sites assessed.

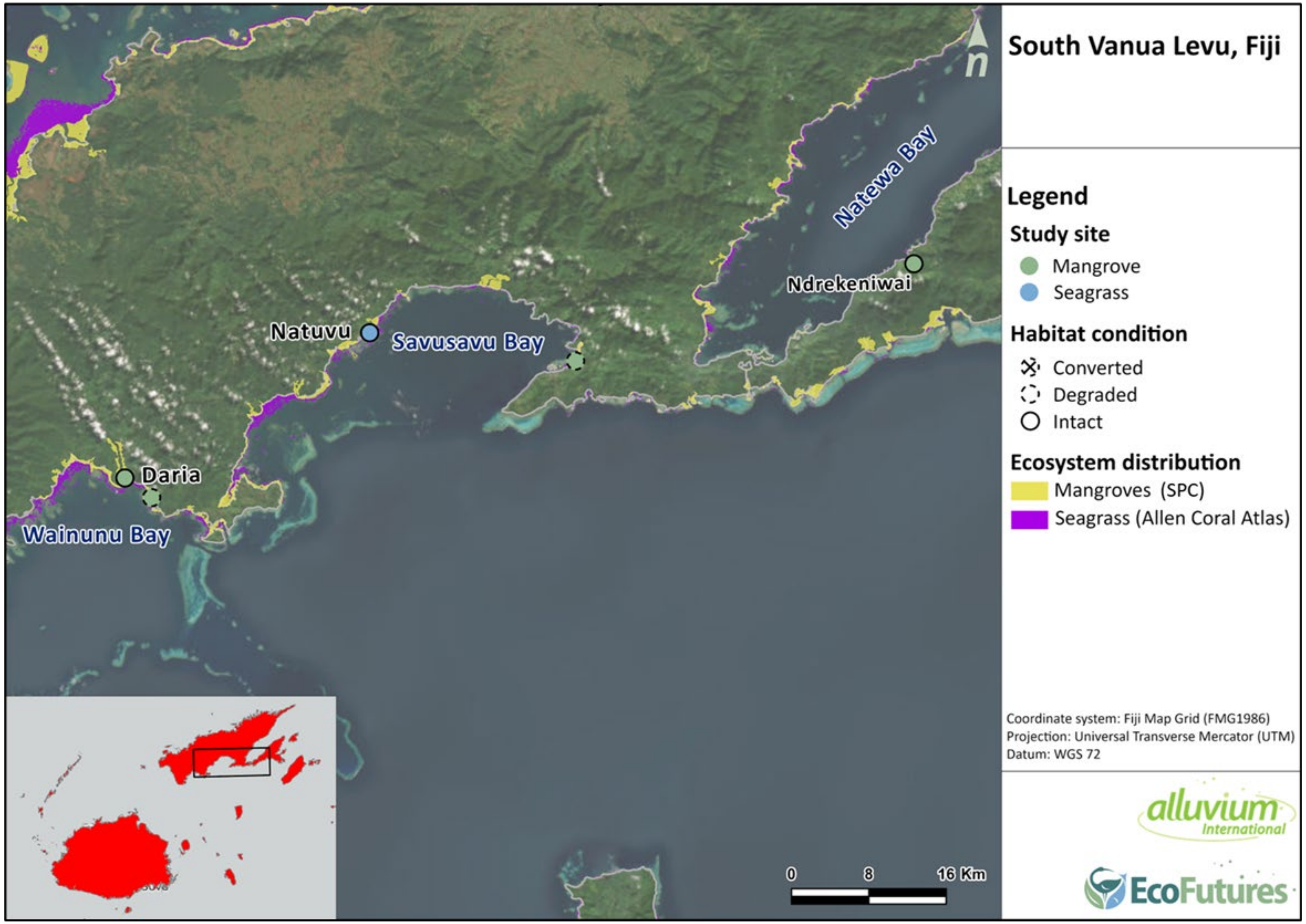

Figure 6. Seagrass and mangrove ecosystem distribution and survey sites at South Vanua Levu. At this location there were three (3) intact mangrove sites, two (2) degraded mangrove sites, and one (1) intact seagrass site assessed.

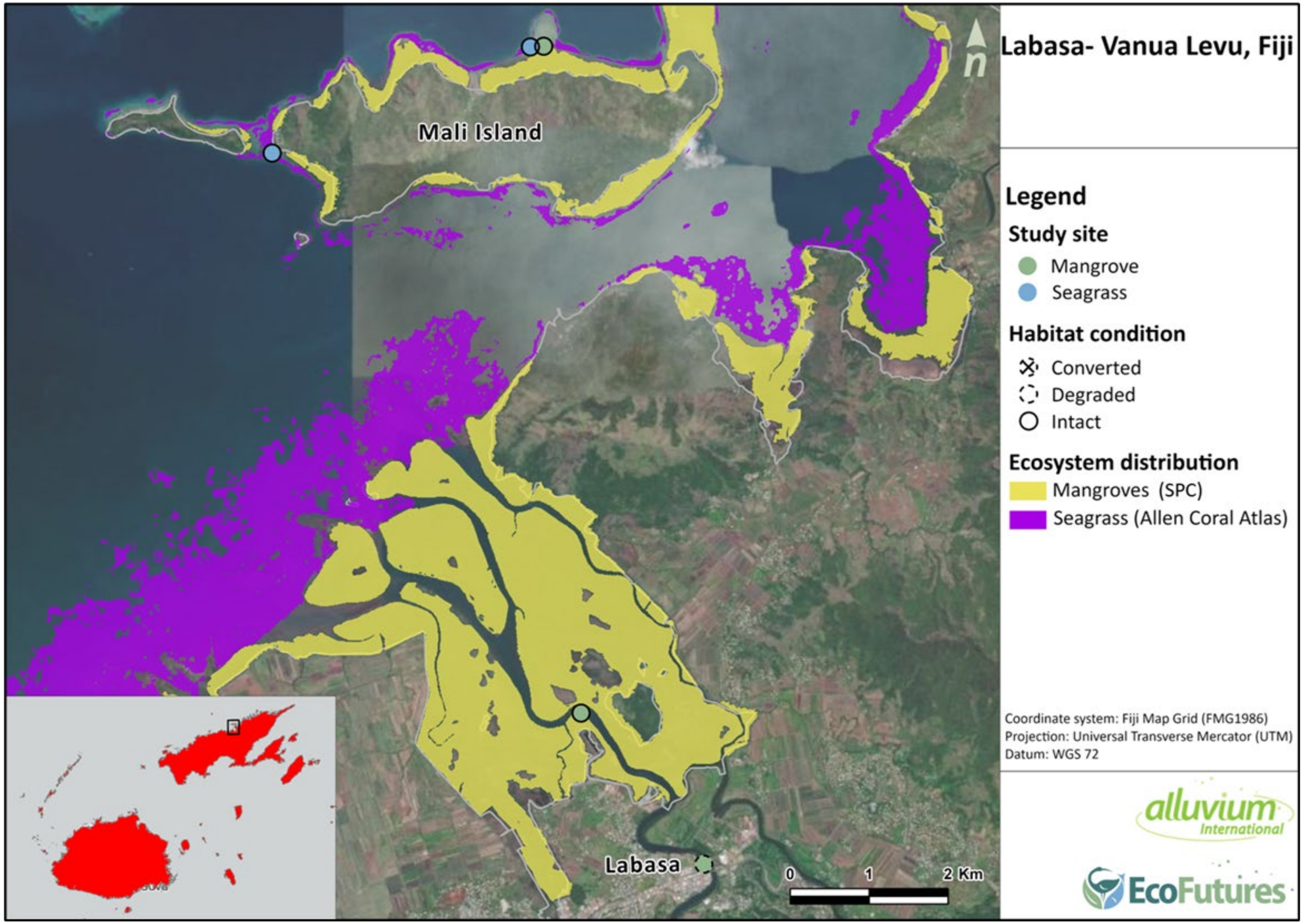

Figure 7. Seagrass and mangrove ecosystem distribution and survey sites at Labasa, Vanua Levu. At this location there were two (2) intact mangrove sites, and two (2) intact seagrass sites assessed.

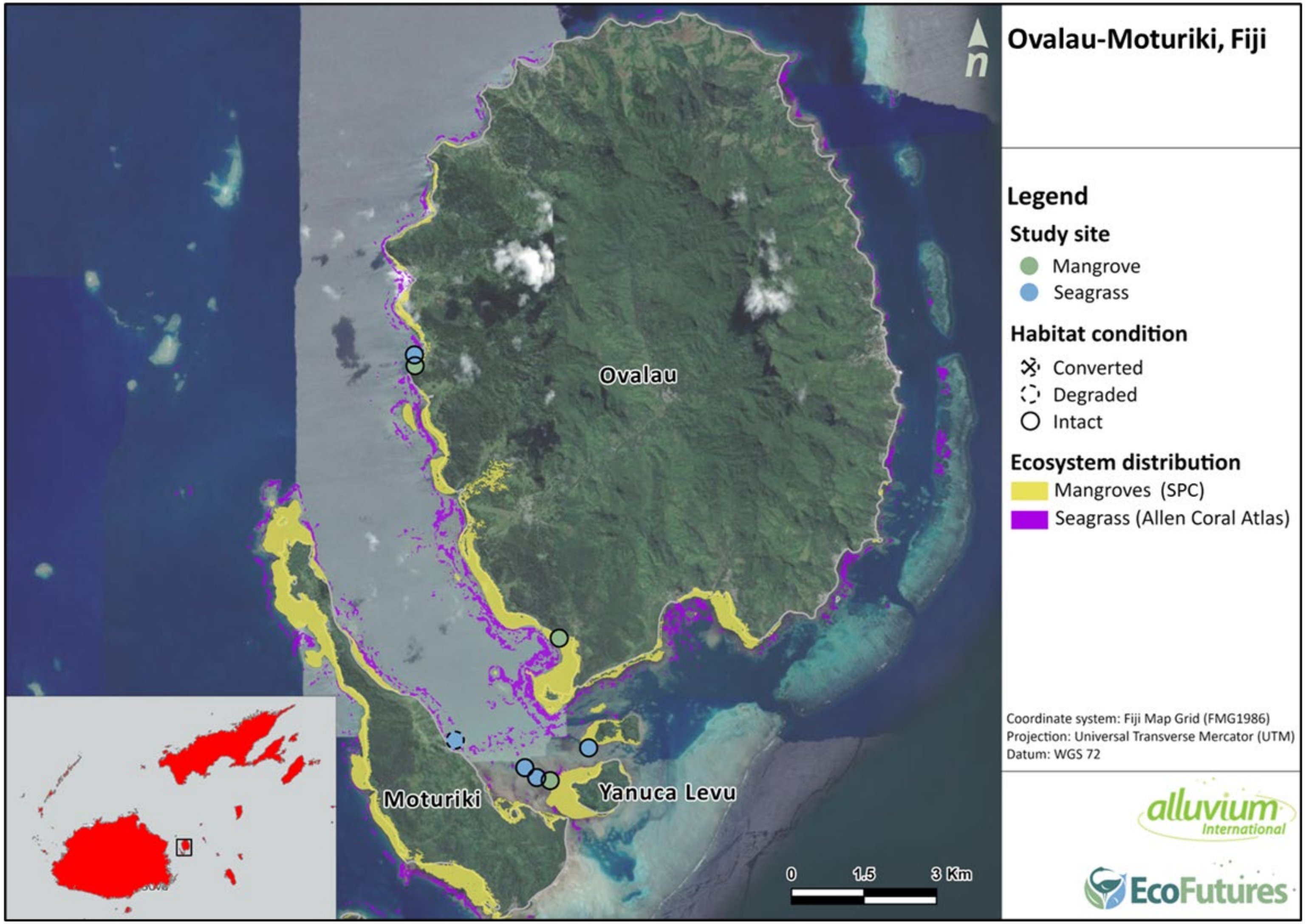

Figure 8. Seagrass and mangrove ecosystem distribution and survey sites at Ovalau-Moturiki. At this location there were three (3) intact mangrove sites, four (4) intact seagrass sites and one (1) degraded seagrass site assessed.

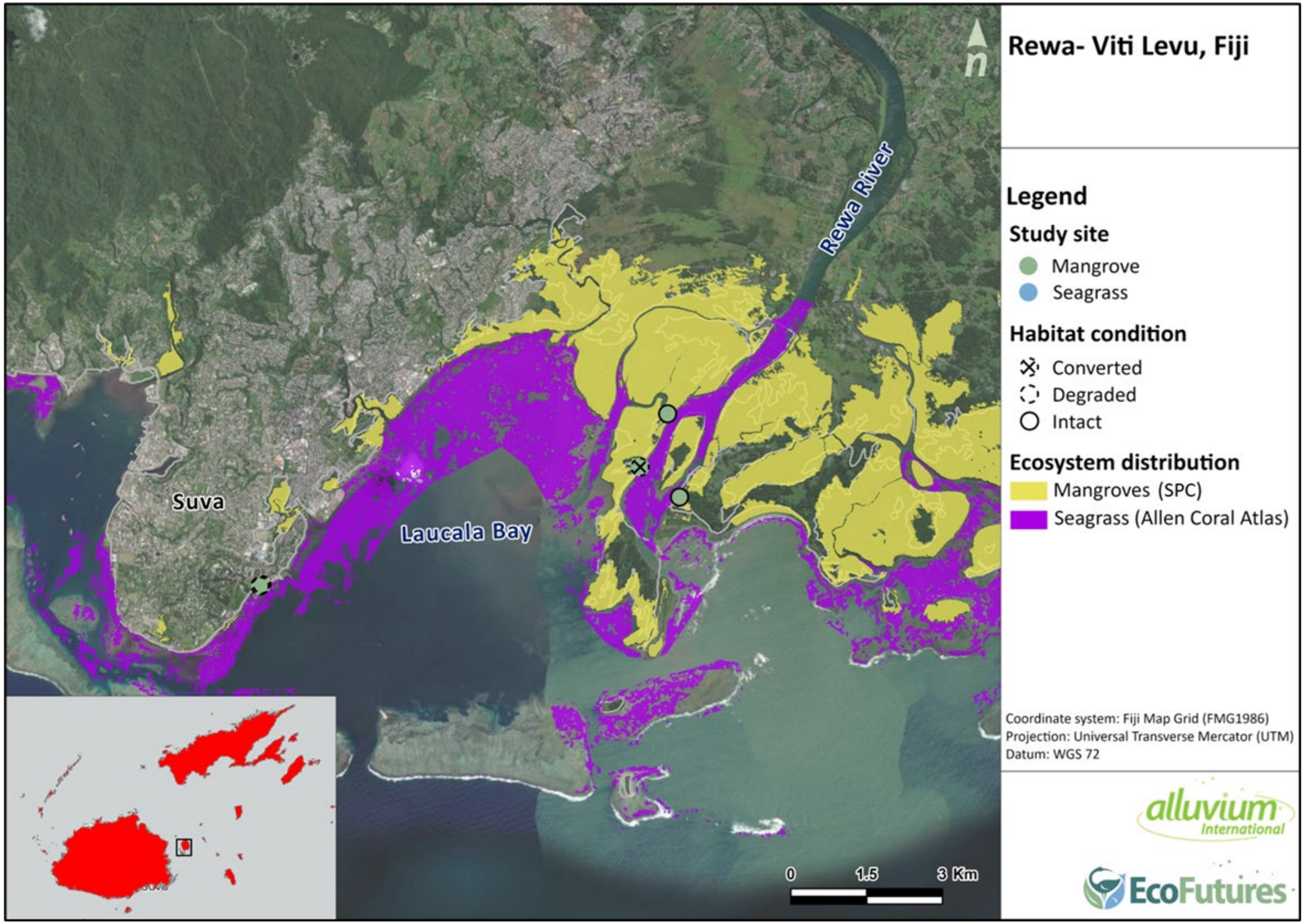

Figure 9. Seagrass and mangrove ecosystem distribution and survey sites at Rewa, Viti Levu. In this location there were two (2) intact mangrove sites, one (1) degraded mangrove site and one (1) converted mangrove site assessed.

3.4 Fiji ecosystem assessment results

3.4.1 Seagrass results

At least three of the six species of seagrass known from Fiji were recorded from the ten seagrass sites sampled (Table 6), noting however that two *Halodule* species are indistinguishable in the field and were not differentiated for this study. The meadows sampled were predominantly on fringing reef flats or islands. Eight of the ten sites were meadows with multiple species of seagrass which is common in Fiji. Photos of each site surveyed were captured and can be found in Appendices.

Table 6. Seagrass species found in the MACBLUE compared to previous seagrass species lists described for Fiji

Species	Ovalau-Moturiki	Vanua Levu	Past studies in Fiji [35]
*Halodule uninervis / Halodule pinifolia**	X	X	X
Halophila decipiens			X
Halophila ovalis *Halophila ovalis* subsp. *bullosa**	X	X	X
Syringodium isoetifolium	X	X	X
Ruppia maritima			X

*For the purpose of this study the sets of species and/or sub-species that require molecular analysis to correctly identify and differentiate, were binned together and not analysed separately. [36]

Halodule univnervis/H. pinifolia were the most commonly recorded species in the assessment, found at 90% of the sites. Only two of the 10 sites were monospecific *Halodule* meadows. Both *Halophila ovalis* and *Syringodium isoetifolium* had the same site coverage of 60%.

Vanua Levu exhibited the highest average seagrass coverage at 37% (± 8 SE), followed by Ovalau-Moturiki with 23% (± 9 SE) coverage (Figure 10). The higher coverage at Vanua Levu is likely due to the sampling of only intact sites, which typically support more robust seagrass growth. In contrast, at Ovalau-Moturiki, the degraded site had an average seagrass coverage of 10%, while the intact site had a significantly higher average coverage of 27% (± 11 SE) (Figure 11).

Threats to the seagrass meadows of Fiji are typically from extreme weather events and species collection and harvesting (Table 7), with these threats being apparent for both Ovalau-Moturiki and Vanua Levu.

[35] McKenzie, L.J., & Yoshida, R.L. (2007). Seagrass-Watch: Guidelines for Monitoring Seagrass Habitats in the Fiji Islands. Proceedings of a training workshop, Corpus Christi Teachers College, Laucala Bay, Suva, Fiji, 16th June 2007. Seagrass-Watch HQ Cairns.
[36] McKenzie, L.J., & Yoshida, R.L. (2007). Seagrass-Watch: Guidelines for Monitoring Seagrass Habitats in the Fiji Islands. Proceedings of a training workshop, Corpus Christi Teachers College, Laucala Bay, Suva, Fiji, 16th June 2007. Seagrass-Watch HQ Cairns.

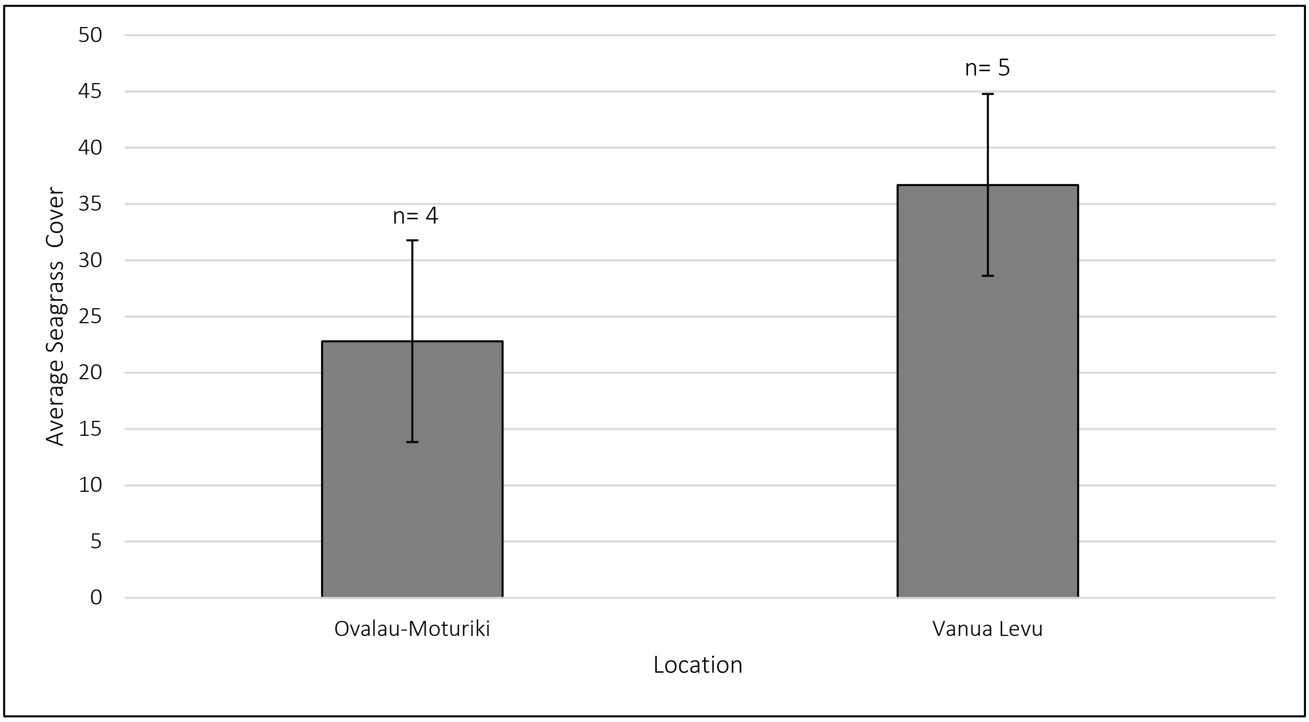

Figure 10. Average seagrass coverage (%) (± SE) across six locations in Fiji, where n is the number of sites surveyed at each location.

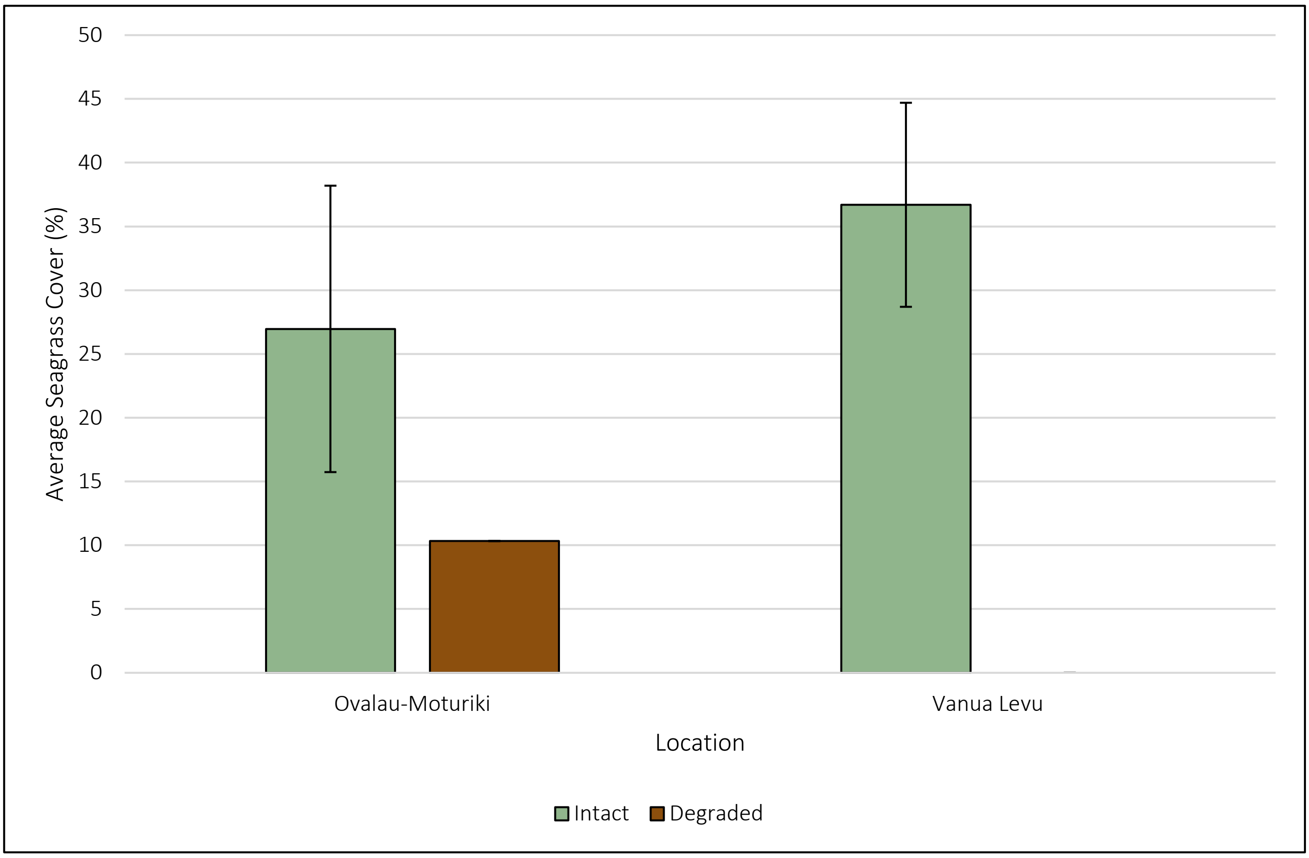

Figure 11. Average seagrass cover (%) (± SE) across intact and degraded locations, where n is the number of sites surveyed at each location.

Table 7. Rapid threat assessment results for the seagrass sites in Fiji, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Ovalau-Moturiki	Severe storms and cyclones, fishing and harvesting	*Habitat*	25	NA	3	3	4	NA	4	4	1	3	2
		Landscape	19	4	NA	NA	NA	4	3	3	1	3	1
Vanua Levu	Wind/wave induced sediment resuspension, coconut plantation, fishing, boat activity, aquaculture, cyclones and storms	*Habitat*	29	NA	5	5	5	NA	4	4	2	3	1
		Landscape	23	5	NA	NA	NA	4	4	4	2	3	1

3.4.2 Mangrove results

A total of six (6) of the twelve (12) mangrove species known to inhabit Fiji were recorded in the assessments, with the distribution of the species amongst the three locations outlined in Table 8. Overall, *Rhizophora stylosa* was the most abundant species recorded across the locations (n = 530), followed by *Bruguiera gymnorhiza* (n = 400), *Excoecaria agallocha* (n = 111), *Rhizophora samoensis* (n = 75), *Xylocarpus granatum* (n = 63) and *Lumnitzera littorea* (n = 21) (Table 8).

Mangrove forests that have a greater species diversity have been found to have enhanced biomass production and soil carbon storage[37] so protecting forests with a higher diversity of species and restoring degraded forests with multiple species is important for maximising carbon storage. Vanua Levu had the highest species diversity with a total of six (6) species, followed by Rewa, which had a total of five (5) species. Only three (3) mangrove species were recorded at Ovalau-Moturiki (Table 8). Photos of each site surveyed were captured and can be found in Appendices.

Table 8. Mangrove species list for Fiji found in the MACBLUE assessment compared with past studies on mangroves in Fiji (A = Associate mangrove, T = True mangrove, H = Hybrid/Variant).

Species	Category	Recorded during MACBLUE assessment			Past studies in Fiji [38, 39]
		Rewa	Ovalau-Moturiki	Vanua Levu	
Acrostichum speciosum	A				X
Barringtonia racemosa	A				X
Bruguiera gymnorhiza	T	X	X	X	X
Excoecaria agallocha	T	X		X	X
Heritiera littoralis	T				X
Lumnitzera littorea	T		X	X	X
Pemphis acidula	A				X
Rhizophora samoensis	T	X			X
Rhizophora stylosa	T	X	X	X	X
Rhizophora X selala	H				X
Xylocarpus granatum	T	X		X	X
Xylocarpus moluccensis (syn. *X. mekongensis*)	T				X

Across the three locations surveyed in Fiji, Rewa had the highest level of threat at both the habitat and landscape scale. Sites in Rewa had an array of threats, including intensive development, catchment clearing, cyclone damage, coconut plantations, logging, and sea-level rise, among other threats (Table 9; Figure 12).

Vanua Levu was also found to have high threat levels for the landscape scale (Table 9). Threats included cyclone damage, sea-level rise, surrounding industrial areas, logging, and urbanisation (Figure 15). Urbanisation negatively impacts mangrove ecosystems by reducing their area through land reclamation and development, leading to habitat loss and increased pollution. Ovalau-Moturiki exhibited lower threat levels at both the habitat and landscape scales when

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[37] Bai J, Meng Y, Gou R, et al. Mangrove diversity enhances plant biomass production and carbon storage in Hainan Island, China. *Funct Ecol*. 2021; 35: 774–786. https://doi.org/10.1111/1365-2435.13753
[38] Duke, NC, J. Mackenzie & A. Wood 2012, 'A revision of mangrove plants of the Solomon Islands, Vanuatu, Fiji, Tonga and Samoa', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 12/13, James Cook University, Townsville, 22 pp.
[39] Duke, N.C. 2006. Australia's Mangroves. The authoritative guide to Australia's mangrove plants. University of Queensland, Brisbane. 200 pages.

compared to the two other locations (Table 9). The main threats at Ovalau-Moturiki were fishing, species harvesting and major weather events such as cyclones.

Figure 12. Recently planted mangroves (*Rhizophora* spp.) at a degraded site at Rewa. Mangroves had previously been heavily disturbed by surrounding development.

Figure 13. Mangroves significantly affected by urbanization, now confined to a narrow strip along the riverbank of Labasa River, Vanua Levu.

Table 9. Rapid threat assessment results for the mangrove sites in Fiji showing total scores and individual threat scores averaged across sites within a location. The maximum total score for habitat scale and landscape scale is 40 and 35, respectively, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Rewa	Extreme weather events – storms, cyclones, sedimentation, dredging, coconut plantations, conversion to terrestrial forest, rubbish, logging, seawall, development.	*Habitat*	20	NA	2	3	2	NA	4	2	2	2	3
Rewa	Extreme weather events – storms, cyclones, sedimentation, dredging, coconut plantations, conversion to terrestrial forest, rubbish, logging, seawall, development.	*Landscape*	16	3	NA	NA	NA	3	3	2	1	2	2
Ovalau-Moturiki	Fishing, species harvesting, severe weather events – storms cyclones.	*Habitat*	28	NA	3	4	4	NA	4	4	4	4	2
Ovalau-Moturiki	Fishing, species harvesting, severe weather events – storms cyclones.	*Landscape*	22	4	NA	NA	NA	4	3	3	3	4	1
Vanua Levu	Wind/wave induced sedimentation, cyclones, storms, sea-level rise, flooding, surrounding industrial area, commercial fishing, logging for agriculture, timber production and settlements.	*Habitat*	25	NA	4	3	2	NA	4	3	2	4	2
Vanua Levu	Wind/wave induced sedimentation, cyclones, storms, sea-level rise, flooding, surrounding industrial area, commercial fishing, logging for agriculture, timber production and settlements.	*Landscape*	20	4	NA	NA	NA	3	4	3	2	3	2

In forests, larger trees play a keystone role[40] by contributing a disproportionate level of reproductive components, habitat for other species, and above ground biomass for carbon storage. The largest trees recorded in Fiji were typically found in Vanua Levu, followed by Rewa (Table 10).

Table 10. The distribution of larger trees across the three (3) locations assessed in Fiji. Numbers refer to the percentage (%) of trees recorded in that location. DBH refers to Diameter at Breast Height.

Tree size	Rewa	Ovalau-Moturiki	Vanua Levu
<20cm DBH	90	94	88
>20cm DBH	9	6	10
>50cm DBH	1	0	2

In Rewa, *Excoecaria agallocha* had the largest average Diameter at Breast Height (DBH) at 16 cm (Figure 14), followed by *Xylocarpus granatum* (DBH = 14 cm), *Rhizophora stylosa* (DBH = 11 cm), and *Bruguiera gymnorhiza* (DBH = 11 cm). *Bruguiera gymnorhiza* was the largest outlier (DBH = 59 cm) and had the most outliers in general, in comparison with all other species. Human and natural (e.g. cylone) disturbances can also cause losses of cohorts, skewing the DBH distribution of the population and increasing the number of outliers. *Rhizophora samoensis* demonstrated the least variability among the recorded species.

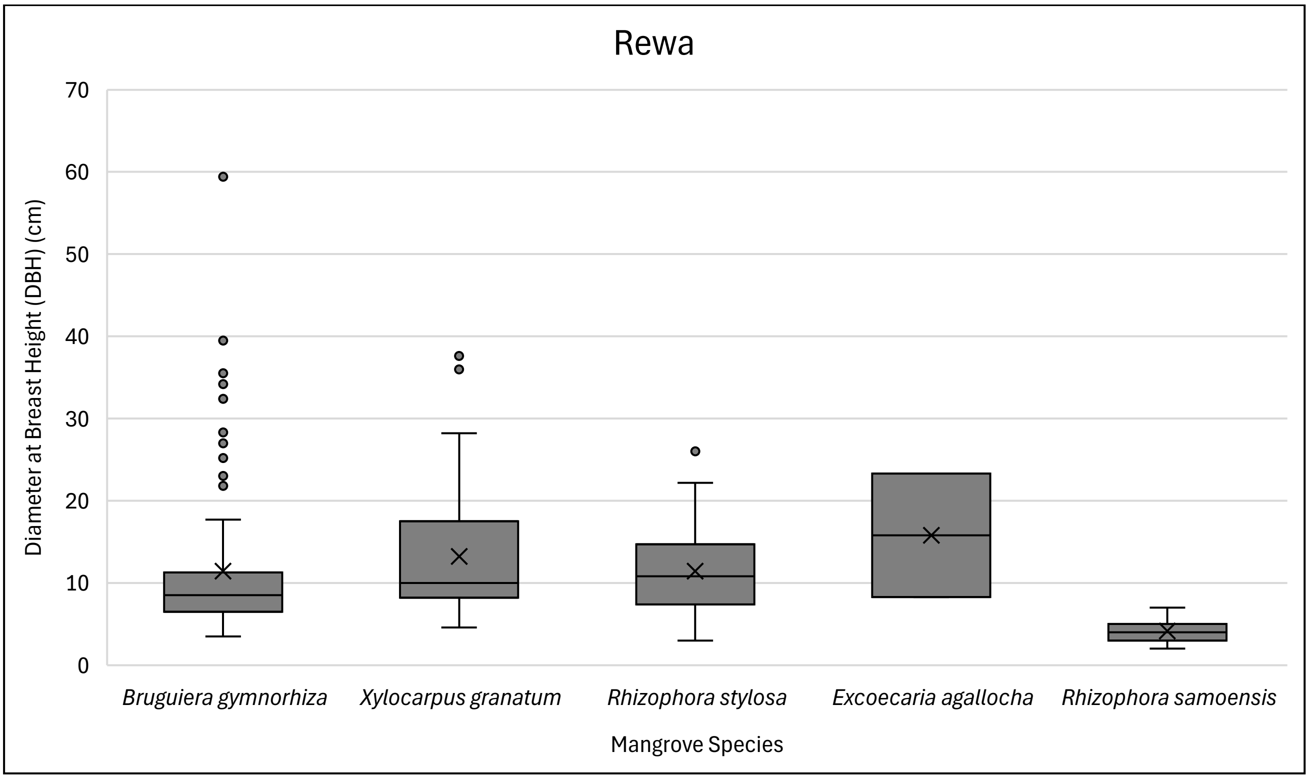

Figure 14. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Rewa. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were three sites assessed at Rewa for DBH. Note one site was not assessed for DBH due to only non-mangrove species occurring.

[40] D.B. Lindenmayer, W.F. Laurance, J.F. Franklin. (2012). Global decline in large old trees. Science, 338 (6112), pp. 1305-1306

At the Ovalau-Moturiki sites, *Lumnitzera littorea* demonstrated the largest average DBH (DBH = 18 cm) among all species. This species also exhibited the widest range of DBH measurements, spanning 8.5 to 39 cm. *Rhizophora stylosa* and *Bruguiera gymnorhiza* had similar DBH measurements of 8.3 and 8.0 cm, respectively (Figure 15). However, this location had fewer species than Rewa.

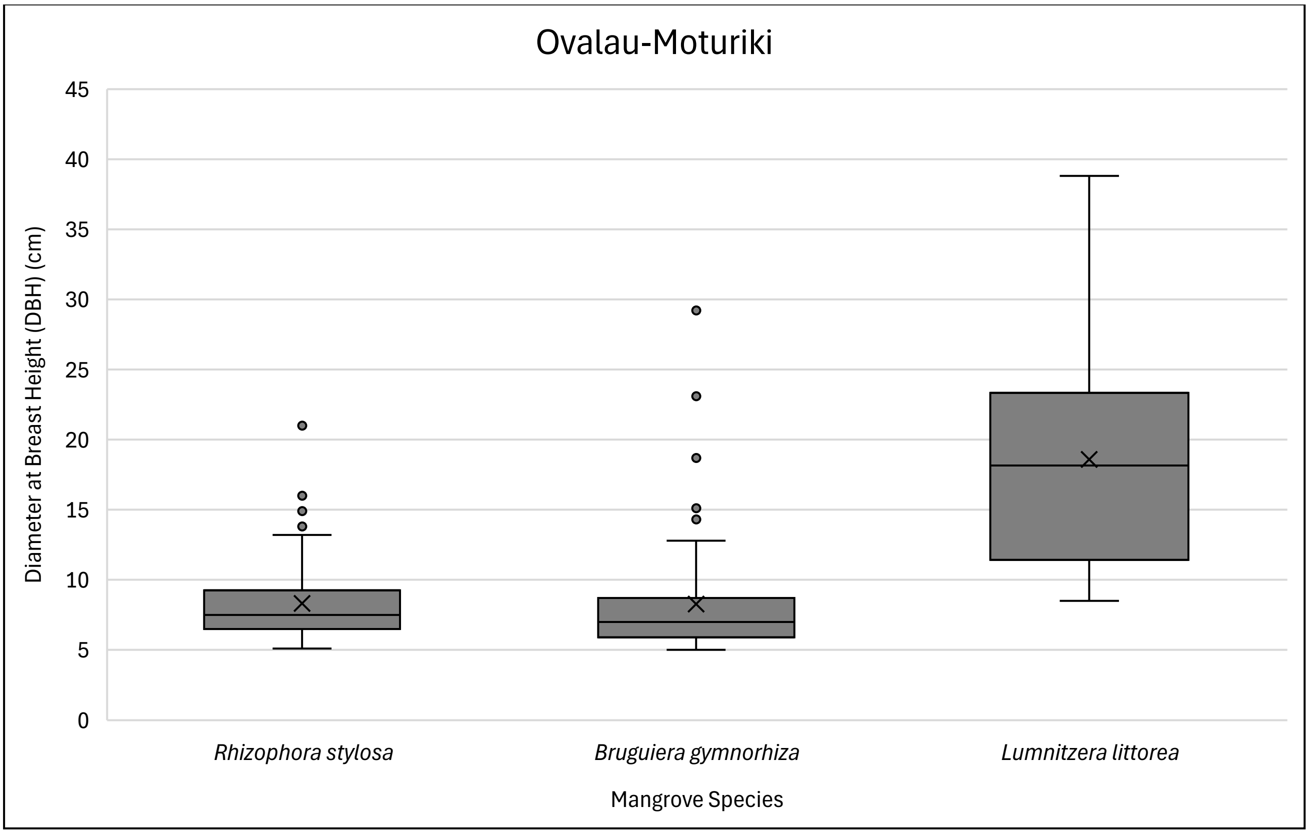

Figure 15. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Ovalau-Moturiki. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were four sites assessed at Ovalau-Moturiki.

In Vanua Levu, *Excocaria agallocha* had the highest average DBH of 24 cm, followed by *Xylocarpus granatum* (DBH = 17 cm), and *Lumnitzera littorea* (DBH = 15 cm). However, *Bruguiera gymnorhiza* exhibited the greatest variation in DBH, ranging from 2 to 58.2 cm. In contrast, *Rhizophora stylosa* had a comparatively lower average DBH of 11 cm (Figure 16).

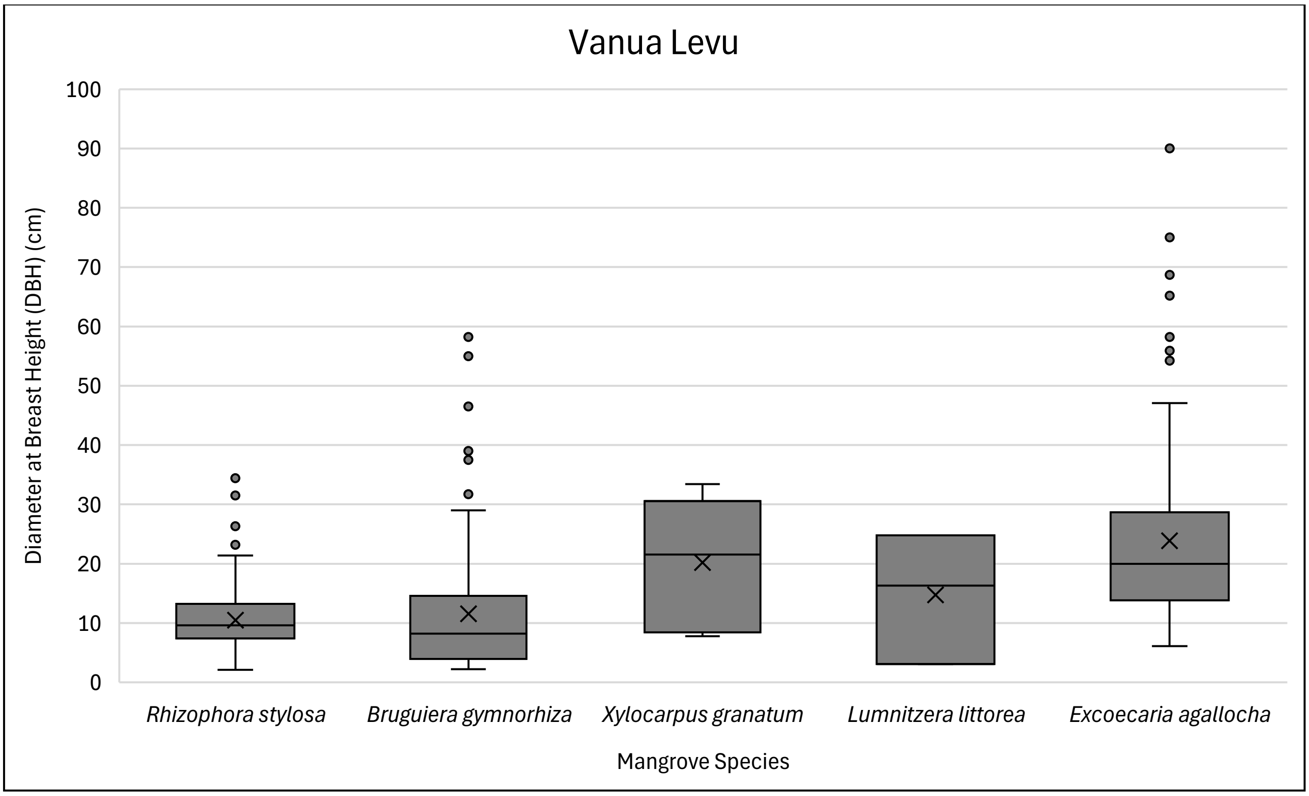

Figure 16. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Vanua Levu. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were 11 sites assessed at Vanua Levu.

Across the three locations, mangrove trees sampled at the sites in Vanua Levu, Rewa, and Ovalau-Moturiki demonstrated a relatively similar average DBH (of 13, 10, and 9 cm, respectively) (Figure 17). Each location had considerable variability in DBH size, most notably in Vanua Levu, with some outliers reaching a maximum DBH of 90 cm (Figure 17). The variability seen at all locations reflects the complexity of intact mangrove ecosystems and outlines their variability due to multiple factors such as extreme weather conditions, anthropogenic influences, tidal inundation, and stratification in structural complexity.

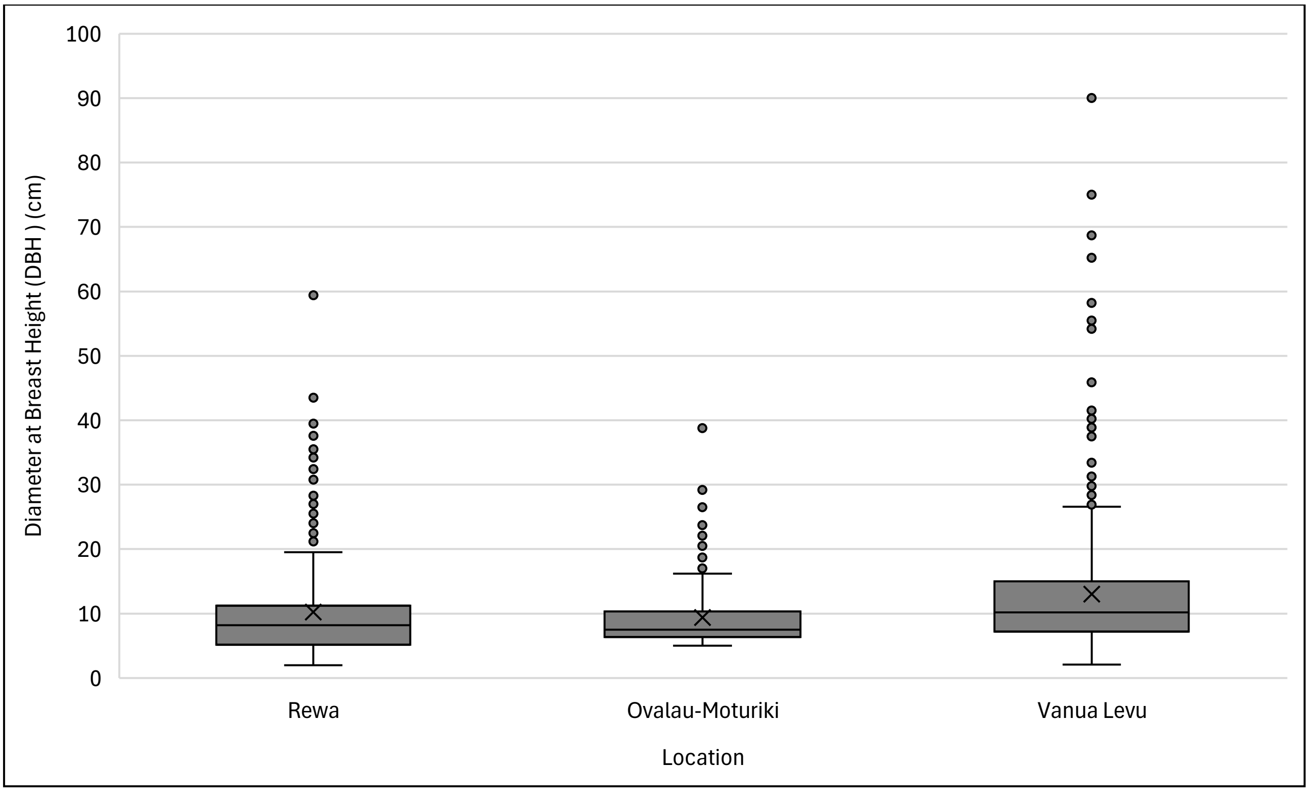

Figure 3. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) across the locations in Fiji. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Across Fiji, degraded sites consistently exhibited lower average DBH values compared to intact sites. For instance, the degraded site in Rewa had an average DBH of 4 cm, whereas intact sites averaged at 12 cm (Figure 18). In Vanua Levu, one degraded site showed evidence of complete mangrove clearance, with only a few scattered *Rhizophora spp*. remaining in the surrounding area (Figure 12).

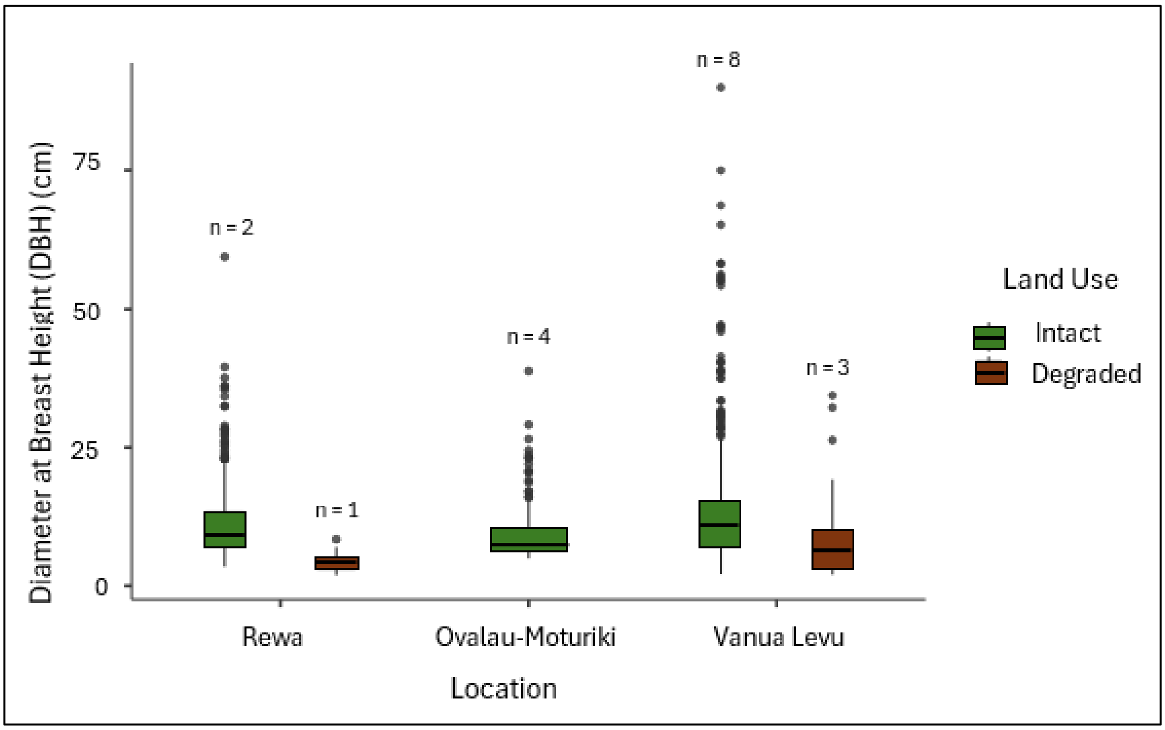

Figure 4. A box plot displaying Diameter at Breast Height (DBH) (cm) compared between land use type (degraded v. intact) and locations across Vanuatu. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. Where n is the number of sites surveyed at each location. Note that one site in Rewa was not included in the DBH analysis due to only non-mangrove species occurring.

Sites in Vanua Levu and Rewa had the highest average mangrove canopy cover at 71% (± 9 SE) and 67% (± 4 SE), respectively (Figure 19). In comparison, Ovalau-Moturiki exhibited slightly lower average canopy cover at 66% (± 14 SE) (Figure 19). It should be noted that mangrove canopy cover was collected as categorical data (ie, 0-10, 11-30, 31-50, 51-75, 76-95, 96-100). The mid-point from this range data were averaged across each site and averaged again for each location.

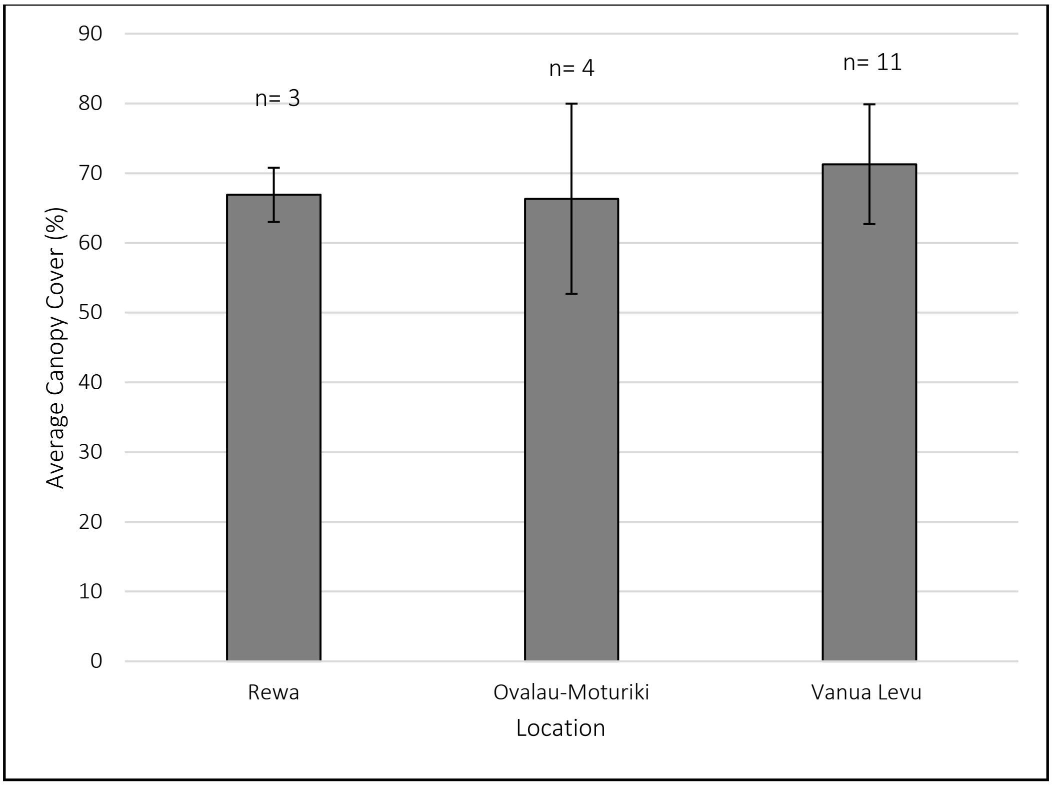

Figure 5. Average mangrove canopy cover (%) (± SE) across locations in Vanuatu (where n is the number of sites surveyed at each location). Note that one site in Rewa was not included in the canopy cover analysis due to only non-mangrove species occurring.

Across all locations, intact sites typically had higher average mangrove canopy cover than degraded sites (Figure 20). However, the degraded site surveyed in Rewa had a slightly higher canopy cover than the intact sites, potentially due to it being a restoration site.

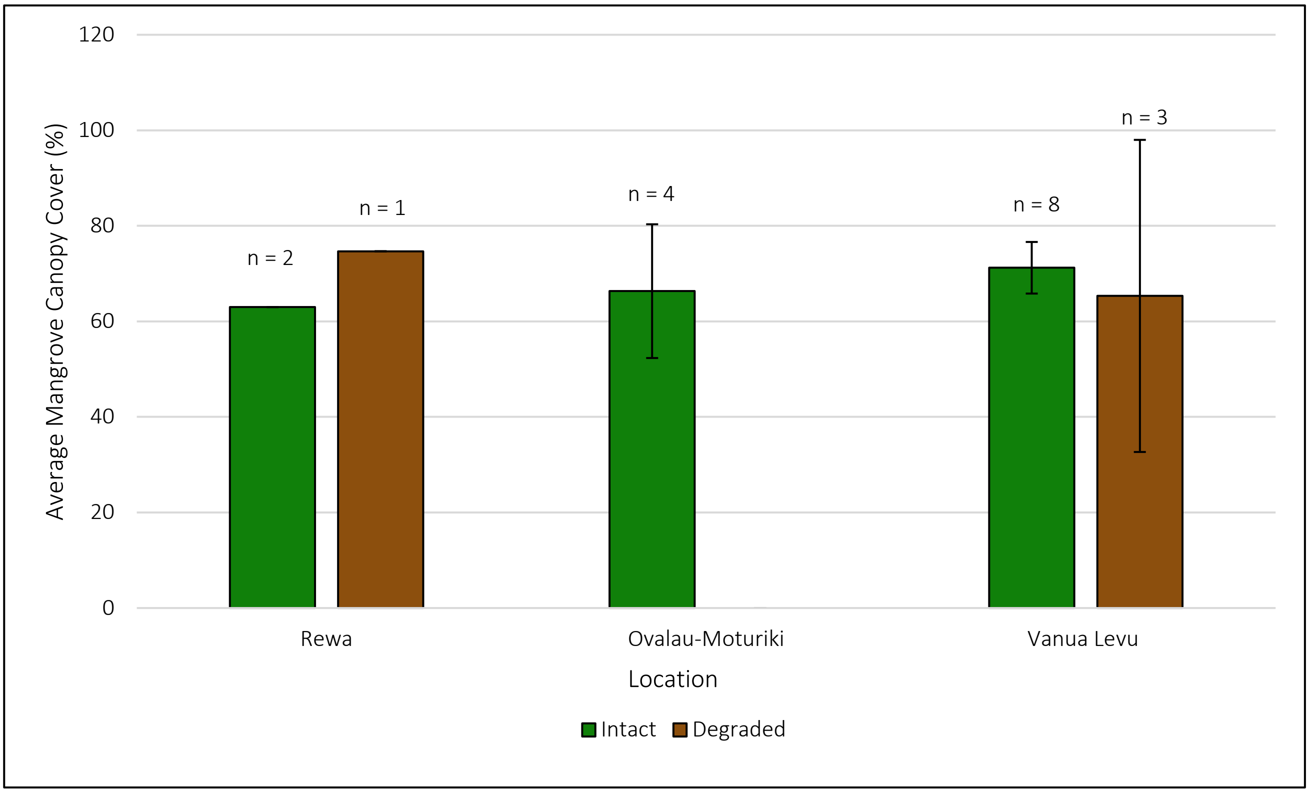

Figure 20. Average mangrove canopy cover (%) (± SE) across intact and degraded locations. Where n is the number of sites surveyed at each location. Note that one site in Rewa was not included in the canopy cover analysis due to only non-mangrove species occurring.

Estimates of seedling abundance were recorded at each site as an indicator of forest productivity and the capacity for a forest to recover from disturbance. If resilient, a disturbed forest may have high seedling abundances compared to an equivalent intact forest, due to increased sunlight on the forest floor. Seedling abundance was assessed at each site as one of three categories (0-10, 10-50 and >50 seedlings). The seedling density/m^2 for each site was calculated using the mid-point of the categories and standardised by the area of each plot.

Of the locations surveyed, Vanua Levu had the highest seedling densities, with an average value of 0.22 seedlings/m^2, with a maximum value of 0.64 seedlings/m^2 (Figure 21). Similar average seedling densities were found in Ovalau-Moturiki and Rewa, which had a seedling density of 0.20 and 0.19 seedlings/m^2, respectively (Figure 21).

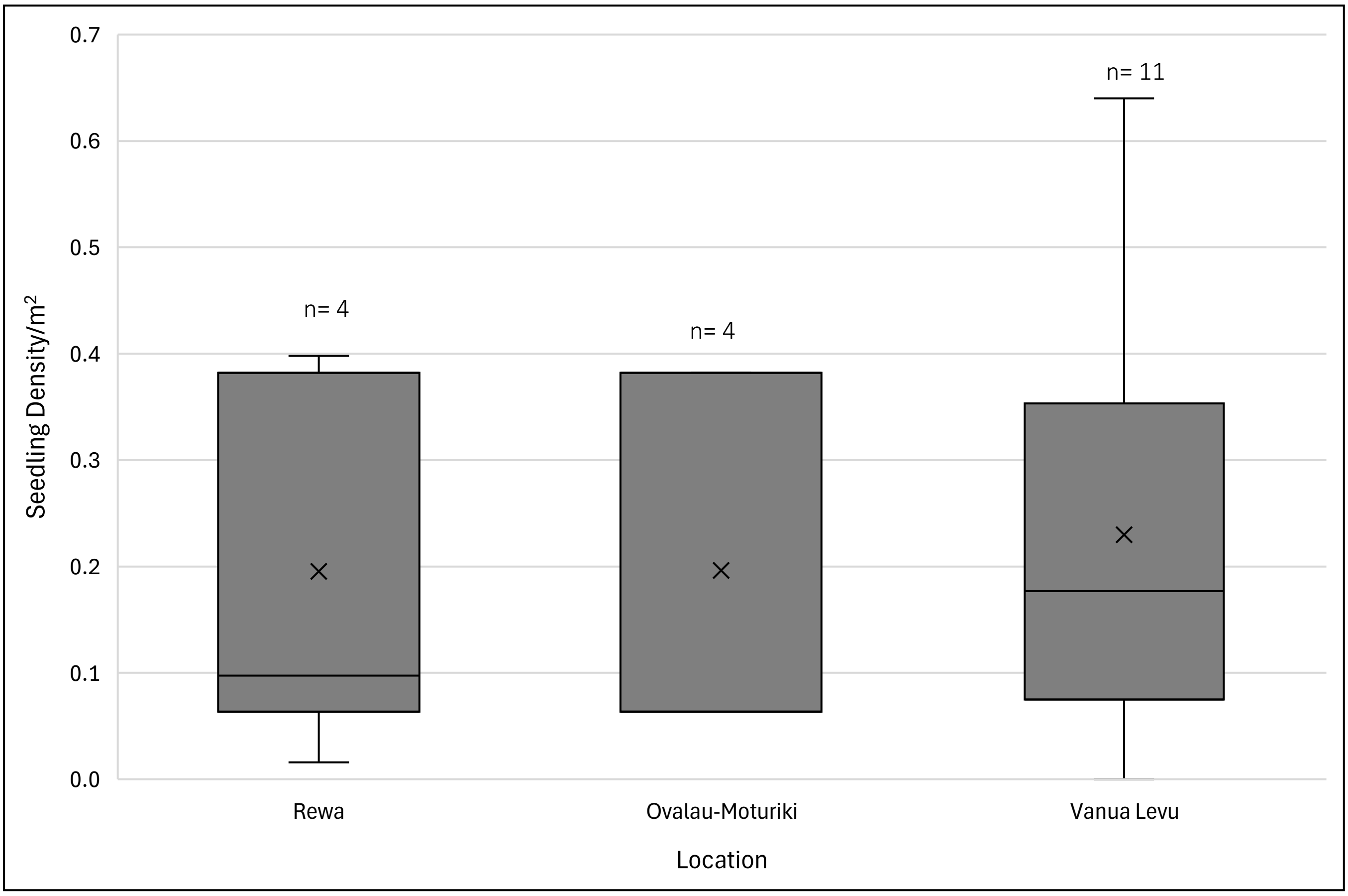

Figure 21. Seedling density/m^2 at each location in Fiji. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

When comparing degraded and intact sites across locations (Figure 22), Rewa had the highest seedling density for intact sites at 0.21 seedlings/m^2. However, the degraded site at Vanua Levu recorded the highest overall seedling abundance at 0.25 seedling/ m^2. Degraded sites sometimes have more mangrove seedlings, presumably due to the increased availability of light and space, as long as they are adjacent to intact mangrove forests and therefore have access to a plentiful supply of seeds. However, these seedlings may face challenges such as increased vulnerability to erosion and reduced protection from extreme weather events[41].

It should be noted that there was a large variation in seedling density at degraded sites in Vanua Levu, with one site having zero seedlings, while another site had a maximum density of 0.64 seedlings/m^2 (Figure 22). The site with no seedlings was cleared five years ago for settlement construction and river access, likely hindering any recruitment of seedlings.

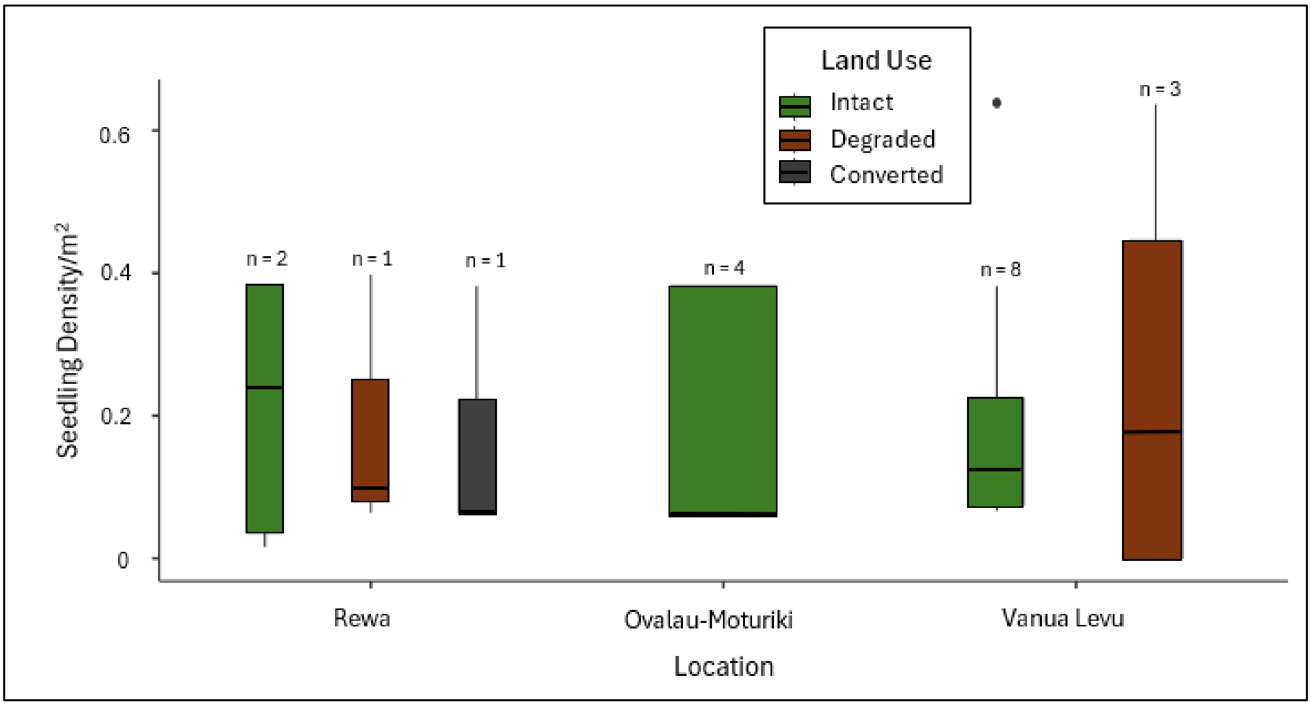

Figure 6. Seedling density/m^2 at each location in Fiji was compared between intact, degraded, and converted sites. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median, and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

[41] Echeverría-Ávila, S., Pérez-Ceballos, R., Zaldívar-Jímenez, M., Canales-Delgadillo, J., Brito-Pérez, R., Merino-Ibarra, M., & Vovides, A. (2019). Natural regeneration of degraded mangrove sites in response to hydrological restoration. *Madera Y Bosques*, *25*(1). https://doi.org/10.21829/myb.2019.2511754

3.5 Biodiversity results

The rapid biodiversity assessment completed at the seagrass and mangrove sites for Fiji found a range of species present. The assessment was based on opportunistic observations while on-site and should not be considered comprehensive. The focus was on recording any evidence of IUCN-listed species observed at each site. Unfortunately, no IUCN species were observed during the survey period in Fiji.

Incidental observations of fauna biodiversity were made in each of the seagrass and mangrove sites assessed. A range of fauna species were recorded as per Table 11 and shown in Figure 23.

Table 11. Species recorded in the mangrove forests assessed in Fiji.

Habitat	Organism type	Species	Common name
Seagrass	Bivalve	*Siliqua patula*	Razor clam
		Family: Mytilidae	Muscle
	Birds	*Thalasseus bergii*	Great Crested Tern
		Fregata ariel	Lesser Frigatebird
	Crustacean	Brachyura	Multiple crab species
		Family: Paguridae	Hermit Crab
	Echinoderm	*Linckia laevigata*	Blue Seastar
		Family: Holothuriidae	Sea Cucumber
		Family: Asteroidea	Sea star
	Gastropod	Family: Strombidae	Shell
		Potamididae	Water Snails
		Family: Strombidae	Multiple snail species
Mangrove	Bivalve	Family: Ostreidae	Oyster
		Siliqua patula	Razor Clams
	Birds	*Todiramphus sanctus*	Sacred Kingfisher
		Family: Hirundinidae	Swallow
		Family: Pachycephalidae	Whislter spp.
		Todiramphus chloris	Collared Kingfisher
		Zosterops lateralis	Silvereye
		Thalasseus bergii	Great Crested Tern
		Fregata ariel	Lesser Frigatebird
		Pycnonotus cafer	Red-vented bulbuls
		Family: Ardeidae	Heron
		Acridotheres fuscus	Jungle Myna
		Family: Columbidae	Pigeon spp.
	Crustacean	Family: Paguridae	Hermit Crab
		Brachyura	Multiple crab species
	Fish	Family: Oxudercidae	Mudskipper
	Gastropod	Family: Strombidae	Multiple snail species
		Family: Potamididae	Water snails

Figure 7. Observed fauna across Fiji. A range of gastropods, crustaceans, bivalves, birds, fish and echinoderms were recorded across the four locations. From the top left, the fauna are fiddler crab, hermit crab, sea star, brittle star, crab and mudskipper.

The abundance of crab holes was recorded at each of the sites as a simple indicator of the interaction between the benthic biodiversity of the forest and ecosystem functioning. Through burrowing and feeding activities, mangrove crabs contribute to recycling of organic matter, changes in surface topography, nutrient cycling and removal, oxygenation of mangrove sediments and the success of mangrove propagules[42]. Degraded mangrove forests typically have lower abundances of mangrove crabs which results in poor ecosystem functioning.

Across all locations, a wide range of crab hole sizes was observed (Figure 24). Ovalau-Moturiki exhibited the highest average abundance of crab holes across all size categories, which likely reflects the relatively healthy ecological condition and lower threat levels recorded at this site. Interestingly, Vanua Levu exhibited the lowest abundance of crab hole across all size classes, despite having relatively low threat levels at the habitat scale. The abundances and size

[42] Lee SY (1998) "Ecological role of grapsid crabs in mangrove ecosystems: a review," *Marine and Freshwater Research*, 49(4):335.

distributions of crab holes at the Vanua Levu sites are unlikely to be a true reflection of crab hole densities, as they were difficult to record during the assessments owing to the predominance of high tides and heavy rainfall during the sampling period.

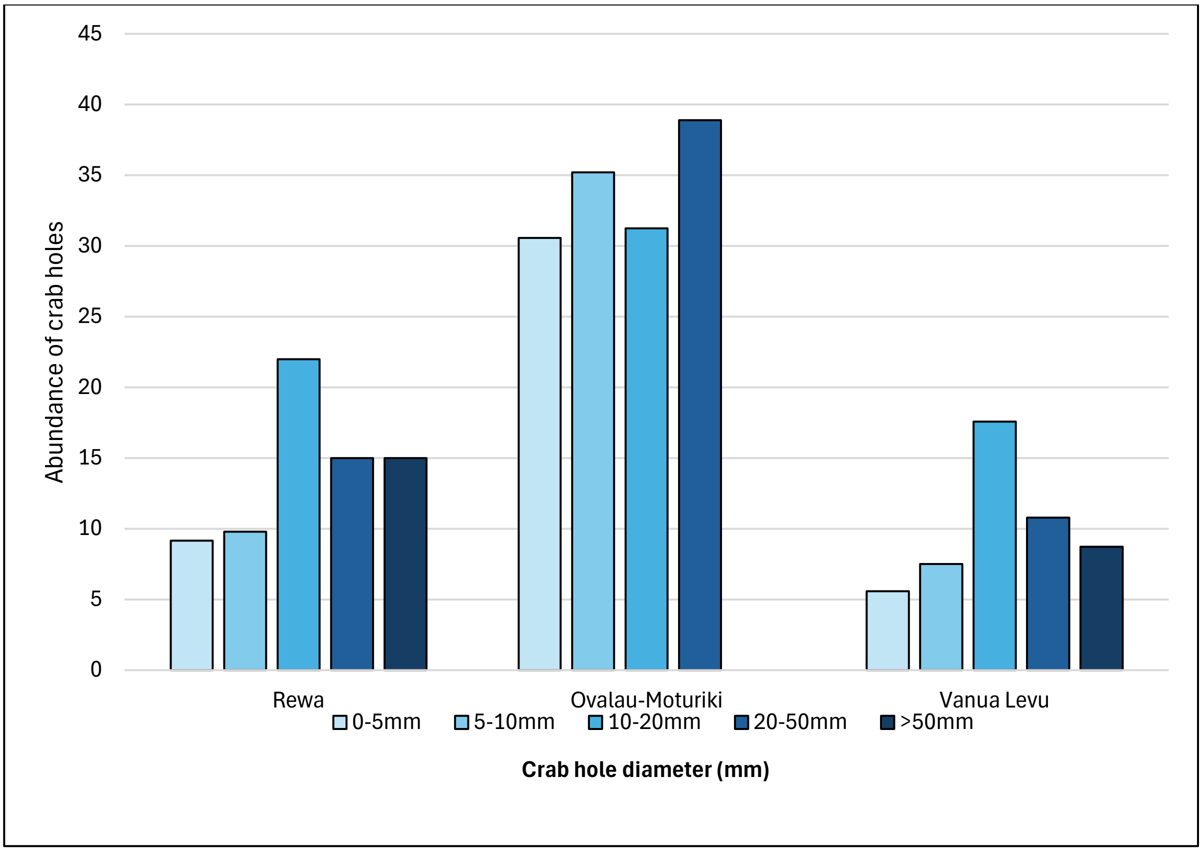

Figure 8. Average abundance of crab holes at each of the four locations sampled in Fiji, across five crab hole size categories (0-5mm, 5-10mm, 10-20mm, 20-50mm, >50mm). Note that for some sites in Vanua Levu, there was missing data due to tidal inundation preventing crab hole observations during surveys.

3.6 Summary

The seagrass and mangrove ecosystems of Fiji provide essential services like biodiversity enhancement, coastal protection, carbon sequestration, food production, as well as sources of firewood and construction materials. The results of this rapid assessment found that, despite varying between sites and locations, many seagrass and mangrove systems across Fiji remain resilient and continue to support essential ecosystem functions, likely sustaining high levels services. However, there was indication that ecosystem function and associated services, were measurably reduced at sites and locations exposed to high levels of threats.

Key findings:

Seagrass Ecosystems

- Fiji is host to six recorded species of seagrass, with the most common species in the region being *Halodule univeris, Halophila ovalis* and *Syringodium isoetifolium*. This project recorded at least three of those six species (noting that two *Halodule* species indistinguishable in the field were not differentiated in this study).
- Average seagrass cover across intact sites was estimated at 27-37%. Seagrass meadows are typically located in sheltered bays and lagoons, often adjacent to mangroves and reefs.
- The rapid biodiversity assessment found a range of species that inhabit seagrasses; however, no IUCN species were observed during the survey period in Fiji. Note that it was not intended to be a comprehensive search for all species.

Mangrove Ecosystems

- Fiji has approximately 33,000 – 52,000 ha of mangrove forests, with six (main species recorded. A total of six of the twelve mangrove species known to inhabit Fiji were recorded at the study locations. The two most common species were *Rhizophora stylosa* and *Bruguiera gymnorhiza*, as similarly found in studies.[43]
- The range in tree Diameter at Breast Height (DBH) reflects varying levels of environmental threats and biodiversity value. The degraded sites in Fiji had lower average DBH when compared to the intact sites. The DBH at degraded sites is typically lower than at intact sites due to the removal or damage of mature trees, which reduces the average tree size. Additionally, environmental stressors and disturbances at degraded sites hinder the growth and development of remaining trees, leading to smaller DBH measurements compared to the more stable conditions at intact sites. The average DBH at degraded sites ranged from 4 – 8 cm, while the DBH at intact sites ranged from 9 – 14 cm.
- The Rewa and Vanua Levu sites supported higher mangrove species diversity (5 - 6 species) than Ovalau-Moturiki (3 species).
- In Ovalau-Moturiki, relatively high levels of benthic biodiversity and abundance were recorded, suggesting that despite lower mangrove diversity, a narrower range of tree size classes, and the presence of pressures (e.g. cyclone and storm events), the mangrove forests continued to maintain healthy ecological functions and support biodiversity.
- In Vanua Levu, relatively high seedling abundance was recorded, particularly at disturbed sites, indicating these mangrove systems remain resilient despite existing pressures.
- The rapid biodiversity assessment recorded a wide range of fauna species, including sacred kingfisher, crabs, mudskippers, and water snails.

[43] Rubaiyat, A., Rollings, N., Galvin, S., Mitloehner, R., Miah, S., & Boehmer, H. J. (2023). Tree diversity, vegetation structure and management of mangrove systems on Viti Levu, Fiji Islands. *Southern Forests: a Journal of Forest Science*, *85*(3-4), 3-4.

Threat Assessment

- Threats to mangroves include extreme weather events, land use change (including but not limited to unsealed roads, agriculture, catchment clearing and plantations), invasive species, and species harvesting.
- Current threats to seagrasses include species collection and harvesting, including seagrass fauna, sand mobilisation from cyclones, development, as well as destructive fishing practices.
- The threat assessments indicated that while some areas are relatively intact, others are significantly impacted by human activities and natural events. Rewa had the highest level of threat at both the habitat and landscape scale, primarily due to logging, land use change, plantations, dredging, sedimentation and extreme weather events. Ovalau-Moturiki and Vanua Levu had the lowest level of threat at both the habitat and landscape scale.

PAPUA NEW GUINEA

4 Seagrass and mangroves of Papua New Guinea

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4.1 Seagrass past studies

The distribution and ecology of seagrasses in Papua New Guinea (PNG) received a relatively high level of attention in the late 1970's and 1980's. Work by Ian Johnstone from the University of Papua New Guinea in the late 1970's documented the seagrass species identified in PNG waters and estimated the distribution of seagrass meadows throughout the country. Based on this work, by the early 1980's it was estimated that PNG was home to 10 species of seagrass[44]. By the mid to late 1980's, thirteen species of seagrass belonging to eight genera had been recorded in PNG, [45] including: *Cymodoceae rotundata, Cymodoceae serrulata, Enhalus acoroides, Halodule pinifolia, Halodule uninervis, Halophila decipiens, Halophila minor, Halophila ovalis, Halophila spinulosa, Syringodium isoetifolium, Thalassia hemprichii, Thalassodendron ciliatum* and *Zostera muelleri.* However, subsequent molecular studies have shown that *Halophila minor* is conspecific with *H. ovalis*[46]. Additionally, there is contradictory evidence to support that *Halodule uninervis* and *H. pinifolia* are distinct species, due to being indistinguishable using molecular markers and morphological differences possibly being caused by environmental factors[47]. This reduces the confirmed number of seagrass species in PNG from thirteen to eleven.

Species diversity is highest in the southern coastline and declines eastward[48]. Most of the species found in PNG inhabit intertidal to shallow subtidal areas although *Halophila decipiens* has been reported much deeper[49]. Seagrasses are found

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[44] Johnstone, I.M. (1978). The ecology and distribution of Papua New Guinea seagrasses. I. Additions to the seagrass flora of Papua New Guinea. Aquatic Botany. 5:229-233.
[45] Brouns, J. J. W. M. and Heijs, F. M. L., (1985). Tropical seagrass ecosystems in Papua New Guinea. A general account of the environment, marine flora and fauna. Proc. K. Ned. Aka& Wetensch.,C88: 145-182.
[46] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. Marine pollution bulletin, 160, 111636.
[47] Wagey, B. T., & Calumpong, H. P. (2013). Genetic analysis of the seagrass Halodule in Central Visayas, Philippines. Asian Journal of Biodiversity, 4(1), 241-257.
[48] McKenzie, M., R.L. Yoshida, J.W. Aini, S. Andréfouet, P.L. Colin, L.C. Cullen-Unsworth, A.T. Hughes, C.E. Payri, M. Rota, C. Shaw, R.T. Tsuda, V.C. Vuki, R.K.F. Unsworth. (2021). Seagrass ecosystems of the Pacific Island countries and territories: a global bright spot Mar. Pollut. Bull. 10.1016/j.marpolbul.2021.112308
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across a wide variety of habitat types including in the lee of fringing reefs, sheltered muddy bays and on reef platforms. Extensive mixed species meadows are dominant in the bays and harbours along the coasts of the PNG mainland and the islands of New Britain and New Ireland[45, 50].

The distribution and extent of seagrass in PNG is not conclusive and remains largely unmapped, likely owing to the difficulty in accessing many regions of the largest coastline of any of the South Pacific countries[48]. Estimates range from 11,720 ha in 2003[51] (incomplete mapping) to 109,250 ha in 2020[52]. An estimate of 931,551 ha was reported in 2020, however it is unclear where this value was generated[53].

The condition of seagrass ecosystems across PNG is largely unknown. This is because the majority of studies that report condition are typically from small scale locales rather than larger regional scale or country wide assessments (for example see [49, 54]). As such there is also limited understanding of any changes in condition of seagrass across the country over time. There was however a qualitative condition assessment undertaken by McKenzie et. al.[55], that concluded there is no trend in seagrass condition.

As with the other four countries in the MACBLUE project, the threats to coastal ecosystems like seagrass are typically low level and localised[56]. Key threats to seagrass meadows in PNG are land clearing for coastal development, logging and mining, coastal agriculture like palm oil plantations, sewage discharge, catchment and industrial pollution and overfishing[57]. Storm surges, cyclone damage and sea level rise from climate change also threaten PNG seagrass meadows along with a general lack of awareness of the benefits of seagrass ecosystems to local communities[55].

Seagrass meadows support a wide range of ecosystem services across the South Pacific. In terms of biodiversity, seagrass meadows are a well-known key habitat that supports different coral and seagrass- dwelling fish species as well as many other marine species. PNG seagrass meadows are estimated to support at least 60 fish species[58], six (6) sea turtle species[59] and 59 gastropod and bivalve species[60]. They also support an estimated 350 dugongs that a predominantly found on the southern coastline adjacent to the Torres Strait. Dugong research in PNG is reasonably well covered owing to the interest and focus of dugong herds using the Torres Strait.

Seagrass ecosystems play a significant role in supporting the cultural and economic values of PNG. They contribute to small scale local fisheries and protect coastlines from erosion[61]. Protection of these benefits is limited in PNG with very

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few marine protected areas encompassing seagrass meadows and all of these managed locally and largely without support from the central government[62].

4.2 Mangrove past studies

Papua New Guinea hosts a significant portion of the world's mangrove forests, with approximately 75% of the Pacific's mangroves located here. The mangrove forests of PNG are of global significance and are among the most taxonomically diverse in the world with 47 different species recorded, including 33 true mangroves and their hybrids and 17 mangrove associates. There have been numerous PNG mangrove maps development from the mid 80's through to the present although these tend to focus on sub-regions so the full extent and condition of mangroves in PNG has not been comprehensively estimated or mapped[63, 64]. These studies tended to focus on select provinces or regions of PNG (e.g. Western and Gulf Province[63, 65]). Since that time, remote sensing techniques have become a preferred method to map vegetation and habitat types at large scales. However, despite the globally significant mangrove extent, there is a paucity of remote sensing studies for PNG[64].

Past studies have used global datasets generated by the Global Mangrove Watch[66] and using earth observation satellite data[67] to generate mangrove maps and assess land-use change in PNG. A land-use change study found that mangroves were estimated to have gone from 473,230 ha in 2000 to 456,618 ha in 2020[68, 69]. A second remote sensing study estimated 480,121 ha of mangroves in 2011[70]. However, the low spatial resolution used for these remote sensing studies suggests the areas may be underestimates of true mangrove cover across PNG. A 2009 land cover study estimated 592,900 ha of mangroves were distributed through all coastal provinces[71]. Notably the largest contiguous area of mangroves is the Purari and Kikori mangrove systems of the Gulf of Papua, which covers an area of approximately 260,822 ha[72]. When combined with the Fly River, these delta areas comprise the most extensive areas of mangroves in PNG[73].

The mangrove forests of New Guinea are the most floristically diverse in the Indo-Pacific, both in structure and species[74]. In a 1997 review by Ellison[63], it was reported that PNG has 33 mangrove species and three (3) hybrids from 16 genera and 13 families[75]. However, the present study compiled a species list from the broader literature which totals 47 species

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known to occur in PNG, including five (5) hybrids, from 21 genera[76, 77, 78] (see Table 14 in the results section below for the full compiled species list). The largest and most diverse mangrove forests are found in deltas and estuaries such as those found in the Gulf of Papua[63].

Height above the tide and the complex hydrology found in mangrove forests along with differences in tolerances of species to these conditions tends to lead to zonation patterns made up of groups of species. Species composition of these zones tend to differ in different areas of PNG[79]. The south coast of PNG is more species rich than the north coast with several species only found in the south[79]. Within the Kikori and Purari deltas, there is considerable zonation in mangrove species distribution[80, 81, 82]. At the seaward edge, mudbanks are predominantly colonised by *Avicennia* and *Sonneratia species*. Further inland, these give way to stands dominated by *Rhizophora* as well as mixed *Rhizophora* and *Bruguiera* forests. In tidal creeks to the north of this region where fresh and saline waters meet, forests are dominated by *Nypa* woodland (*Nypa fruiticans*)[83].

Mangroves of New Guinea island are regarded to be relatively undisturbed by anthropogenic activity compared to other areas in the region[84, 85]. In contrast to many countries of south east Asia and the South Pacific, there has not been large scale clearing of mangroves in PNG for the creation of aquaculture or for land reclamation[83]. The mangroves forests in the deltaic areas of the western and gulf provinces are largely undisturbed and are therefore in good condition relative to the other countries in the Indo-pacific region. Despite this, there is some evidence of over-exploitation and degradation of mangroves in southern PNG, especially in small pockets where removal of mangroves has led to coastal erosion[79].

Key threats to PNG mangrove forests include clearing for aquaculture, urban development, oil and gas industry, agriculture, and forestry[84, 86]. In a recent study by Sillanpää et. al.[87] it was reported that in the 2000–2016 period, about 3.43 % of the total mangrove area has undergone land-use change at varying intensities, by either natural (erosion, extreme weather) or anthropogenic (settlement, infrastructure, commodities) factors. Approximately 324,025 ha of mangroves in PNG are estimated to be unprotected[87] meaning a significant proportion of the countries mangroves forests are vulnerable to future threats. Marine debris is also a significant threat, as it accumulates in PNG's mangroves forests. Surveys of stranded marine debris around Motupore Island, a small island in Bootless Bay, revealed exceptionally high plastic-dominated debris loads (90%), with major concentrations in mangrove-dominated, depositional areas[88]. Due to their threatened status, there is an increasing global interest in managing mangroves to preserve their ecosystem services and particularly, their carbon.

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Mangrove forests in PNG support a vast array of fauna species, providing essential habitats for both marine[89] and terrestrial[90] species. The high productivity and complexity of mangrove environments along environmental gradients create numerous niches that are exploited by a diverse range of fauna. Notably, the mangrove-restricted avifauna of northern Australia and New Guinea is the richest in the world. Many other species also utilize mangroves as part of their range or for foraging expeditions[90].

Mangrove forests deliver crucial services to the communities of PNG and other South Pacific countries. These services include pollution mitigation, protection from storm events, coastal erosion control, and climate regulation. As one of the largest carbon stocks globally, PNG mangroves significantly contribute to global carbon regulation.

Mangrove forests provide numerous cultural, social and livelihood benefits within local communities. For example, species in the family *Rhizophoraceae* are used for construction, such as house poles[91]. Various extracts from mangrove species are utilized in traditional medicines[91]. The nursery and marine species habitat services support a range of shellfish and finfish, which are harvested for subsistence throughout the country[92]. They provide cultural benefits not only to those living within or adjacent to them but also to trading partners and visitors. Shells of mangrove bivalves are traded into the Highlands of New Guinea for use as body ornaments, symbols of prestige, tokens functioning like money, and tools. Tannins extracted from the bark of *Bruguiera species* are used as dye[93], while syrup made from the inflorescence of *Nypa species* and propagules are used as food[94].

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4.3 Papua New Guinea study sites

Seagrass meadows and mangrove forests were surveyed across five (5) locations in PNG. The survey locations for both mangroves and seagrass are shown in Figure 25, including Western, Central, Milne Bay, West New Britain and New Ireland Provinces. A total of 24 mangrove sites and 17 seagrass sites were surveyed across a diversity of geomorphological settings in order to capture representative data for these dynamic ecosystems. Locations and sites are shown in detail in Figure 25 to Figure 30.

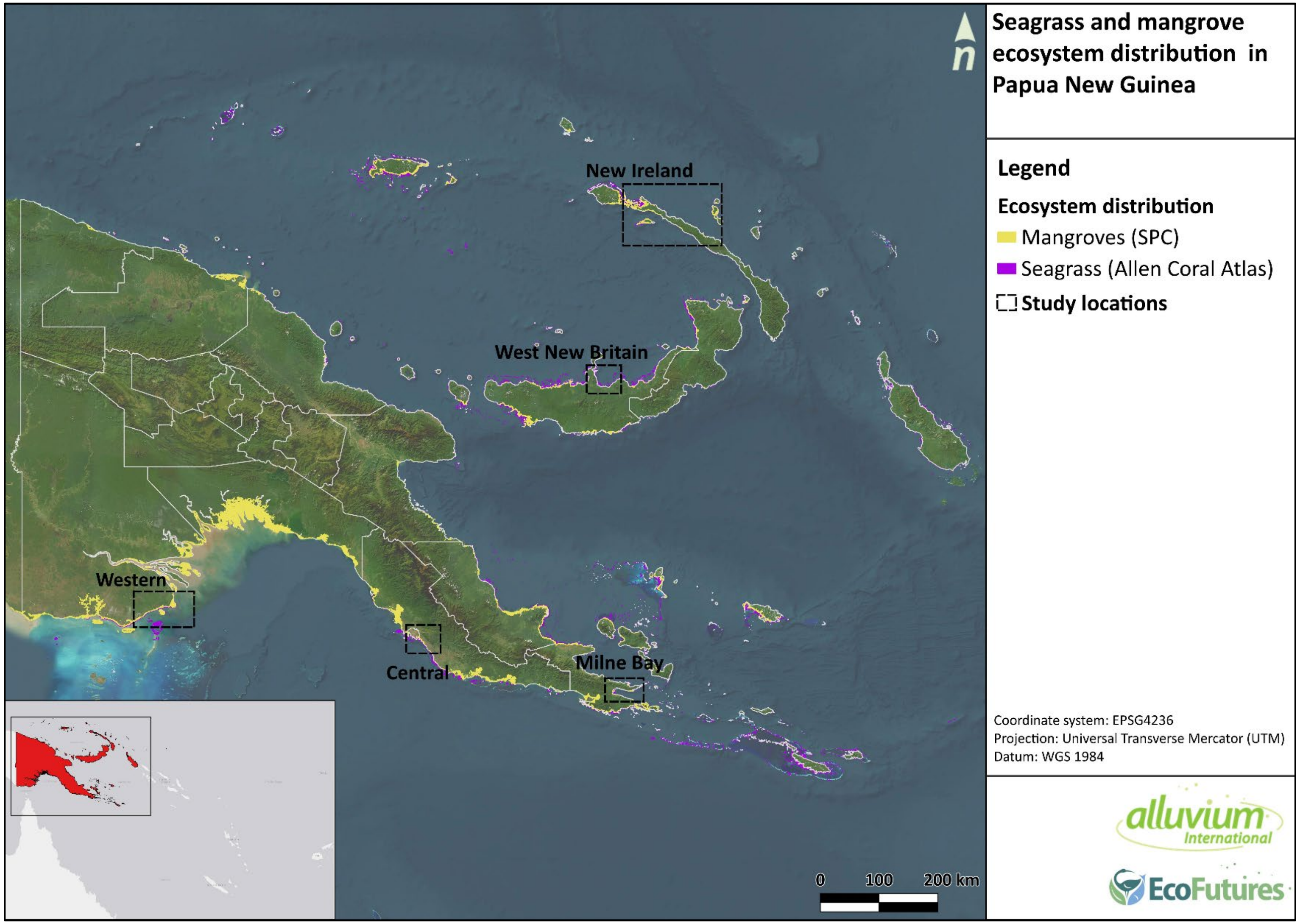

Figure 25. Seagrass and mangrove ecosystem distribution and survey locations in PNG.

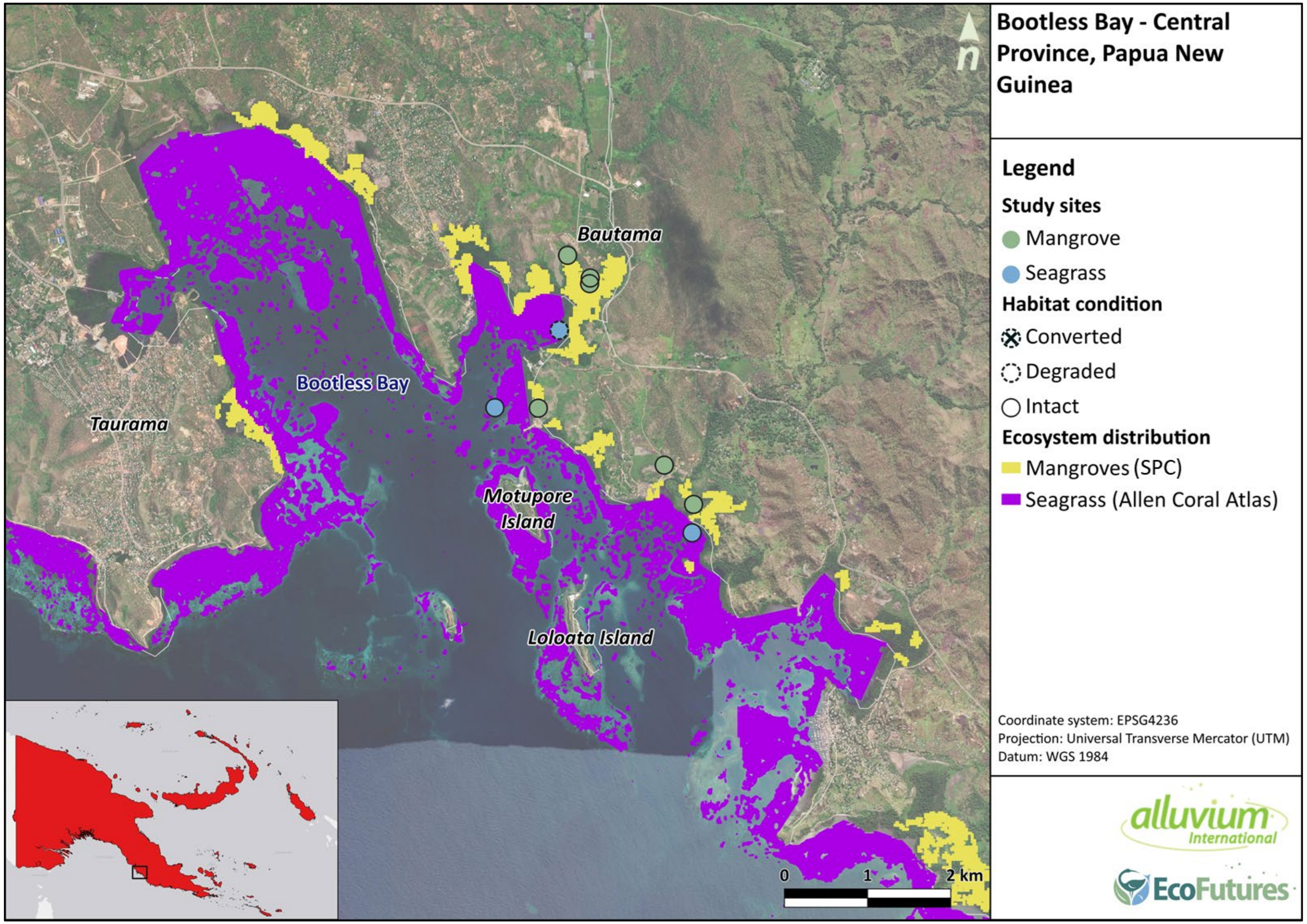

Figure 26. Seagrass and mangrove ecosystem distribution and survey sites in Central Province, in the area of Bootless Bay. At this location there were six (6) intact mangrove sites, two (2) intact seagrass sites and one (1) degraded seagrass site.

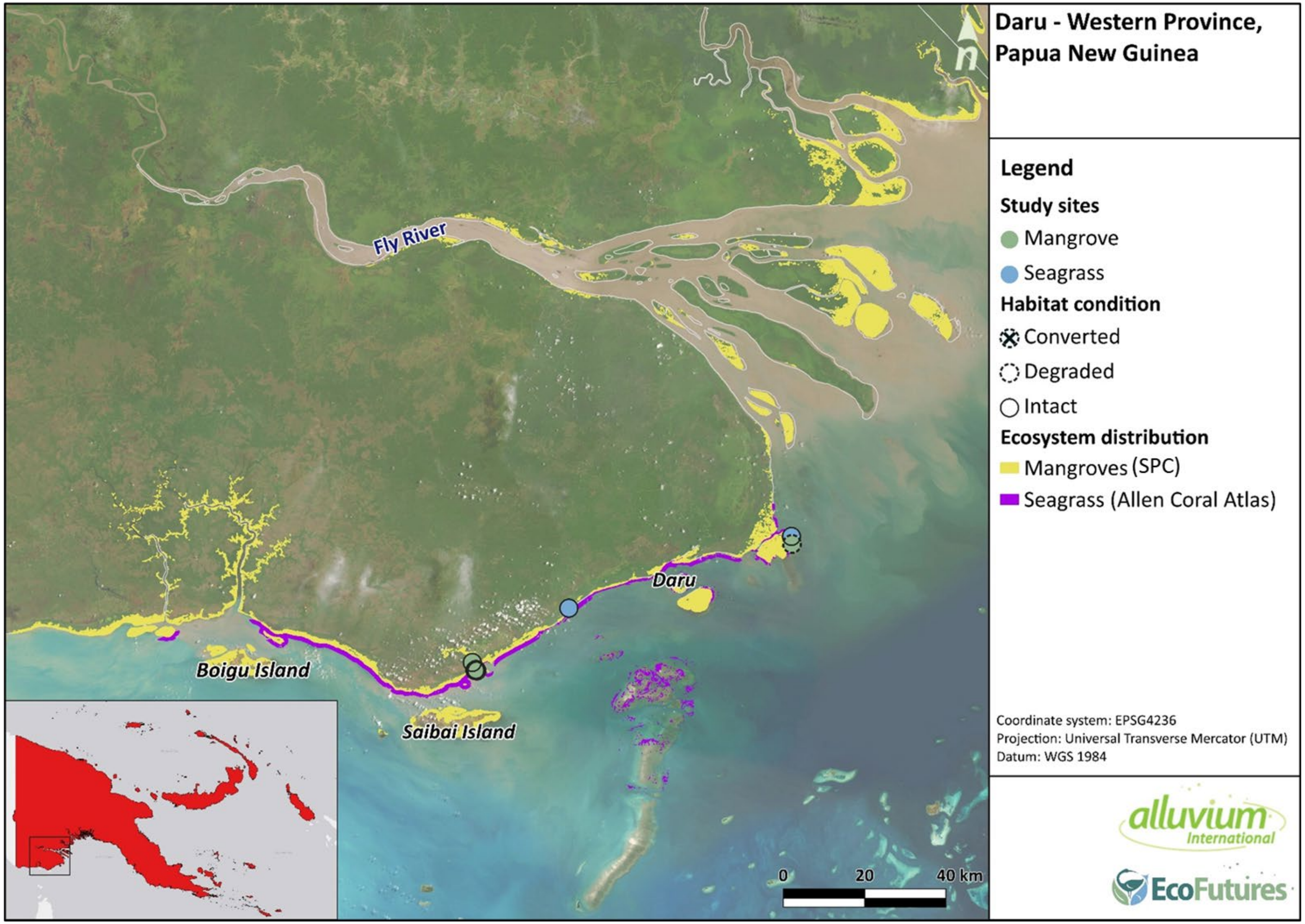

Figure 27. Seagrass and mangrove ecosystem distribution and survey sites in Western Province in the coastal areas surrounding Daru. At this location were four (4) intact and one (1) degraded mangrove side as well as two (2) intact seagrass sites.

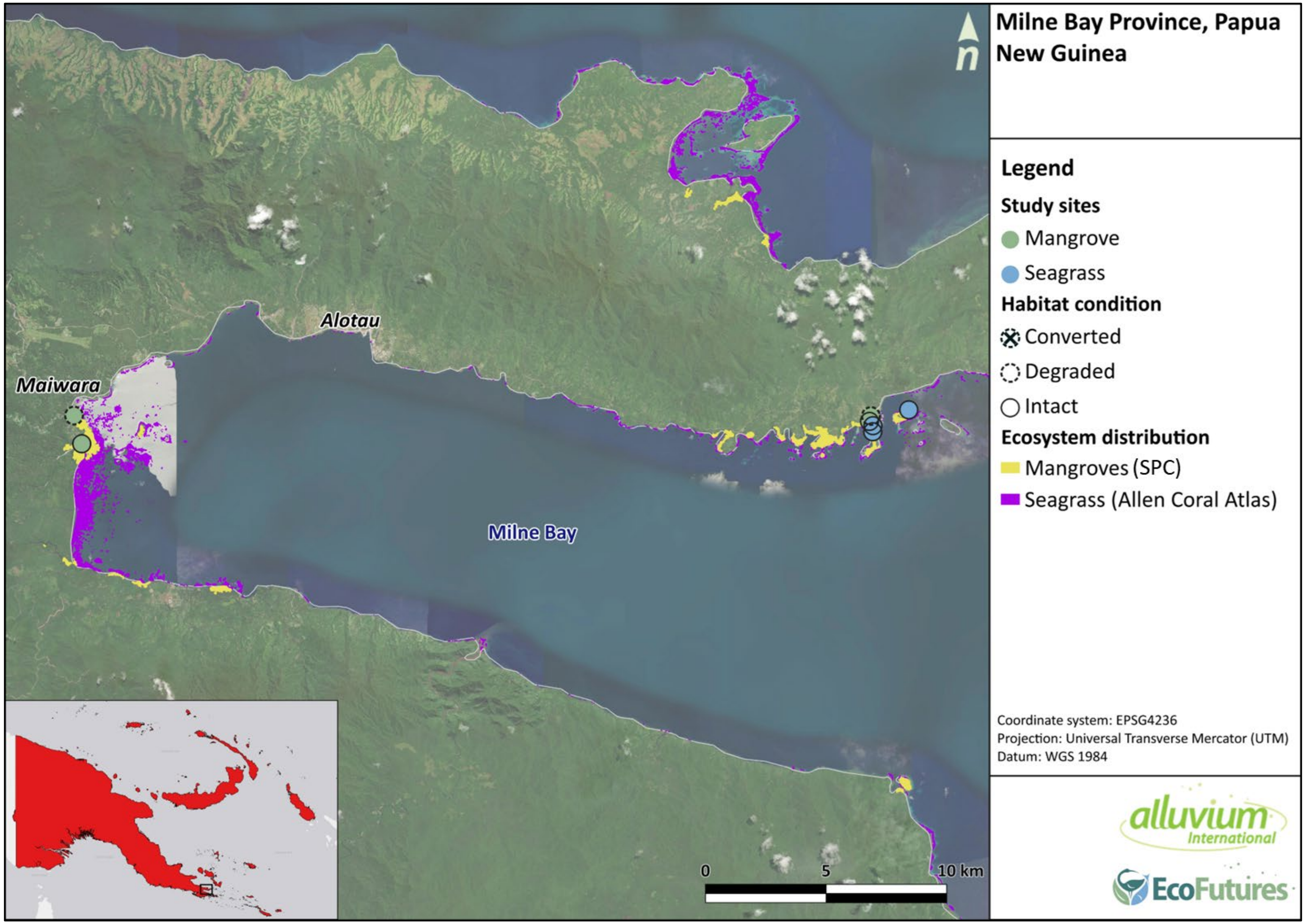

Figure 28. Seagrass and mangrove ecosystem distribution and survey sites in Milne Bay Province. At this location there were two (2) degraded and two (2) intact mangrove sites and three (3) intact seagrass sites.

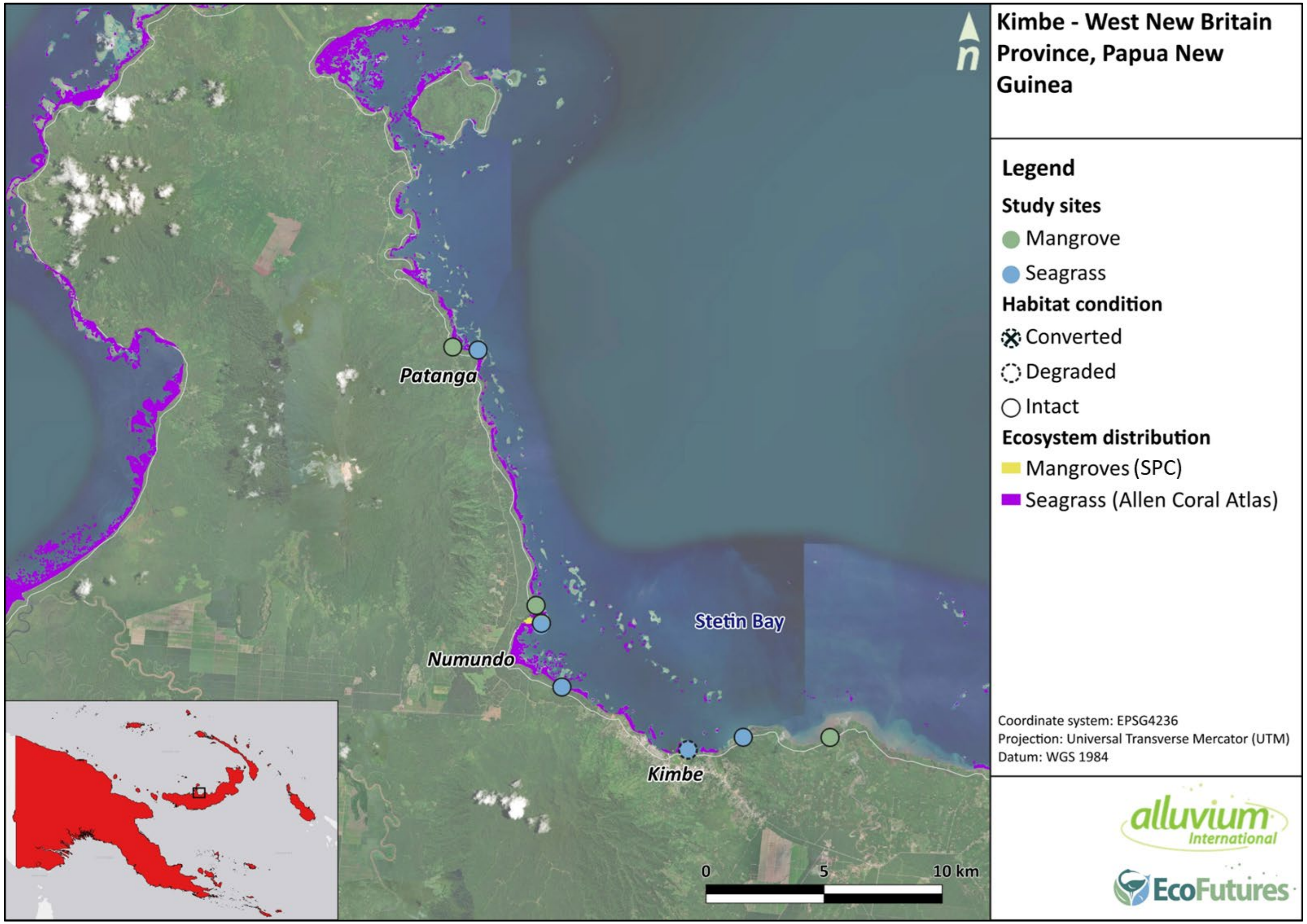

Figure 29. Seagrass and mangrove ecosystem distribution and survey sites in West New Britain Province in the coastal areas surrounding Kimbe. At this location were three (3) intact and one (1) degraded seagrass sites and four (4) intact mangrove sites.

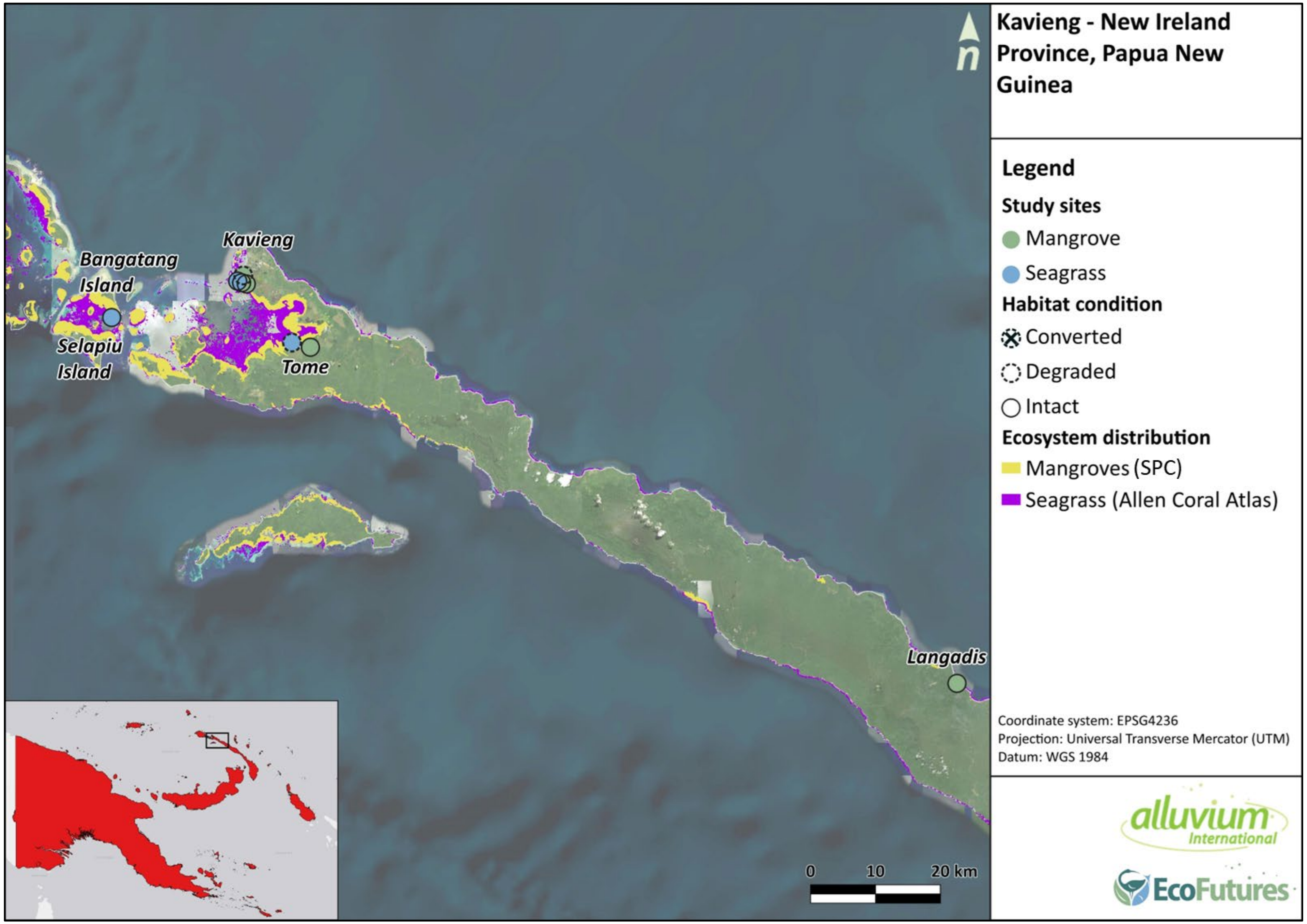

Figure 30. Seagrass and mangrove ecosystem distribution and survey sites in New Ireland Province. At this location were one (1) degraded and four (4) intact mangrove sites and one (1) degraded and two (2) intact seagrass sites.

4.4 Papua New Guinea ecosystem assessment results

4.4.1 Seagrass results

A total of seven (7) of the eleven species (11) of seagrass known from PNG were recorded across the 17 study sites sampled (Table 12). Meadows sampled were predominantly on fringing reef flats or islands. Across all locations, 14 sites were meadows with multiple species of seagrass, which is common in PNG [95, 96]. All five locations sampled in PNG appeared to have high species diversity, with 5 to 6 species identified (Table 12). Photos of each site surveyed were captured and can be found in the Appendices.

Table 62. Seagrass species found in the MACBLUE compared to previous seagrass species lists described for PNG.

Species	Recorded during MACBLUE assessment					Past studies in PNG [97, 98, 99, 100]
	Central	Milne Bay	West New Britain	New Ireland	Western	
Cymodoceae rotundata	X	X	X	X	X	X
Cymodoceae serrulata		X	X			X
Enhalus acoroides	X	X	X	X	X	X
Halodule pinifolia / Halodule uninervis *	X	X	X	X	X	X
Halophila decipiens						X
Halophila ovalis / Halophila minor **	X	X	X	X	X	X
Halophila spinulosa						X
Syringodium isoetifolium	X	X		X		X
Thalassia hemprichii	X				X	X
Thalassodendron ciliatum						X
Zostera muelleri subsp. *capricorni*						X

* For the purpose of this study the sets of species and/or sub-species that require molecular analysis to correctly identify and differentiate, were binned together and not analysed separately [101] ** Note that molecular studies have found *H. minor* is conspecific with *H. ovalis*[102]

[95] Brouns, J. J. W. M. and Heijs, F. M. L., (1985). Tropical seagrass ecosystems in Papua New Guinea. A general account of the environment, marine flora and fauna. Proc. K. Ned. Aka& Wetensch.,C88: 145-182.
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Four seagrass species were consistently observed at all locations, these were: *Enhalus acoroides, Cymodoceae rotundata, Halodule pinifolia/ Halodule uninervis* and *Halophila ovalis* (Table 12). *Enhalus acoroides* was the most commonly recorded species in the assessment, found at 80% of the sites. In West New Britain and New Ireland, monospecific meadows of *Enhalus acoroides* were observed at two and three sites, respectively. However, seagrass meadows across all locations were more typically mixed species meadows with 4-6 species present.

West New Britain and New Ireland Provinces exhibited the highest average seagrass coverage at 65% (± 7 SE) and 66% (± 13 SE) respectively (Figure 31). The lowest average seagrass cover was recorded at sites in Central Province, at 27% (± 3 SE). Comparing seagrass cover between degraded and intact sites suggests that degraded sites typically had lower levels of cover relative to average seagrass cover for each location.

Observed threats to the seagrass meadow in the locations assessed included coastal and catchment clearing for oil palm plantations and other agriculture, sediment runoff, extreme weather events, boat activity and intensive fishing (Table 13). The sites in New Ireland Province had the lowest threat score when compared to all other locations (Table 13), likely due to less intensive catchment land and sea use in the area compared to the other locations.

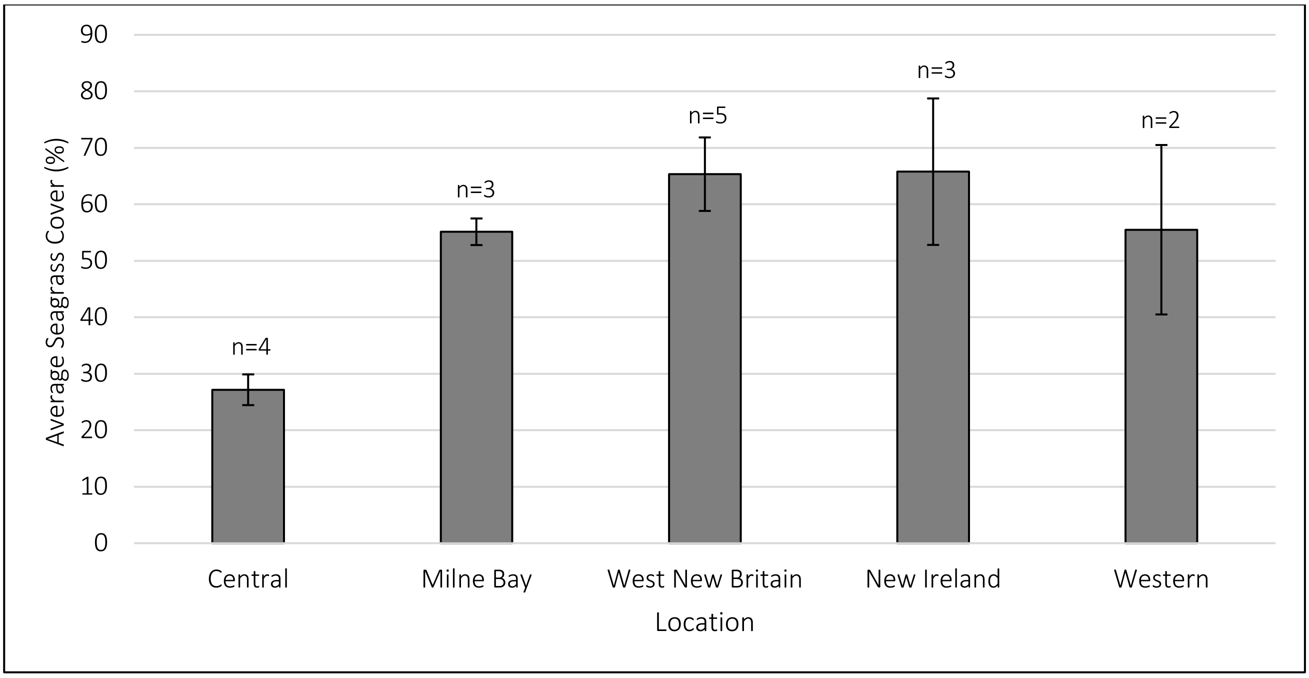

Figure 31. Average seagrass coverage (%) (± SE) across six locations in PNG, where n is the number of sites surveyed at each location.

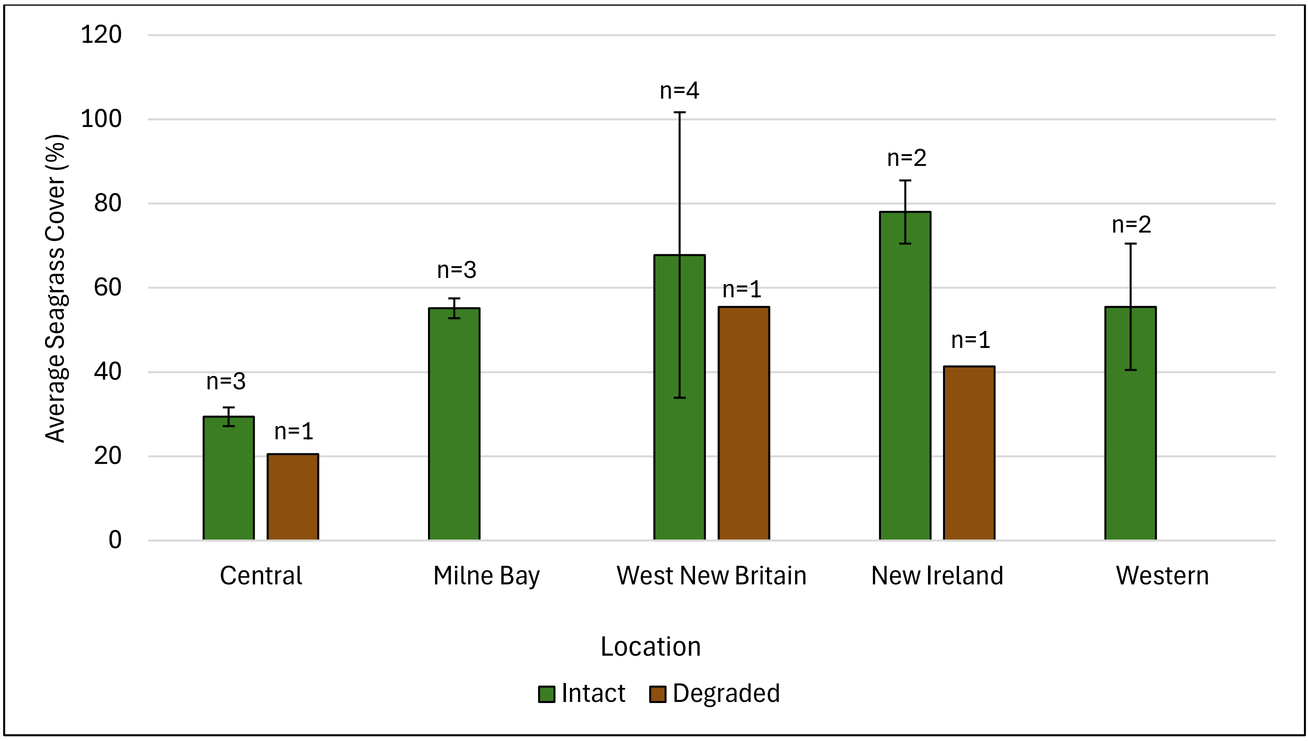

Figure 32. Average seagrass cover (%) (± SE) across intact and degraded locations, where n is the number of sites surveyed at each location.

Table 13. Rapid threat assessment results for the seagrass sites in PNG, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Central	Fishing, sedimentation from run off, physical damage from boating and cyclones	*Habitat*	28	NA	4	5	4	NA	3	4	2	2	4
		Landscape	20	5	NA	NA	NA	1	3	4	2	3	4
Milne Bay	Local fishing, minor roads, extreme weather events, palm oil plantations and villages	*Habitat*	24	NA	2	3	4	NA	4	2	2	4	3
		Landscape	25	5	NA	NA	NA	4	4	3	2	4	3
West New Britain	Fishing, invasive species (crown of thorns/cane toads), oil palm spillage (crude palm oil – 2022), extreme weather events (heatwaves, storms, floods), storm water pipes inlet, surrounding villages, large commercial boats	*Habitat*	24	NA	3	3	4	NA	4	3	2	4	2
		Landscape	19	3	NA	NA	NA	3	4	2	1	4	2
New Ireland	Inflow from surrounding villages, fishing, and extreme weather events, palm oil plantations and village.	*Habitat*	34	NA	4	4	4	NA	5	5	4	5	4
		Landscape	32	5	NA	NA	NA	4	5	5	5	5	4
Western	Boat activity, jetties, extreme weather events, sediment runoff	*Habitat*	19	NA	1	3	2	NA	4	1	2	4	2
		Landscape	20	4	NA	NA	NA	4	4	1	2	3	2

4.4.2 Mangroves results

A total of 29 of the 47 mangrove species known to inhabit PNG were recorded in the assessments, with the distribution of the species amongst the four locations outlined in (Table 14). Overall, *Rhizophora stylosa* was the most abundant species recorded across the locations (n= 505), followed by *Bruguiera gymnorhiza* (n= 323), *Ceriops tagal* (n= 279), *Rhizophora apiculata* (n = 169), *Avicennia marina* (n = 155), *Avicennia alba* (n= 93), *Xylocarpus granatum* (n= 67) *Ceriops decandra* (n = 63) and (Table 14). The abundance of all other species is < 40.

Mangrove forests that have a greater species diversity have been found to have enhanced biomass production and soil carbon storage[103] so protecting forests with a higher diversity of species and restoring degraded forests with multiple species is important for maximising carbon storage. Western Province sites had the highest species diversity with a total of 20 species, followed by Milne Bay, which had a total of 17 species and Central, which had a total of 12 species. New Ireland and West New Britain sites had the lowest diversity with six (6) and eight (8) mangrove species, respectively (Table 3). Photos of each site surveyed were captured and can be found in Appendices.

Table 14. Mangrove species list for PNG found during the MACBLUE assessment in comparison with past studies on mangroves in PNG (T = True Mangrove, A = Associate Mangrove, H = Hybrid/Subspecies/Variant).

Species	Category	Recorded during MACBLUE assessment					Past studies in PNG[104, 105, 106, 107, 108]
		Central	Milne Bay	West New Britain	New Ireland	Western	
Acanthus ilicifolius	A						X
Acrostichum aureum	A						X
Acrostichum speciosum	A						X
Aegialitis annulata	A						X
Aegiceras corniculatum	A	X	X	X		X	X
Aglaia cucullata (syn. *Amoora cucullata*)	A						X
Avicennia alba	T	X					X
Avicennia marina	T	X	X	X		X	X
Avicennia marina subsp. *eucalyptifolia*	H					X	X
Avicennia officinalis	T		X			X	X
Avicennia marina var. *rumphiana*	T						X
Barringtonia racemosa	A						X
Bruguiera cylindrica	T	X				X	X
Bruguiera exaristata	T		X				X
Bruguiera gymnorhiza	T	X	X		X	X	X

[103] Bai J, Meng Y, Gou R, et al. (2021) Mangrove diversity enhances plant biomass production and carbon storage in Hainan Island, China. *Funct Ecol*. 2021; 35: 774–786. https://doi.org/10.1111/1365-2435.13753
[104] Duke, N.C. 2006. Australia's Mangroves. The authoritative guide to Australia's mangrove plants. University of Queensland, Brisbane. 200 pages
[105] Balun, L. 2011. Functional Diversity in the Hyper-diverse Mangrove Communities in Papua New Guinea. PhD diss., University of Tennessee. https://trace.tennessee.edu/utk_graddiss/1166
[106] Robertson, A.I., Daniel, P.A. and Dixon, P. 1991. Mangrove forest structure and productivity in the Fly River estuary, Papua New Guinea. Marine Biology 111: 147-155.
[107] Ellison, Joanna. (1997). Mangrove ecosystems of the western and Gulf Provinces of Papua New Guinea, a review. Science in New Guinea. 23. 3-16.
[108] WFO (2025): Cynometra iripa Kostel. Published on the Internet;http://www.worldfloraonline.org/taxon/wfo-0000187706. Accessed on: 30 Apr 2025

Species	Category	Recorded during MACBLUE assessment					Past studies in PNG[104, 105, 106, 107, 108]
		Central	Milne Bay	West New Britain	New Ireland	Western	
Bruguiera parviflora	T	X					X
Bruguiera sexangula	T		X				X
Bruguiera X hainesii	H						X
Camptostemon schultzii	A					X	X
Ceriops australis	T		X				X
Ceriops decandra	T	X	X			X	X
Ceriops tagal	T	X				X	X
Cynometra iripa	T			X			X
Cynometra ramiflora	T						X
Dolichandrone spathacea	A		X				X
Excoecaria agallocha	A				X	X	X
Heritiera littoralis	A		X	X	X	X	X
Lumnitzera littorea	T		X		X		X
Lumnitzera racemosa	T	X					X
Lumnitzera X rosea	H						X
Nypa fruticans	A						X
Osbornia octodonta	A						X
Pemphis acidula	A						X
Rhizophora apiculata	T	X	X			X	X
Rhizophora mucronata	T		X				X
Rhizophora stylosa	T	X	X	X	X	X	X
Rhizophora X lamarckii	H						X
Scyphiphora hydrophylacea	T					X	X
Sonneratia alba	T		X			X	X
Sonneratia caseolaris	T		X				X
Sonneratia lanceolata	T					X	X
Sonneratia ovata	T						X
Sonneratia X gulngai	T					X	X
Sonneratia X urama	T						X
Xylocarpus granatum	T		X	X	X	X	X
Xylocarpus moluccensis (syn. *X. mekongensis*)	T	X			X	X	X
Xylocarpus rumphii	T						X

Across the five locations surveyed in PNG, the sites in Western Province had the highest threat ratings at both the habitat and landscape scale (Table 15). This location had an array of threats, which related to high boat activity, local fishing, agriculture, cleared land and extreme weather events, among other threats. All other locations had a similar threat score. The threats at West New Britain Province sites were related to native vegetation conversion for plantation farming, intensive palm oil plantation land-use, seasonal rain flood plumes, and extreme weather events. In the Central Province, the main threats were native habitat conversion, runoff, solid and plastic pollution, wood harvesting, fishing and collection of crabs and shells. Several degraded sites were assessed in this study, including sites in Western (Figure 33) and New Ireland Provinces (Figure 34), which had been directly impacted by vegetation clearing for coastal development and access.

Figure 33. Example of a degraded site in Western Province. This site was mostly cleared of mangroves and is a sandy beach in front of a village.

Figure 34. Example of a degraded site at New Ireland Province, where mangroves were recently cleared (2023) for heavy machinery.

Table 15. Rapid threat assessment results for the mangrove sites in PNG showing total scores and individual threat scores averaged across sites within a location. The maximum total score for habitat scale and landscape scale is 40 and 35 respectively, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average Total Score	T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection & harvesting	T9. Non-preferred species	T10. Extreme events
Central	Runoff, solid and plastic pollution, wood harvesting, fishing, collection of crabs and shells	*Habitat*	36	NA	4	5	5	NA	5	5	4	5	5
		Landscape	27	5	NA	NA	NA	4	4	1	4	4	5
Milne Bay	Fishing, sea cucumber harvesting, vegetation clearing, population growth, palm oil plantations, invasive species (pigs), extreme weather events, including flooding.	*Habitat*	29	NA	4	3	4	NA	4	4	3	4	4
		Landscape	27	5	NA	NA	NA	4	5	4	3	4	4
West New Britain	Invasive species (cane toads), seasonal rain flood plumes, palm oil conversion/native vegetation clearing, extreme weather events	*Habitat*	27	NA	4	3	3	NA	4	4	2	5	3
		Landscape	21	3	NA	NA	NA	2	3	4	2	1	5
New Ireland	Adjacent village pressures, local fishing, some clearing for roads, extreme weather events, sediment resuspension, large palm oil plantation. Historical chemical spill at Lavatbura.	*Habitat*	29	NA	4	4	4	NA	4	3	3	4	3
		Landscape	25	5	NA	NA	NA	3	4	3	3	4	3
Western	Boat activity, cleared land, fishing, surrounding agriculture, extreme weather events	*Habitat*	20	NA	2	3	2	NA	4	2	1	4	2
		Landscape	20	5	NA	NA	NA	4	3	2	2	3	2

Larger trees in forests play a keystone role[109] by contributing a disproportionate level of reproductive components, habitat for other species, and above ground biomass for carbon storage. The largest trees recorded in PNG were typically found at the West New Britain and New Ireland Province sites (Table 16). Western and Central Province sites had fewest large trees, with only 1% and 3% respectively in the larger than 50cm size class. Central and Milne Bay Province sites had the highest number of small trees, with 93% and 81% of trees respectively in the less than 20 cm DBH size class.

Table 16. The distribution of larger trees across the five (5) locations assessed in PNG. Numbers refer to the percentage (%) of trees recorded in that location. DBH refers to Diameter at Breast Height.

Tree size	Central	Milne Bay	West New Britain	New Ireland	Western
<20cm DBH	93	81	43	58	62
20 - 50cm DBH	6	14	47	33	35
>50cm DBH	1	5	10	9	3

[109] D.B. Lindenmayer, W.F. Laurance, J.F. Franklin. (2012). Global decline in large old trees. Science, 338 (6112), pp. 1305-1306

In the Central Province, *Bruguiera cylindrica* had the largest average Diameter at Breast Height (DBH) of 31 cm (Figure 35), followed by *Rhizophora apiculata* (DBH = 16 cm), *Bruguiera gymnorhiza* (DBH= 15 cm) and *Avicennia alba* (DBH = 11 cm). *Avicennia alba* had the largest outlier (DBH = 72 cm), followed by *Bruguiera gymnorhiza* (DBH = 61 cm). All other species had a DBH < 10 cm (Figure 35).

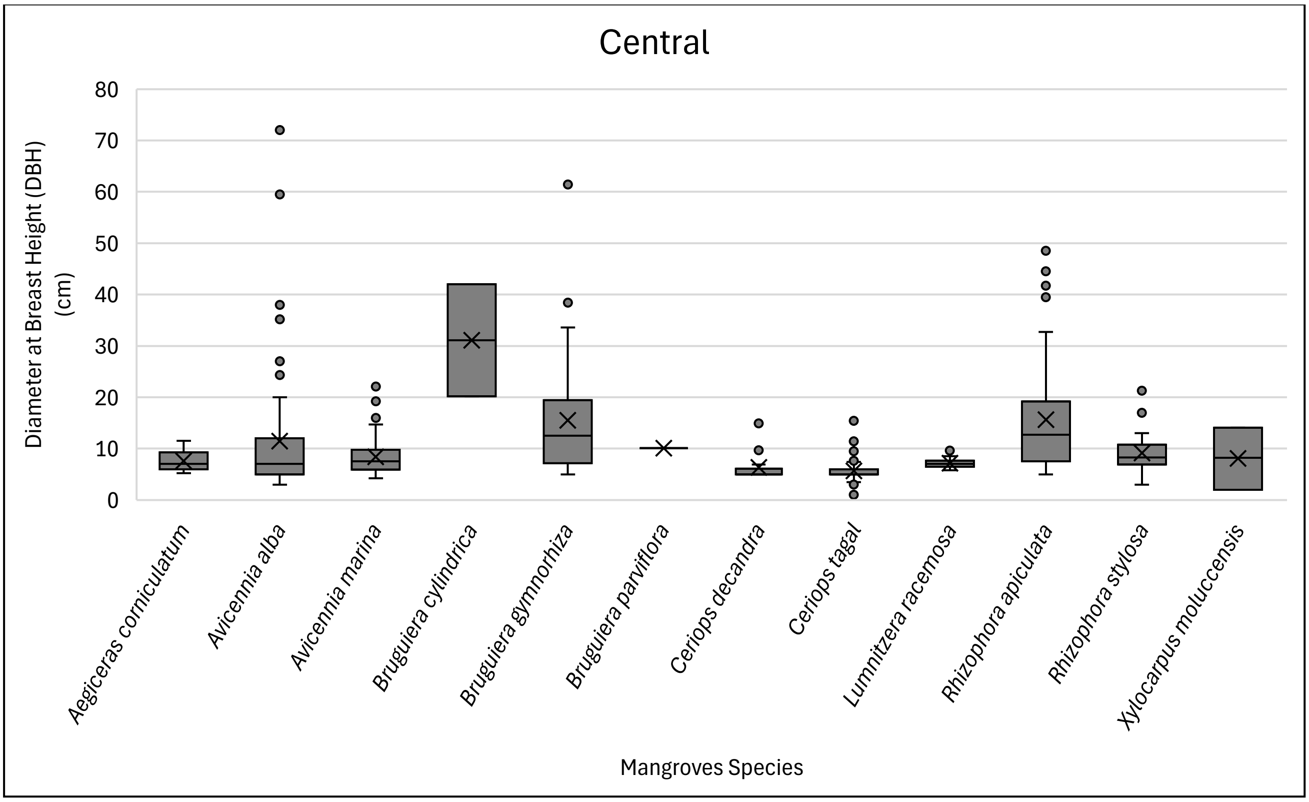

Figure 35. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Central. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were 6 sites assessed at Central.

At Milne Bay Province sites, *Sonneratia alba* had the largest DBH compared to the other species (DBH = 40 cm). This species was followed by *Bruguiera gymnorhiza* (DBH = 33 cm) and *Bruguiera sexangular* (DBH = 24 cm) (Figure 36). *Bruguiera gymnorhiza* had the largest range when compared to the other species (4.9 – 80 cm) (Figure 36). *Ceriops australis* had the least variability when compared to all other species. The remaining species had a DBH < 16 cm.

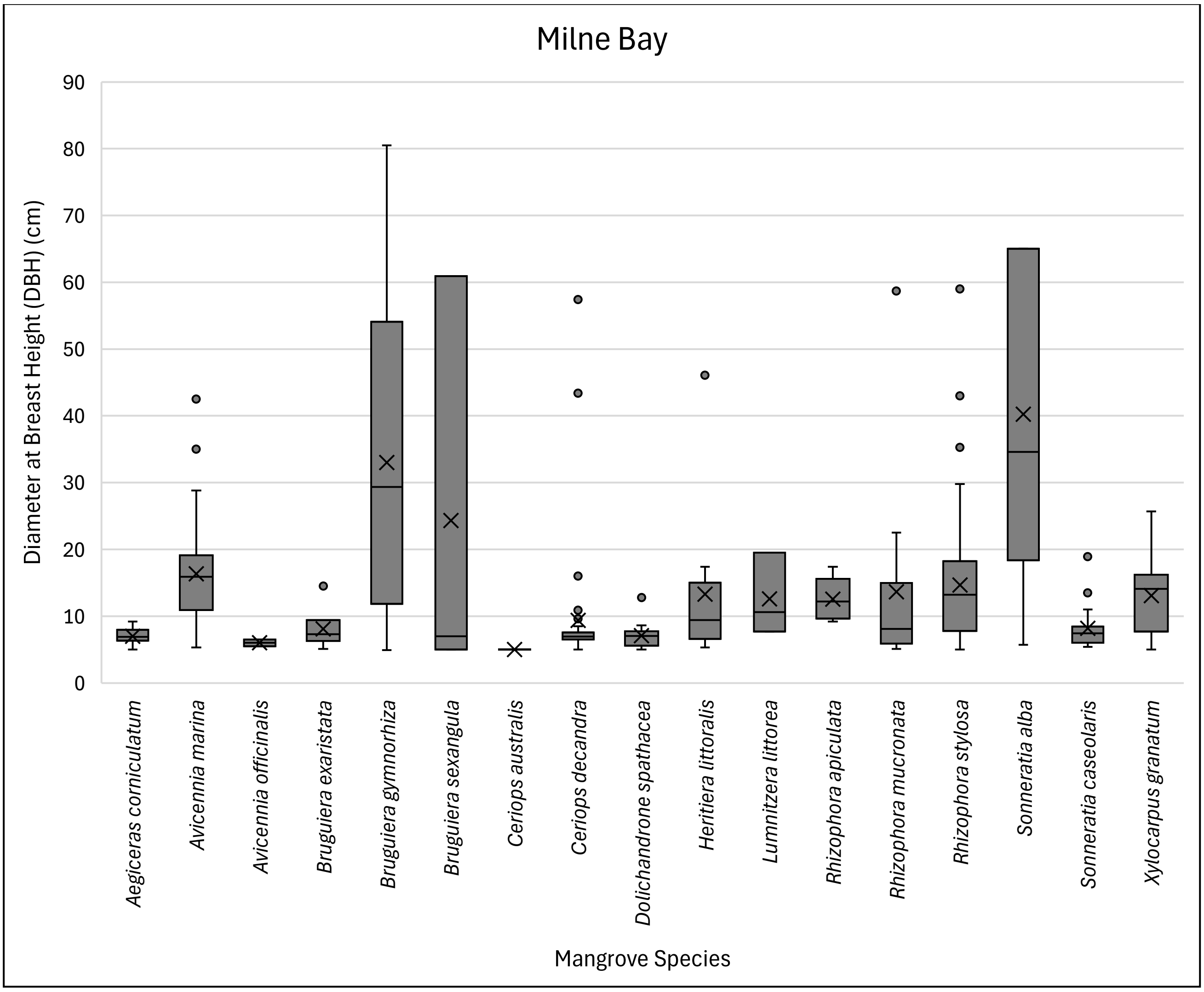

Figure 36. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Milne Bay. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were 4 sites assessed at Milne Bay.

At West New Britain Province sites, *Avicennia marina* had the largest average DBH of 50 cm, followed by *Bruguiera gymnorhiza* (DBH = 38 cm), *Xylocarpus granatum* (DBH = 26 cm), *Heritiera littoralis* (DBH = 26 cm) and *Rhizophora stylosa* (DBH = 20 cm) (Figure 37). *Bruguiera gymnorhiza* had a large variation, with DBH ranging from 5.3 to 80 cm.

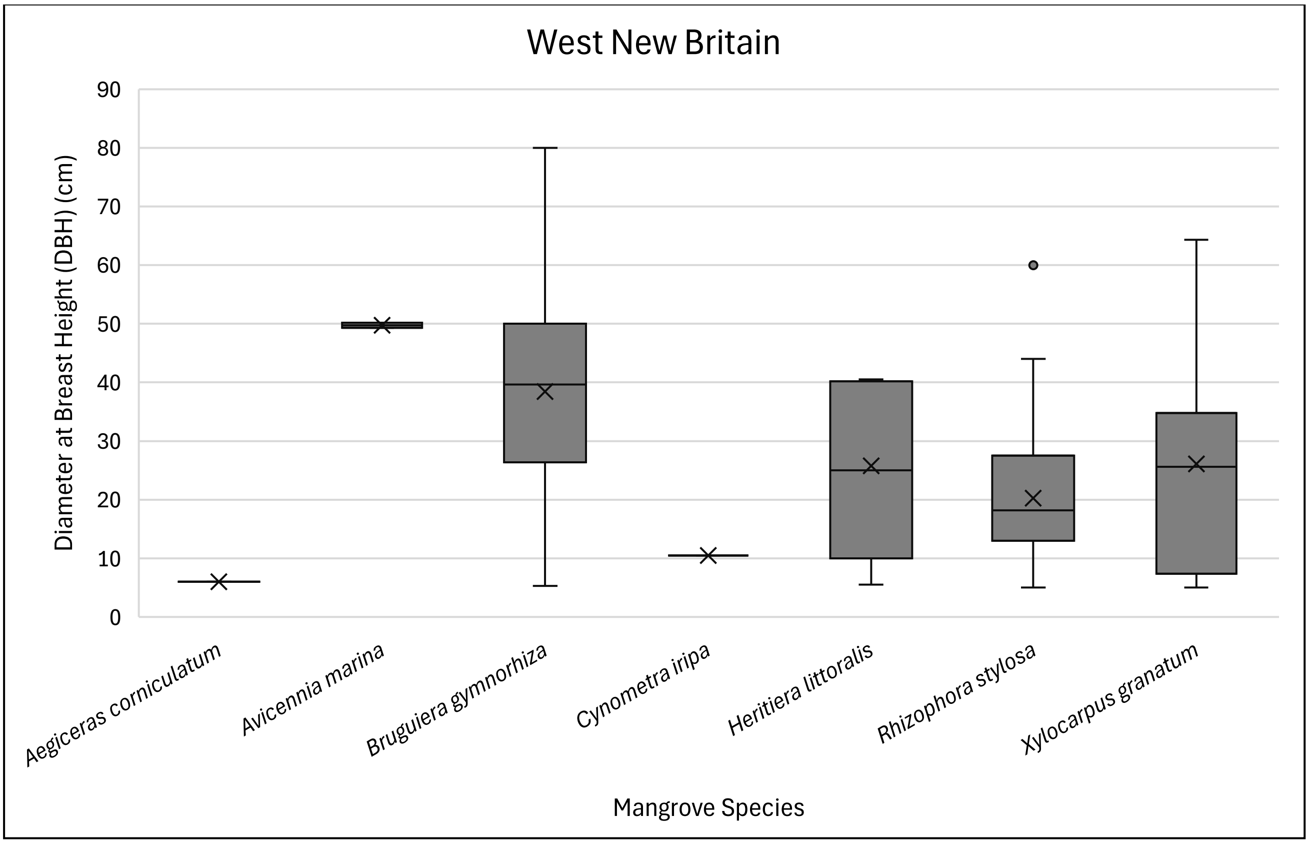

Figure 37. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at West New Britain. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were 4 sites assessed at West New Britain.

At New Ireland Province sites, *Rhizophora stylosa* had the largest average DBH of 27 cm, followed by *Bruguiera gymnorhiza* (DBH = 24 cm), *Heritiera littoralis* (DBH = 24 cm) and *Excoecaria agallocha* (DBH = 19 cm) (Figure 38). All other species have an average DBH around 12 cm. *Rhizophora stylosa* had several outliers, with the largest being 89 cm.

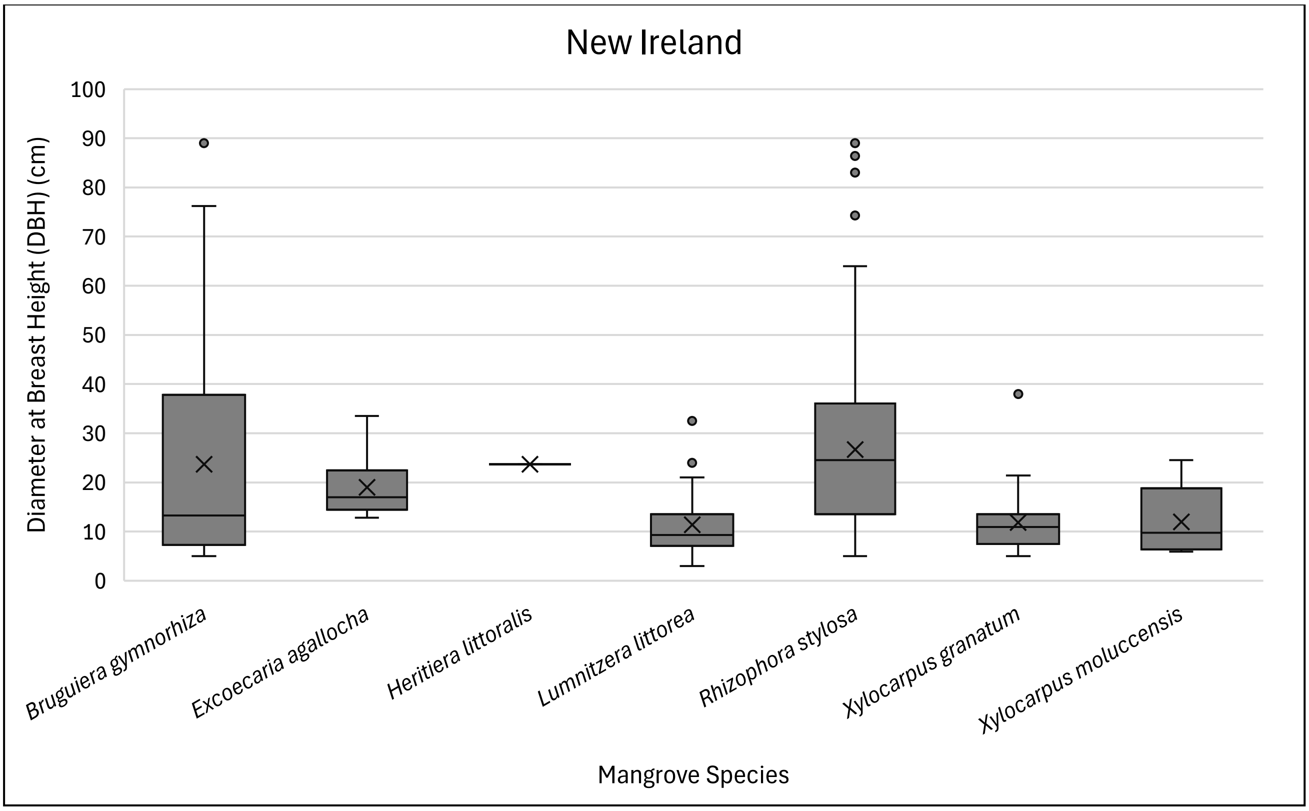

Figure 38. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at New Ireland. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were 5 sites assessed at New Ireland.

At Western, *Xylocarpus moluccensis* (DBH = 28 cm) and *Sonneratia alba* (DBH = 24 cm) had the largest average DBH, when compared to other species (Figure 39). A group of species all had an average DBH around 20 cm, including *Rhizophora apiculata* (DBH = 21 cm), *Avicennia marina var. eucalyptifolia* (DBH = 21 cm), *Avicennia marina* (DBH = 21 cm), *Excoecaria agallocha* (DBH = 20 cm), *Avicennia officinalis* (DBH = 20 cm) and *Xylocarpus granatum* (DBH = 20 cm) (Figure 39). All other species had a DBH < 20 cm. *Xylocarpus moluccensis* (10 – 58 cm) and *Avicennia marina* (5 – 51 cm) had the highest variability when compared to all other species. *Bruguiera gymnorhiza* had the largest outlier, with one tree measuring a maximum DBH of 77 cm.

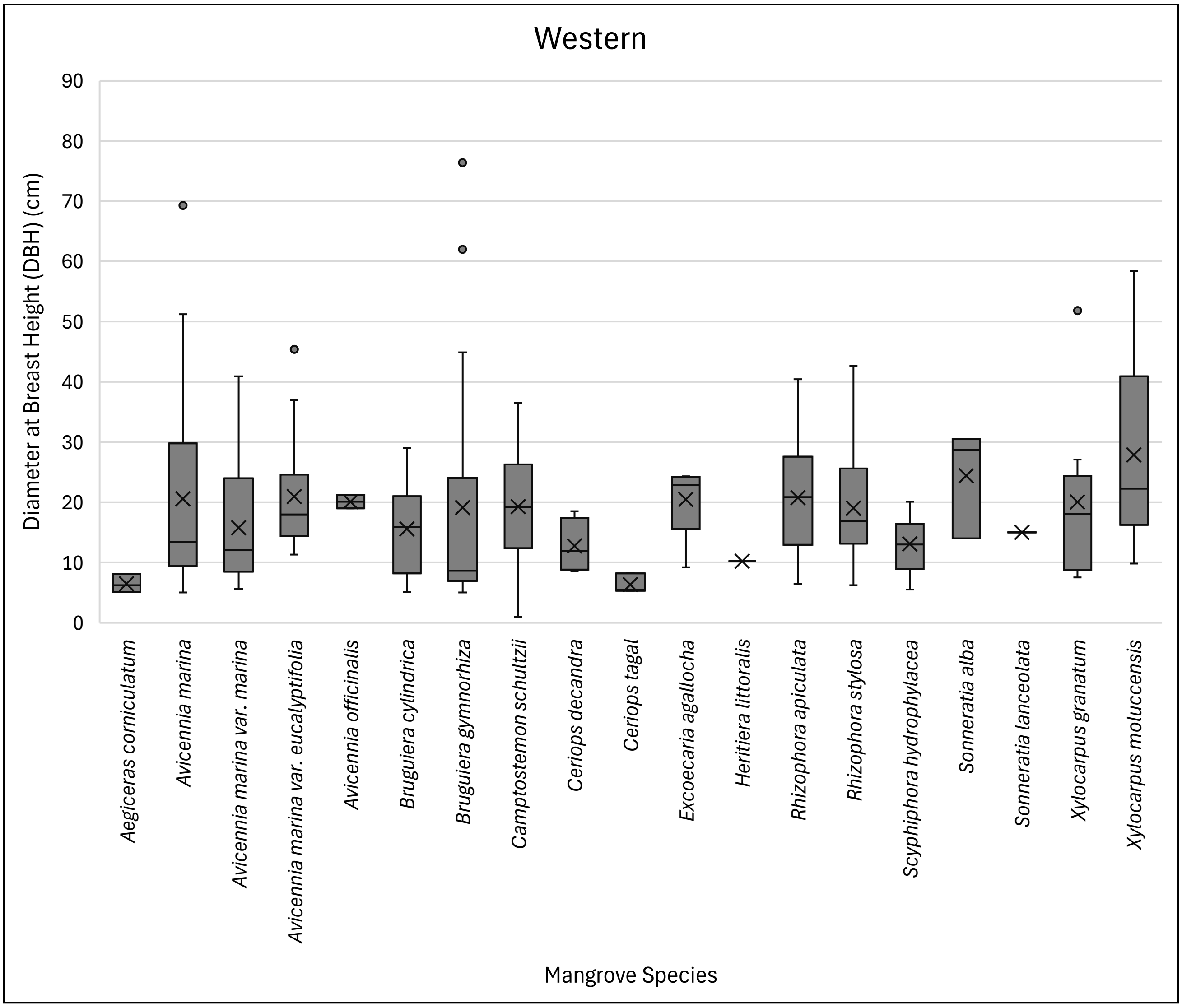

Figure 39. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Western. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. There were 5 sites assessed at Western.

Across the four locations, mangrove trees in West New Britain had the largest average DBH of 27 cm, followed by New Ireland (DBH = 23 cm), Western (DBH = 19 cm), Milne Bay (DBH = 15 cm) and Central (DBH = 9 cm). All sites had considerable variability, with some outliers reaching a maximum DBH of 89 cm (Figure 40). This reflects the complexity of intact mangrove ecosystems and outlines their variability due to multiple factors such as extreme weather conditions, anthropogenic influences, tidal inundation, and stratification in structural complexity.

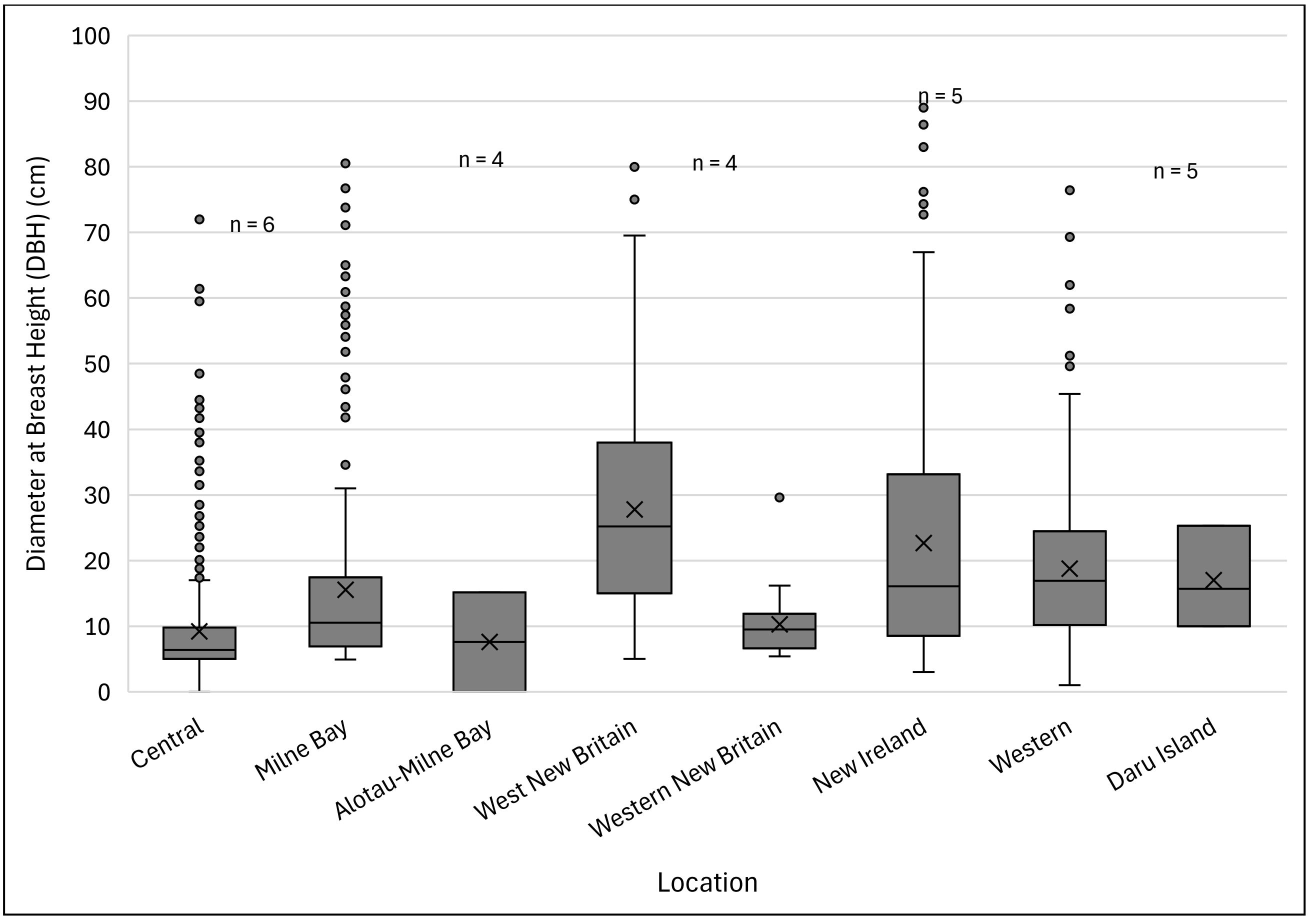

Figure 40. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) across the locations in PNG. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

When comparing all degraded and intact sites across PNG, the degraded sites showed a higher DBH when compared to intact sites. For example, the degraded sites in New Ireland had a DBH of 30 cm, while the intact site had a DBH of 21 cm. This same pattern was observed for New Ireland, Milne Bay and Western Province where both intact and degraded sites were assessed (Figure 41). Degraded mangrove sites often have a higher DBH compared to intact sites because only the hardiest, larger trees survive the adverse conditions. Reduced competition for resources like light and nutrients in these areas allows the remaining trees to grow larger. Additionally, older, more resilient trees tend to persist in degraded sites, contributing to the higher average DBH. Milne Bay followed a similar pattern whereby the degraded sites had a higher DBH, when compared to intact sites (Figure 41).

In contrast, in the mangrove ecosystems of PNG, intact sites typically exhibit much higher species diversity compared to degraded areas. This increased diversity often leads to smaller Diameter at Breast Height (DBH) measurements due to heightened competition for resources such as light, water, and nutrients among the various species. Additionally, the presence of a wider range of species can result in a more complex forest structure, where trees may allocate more energy to survival and reproduction rather than growth, further contributing to the smaller DBH observed in these intact mangrove sites.

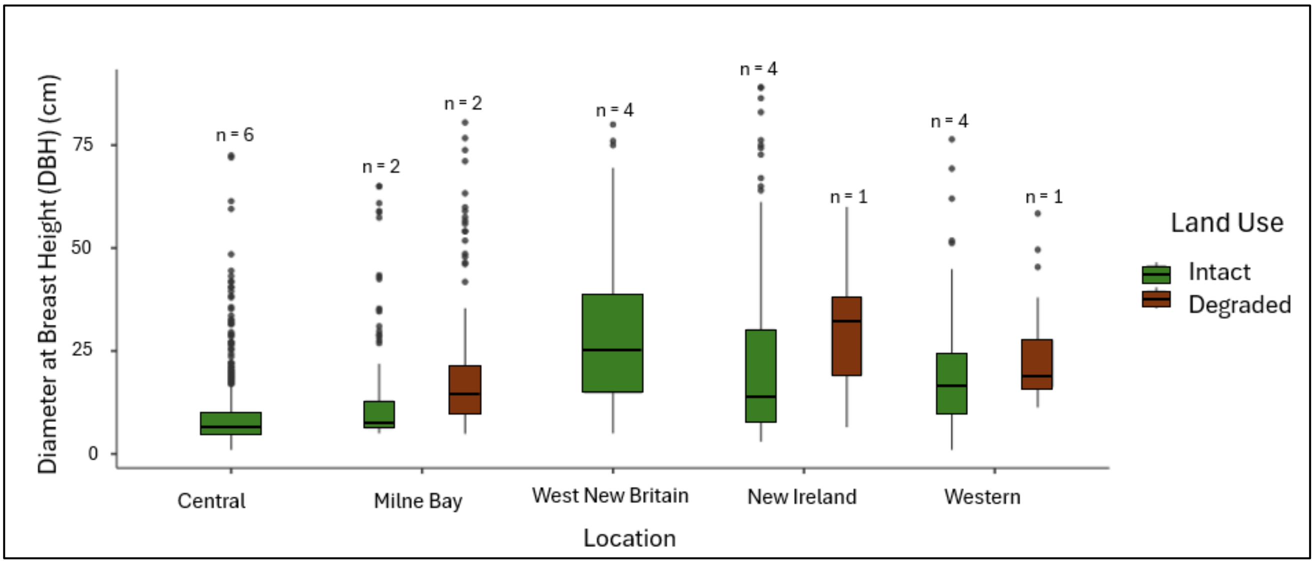

Figure 41. A box plot displaying Diameter at Breast Height (DBH) (cm) compared between land use type (degraded v. intact) and locations across PNG. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

West New Britain had the highest average mangrove canopy cover, with an average coverage of 50% (± 2 SE), followed by Western at 40% (± 7 SE) and Central at 38% (± 7 SE) (Figure 42). Milne Bay had the lowest average canopy cover when compared to the other locations (24% ± 7 SE). The low canopy cover at this location is primarily related to land use in this area whereby the forests are harvested for firewood, resulting in younger forests. It should be noted that mangrove canopy cover was collected as categorical data (ie. 0-10, 11-30, 31-50, 51-75, 76-95, 96-100). The mid-point from this range data were averaged across each site and averaged again for each location.

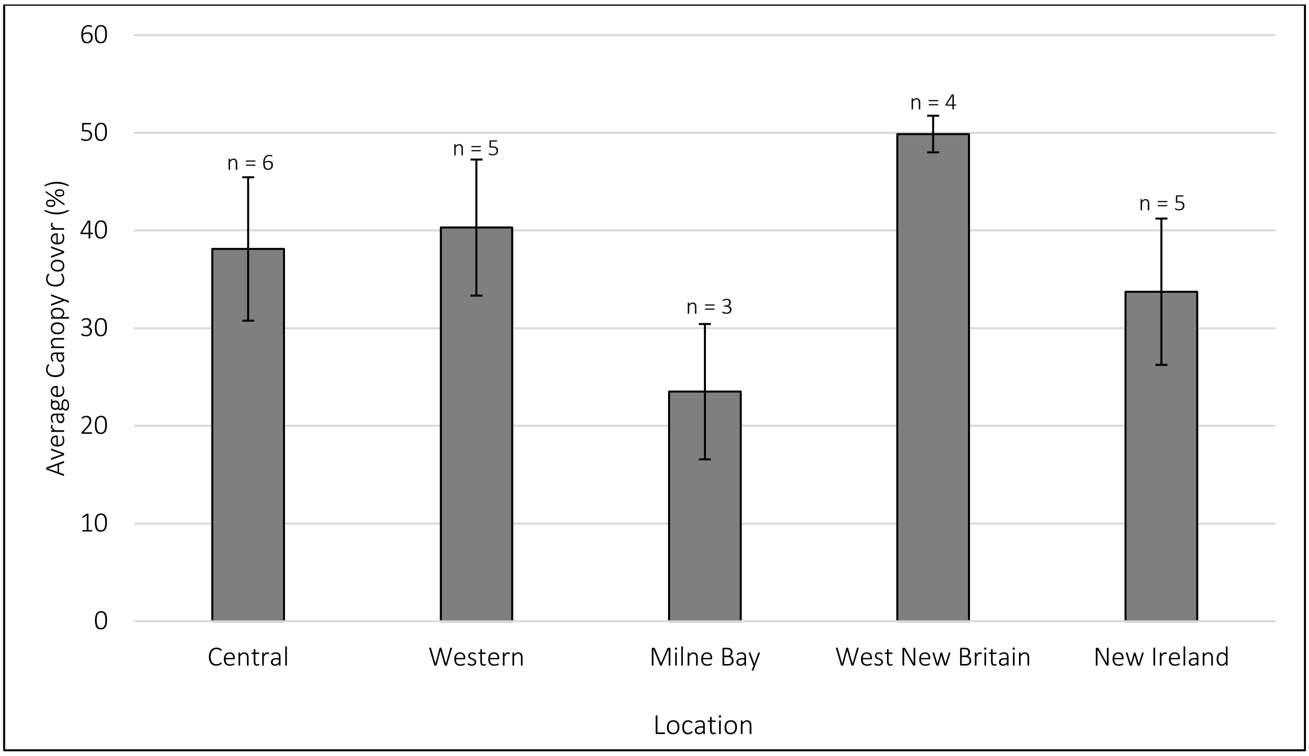

Figure 9. Average mangrove canopy cover (%) (± SE) across locations in PNG. Where n is the number of sites surveyed at each location.

Across all locations, intact sites had higher average mangrove canopy cover than degraded sites (Figure 43). Intact sites at West New Britain had the highest average canopy cover of 50% (± 2% SE), followed by Western (45%) (± 7% SE) and New Ireland (41%) (± 3% SE) (Figure 43). Milne Bay resulted with the lowest average canopy coverage for intact sites, with 28% (± 13% SE) canopy cover (Figure 43), however this was still higher than cover observed in the degraded sites. Average canopy cover at degraded sites in each location ranged between 5% - 22%, noting no degraded sites were sampled in Central and West New Britain (Figure 43).

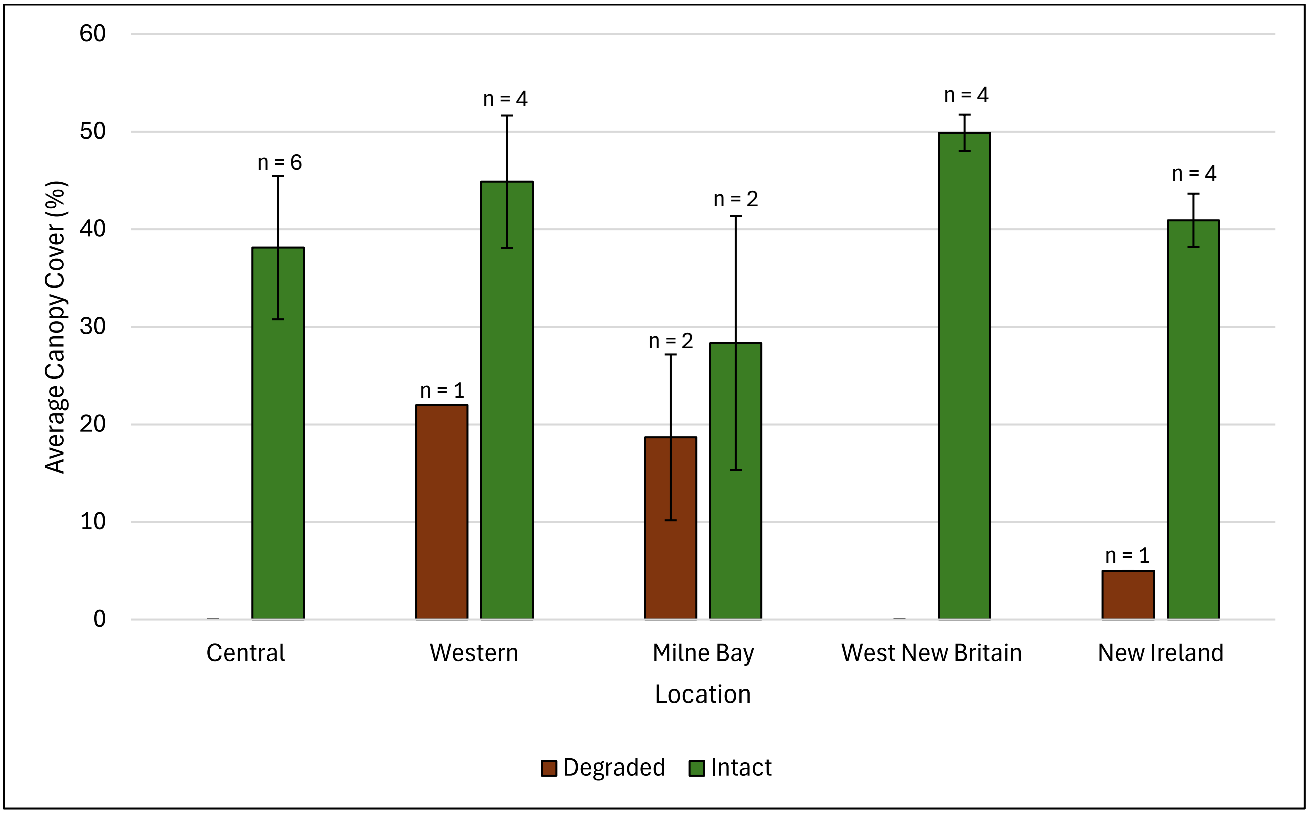

Figure 43. Average mangrove canopy cover (%) (± SE) across intact and degraded locations. Where n is the number of sites surveyed at each location.

Seedling abundance was collected at each site as an indicator of forest productivity and the capacity for a forest to recover from disturbance. If resilient, a disturbed forest may have high seedling abundances compared to an equivalent intact forest, due to increased sunlight to the forest floor. Seedling abundances was assessed at each site as one of three categories (0-10, 10-50 and >50 seedlings). The seedling density/m^2 for each site was calculated using the mid-point of the categories and standardised by the area of each plot.

Western had the highest seedling density when compared to the other locations, with 0.34 seedlings/m^2, with a maximum value of 0.67 seedlings/m^2 (Figure 44). This location was followed by Central (0.21 seedlings/m^2) and Milne Bay (0.16 seedlings/m^2). New Ireland and West New Britain had the lowest seedling abundance, with these locations reporting 0.13 and 0.11 seedlings/m^2 (Figure 44).

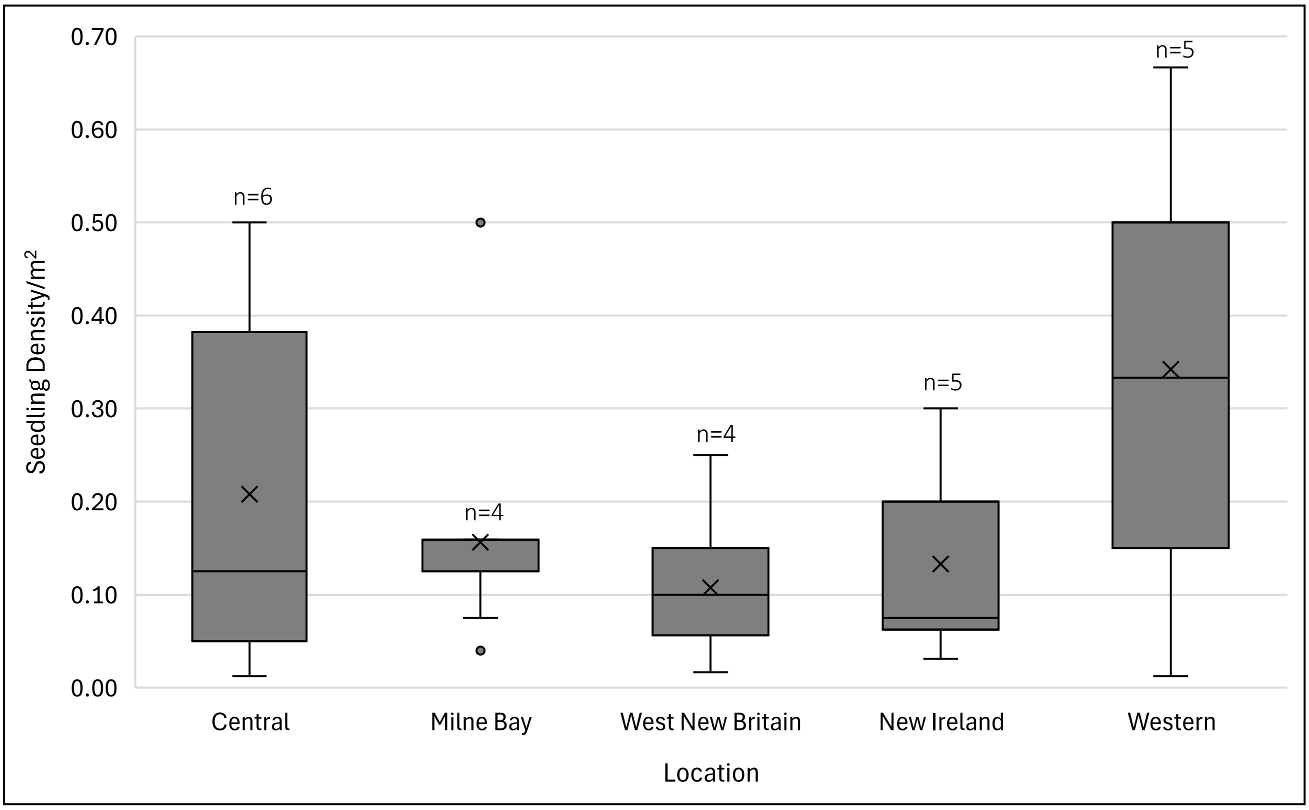

Figure 44. Seedling density/m2 at each location in Papua New Guinea. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers. N is the number of sites surveyed at each location.

Overall, intact sites had a higher seedling density when compared to degraded sites (Figure 45). Western had the highest seedling density across intact sites 0.41 seedlings/m^2 (Figure 45). This location was followed by Central (0.21 seedlings/m^2) and Milne Bay (0.20 seedlings/m^2). The intact sites at West New Britain and New Ireland had a similar seedling density of 0.11 and 0.15 seedlings/m^2 (Figure 45). Intact mangrove sites in PNG may have higher seedling abundance compared to degraded sites due to more stable environmental conditions, better protection from erosion, and lower seedling mortality rates. These factors create a more favourable environment for seedling survival and growth, despite degraded sites having more space and light availability.

At the degraded sites Milne Bay had the highest seedling density of 0.11 seedlings/m^2, followed by New Ireland and Western, which had a seedling density of 0.06 and 0.05 seedlings/m^2 (Figure 45). Degraded mangrove sites typically have a high seedling count due to increased space and light availability. However, these sites often exhibit unstable environmental conditions, such as fluctuating soil moisture and nutrient levels, which can hinder seedling establishment and growth. In addition, higher erosion rates and lack of a protective canopy can lead to increased seedling mortality, further contributing to the lower effective seedling density observed in degraded areas.

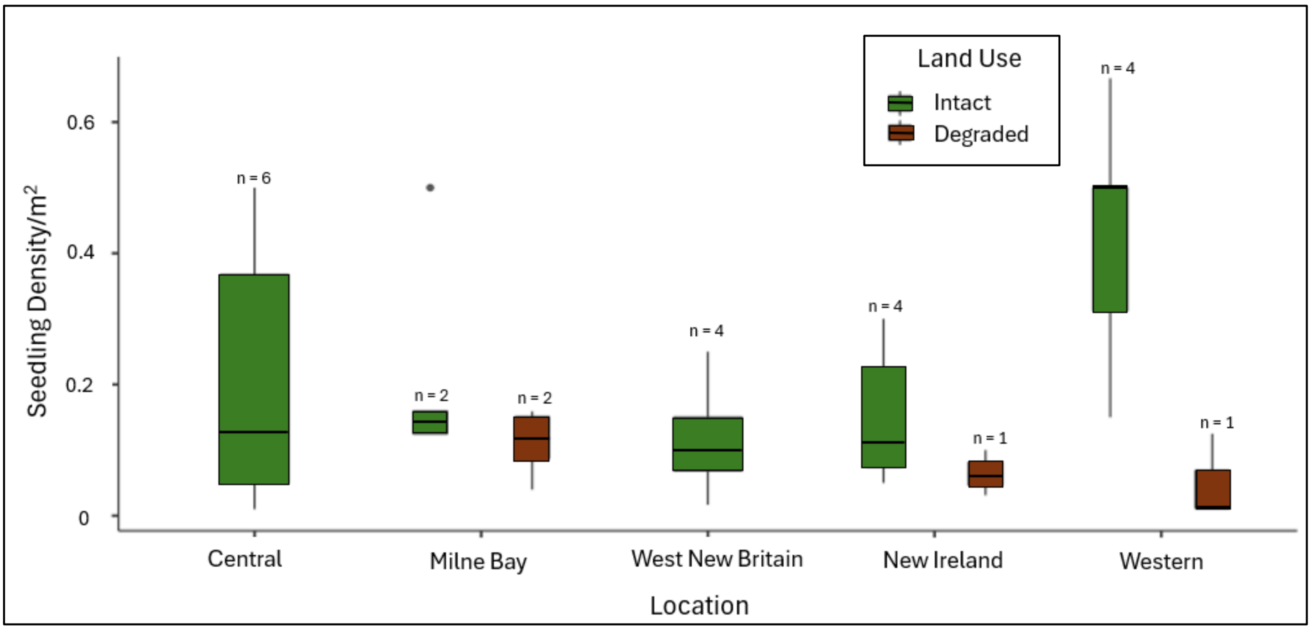

Figure 45. Seedling density/m^2 at each location in Papua New Guinea compared between intact, degraded and converted sites. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

4.5 Biodiversity results

The rapid biodiversity assessment completed at the SaM sites for PNG found a range of species present. The assessment was based on opportunistic observations while on-site and should not be considered comprehensive. The focus was on recording any evidence of IUCN-listed species observed at each site. Although no IUCN species were directly observed during the survey period in PNG, anecdotal observations by local communities outline that Dugongs and turtles are present within the sites that were assessed, specifically in West New Britain. A deceased juvenile dugong was observed in West New Britain close to an assessment site, confirming their presence.

Incidental observations of fauna biodiversity were made in each of the SaM sites assessed. A range of fauna species were recorded as per Table 17 and Figure 46.

Table 17. Species recorded in the seagrass meadows and mangrove forests assessed in PNG.

Habitat	Organism type	Species	Common name
Seagrass	Bivalve	Family name: Pteriidae	Pearl oyster
		Tridacna gigas	Giant Clam
		Pedum spondyloideum	Coral Scallop
	Birds	Family name: Pandionidae	Osprey
		Family name: Scolopacidae	Whimbrel
		Butorides striata	Striated Heron
		Thalasseus bergii	Crested Tern
		Ducula bicolor	Pied Imperial Pigeon
		Family name: Hirundinidae	Swallows
		Sternidae sp.	Tern
	Crustacean	*Galathea squamifera*	Squat Lobster
		Family: Paguridae	Hermit Crab
	Echinoderm	*Culcita novaeguineae*	Pin Cushion Stafish
		Family: Holothuriidae	Sea Cucumber
		Family: Asteroidea	Starfish
		Family: Diadematidae	Diadema Urchin
		Family: Ophidiasteridae	Linckia Starfish
		Toxopneustes pileolus	Flower Urchin
		Diadema savignyi	Savigny Sea Urchin
		Holothuria scabra	Sandfish
		Protoreaster nodosus	Nodose Sea Star
		Nardoa novaecaledonia	Yellow Mesh Sea Star
		Holothuria fuscinaraea	Labuyo Fish
		Family name: Echinarachniidae	Sand dollars
	Gastropod	Family name: Cypraeidae	Cowrie (multiple species)
		Family: Strombidae	Multiple snail species
		Lambis scorpius	Scorpion Spider Snail
	Fish	*Mugil cephalus*	Mullet
		Family name: Chaetodontidae	Butterfly Fish
		Gerres oyena	Silver Biddys
		Nematalosa erebi	Bony Bream
		Family name: Acanthuridae	Surgeonfish
		Amphiprion ocellaris	Ocellaris Clownfish
		Paracanthurus hepatus	Blue Tang
		Chrysiptera cyanea	Blue Damsel Fish
		Family name: Siganidae	Rabbit Fish
		Family name: Balistidae	Trigger Fish
		Seriola lalandi	Yellow Tail
		Trachinotus botla	Dart Fish
		Sardina pilchardus	Sardines
		Family name: Gobiidae	Goby
		Myliobatoidei spp.	Stingray
	Reptile	*Laticauda colubrina*	Sea Snake
		Family: Crocodylidae	Crocodile

Habitat	Organism type	Species	Common name
	Algae	*Halimeda opuntia*	Watercress Algae
		Valonia ventricosa	Sailor's Eyeballs/Bubble Algae
		Turbinaria decurrens	Triangular Sea Bell
		Halimeda *spp.*	
Mangrove	Birds	*Charmosyna papou*	Lorikeet
		Family: Nectariniidae	Sunbird
		Family: Ardeidae	Heron
		Acridotheres fuscus	Jungle Myna
		Family: Columbidae	Pigeon spp.
		Family: Sturnidae	Starling
		Cuculus phasianus	Pheasant Coucal
		Pseudeos cardinalis	Cardinal Lory
		Moluccan eclectus	Eclectus Parrot
		Family: Charadriidae	Plover
		Haliastur indus	Brahminy Kite
		Alcedo atthis	Common Kingfisher
		Corvus sp.	Crow
		Dacelo leachii	Blue-winged Kookaburra
		Family name: Muscicapidae	Flycatcher
		Family name: Phalacrocoracidae	Cormorant
		Family name: Campephagidae	Cuckooshrike
		Family name: Motacillidae	Wagtail
	Fish	Family: Oxudercidae	Mudskipper
		Paracanthurus hepatus	Blue tang
		Amphiprion ocellaris	Ocellaris Clownfish
	Bivalve	Family: Bivalvia	Clam
	Crustacean	*Scylla serrata*	Black mangrove crab
		Family: Nephropidae	Lobster
		Family: Paguridae	Hermit crabs
		Family: Ocypodidae	Fiddler crabs
	Gastropod	Family: Strombidae	Multiple snail species
		Family name: Buccinidae	Whelks
		Family name: Neritidae	Nerite
	Reptile	Family: Crocodylidae	Crocodile
		Family: Scincidae	*Emoia* sp.

Figure 46. Observed fauna across PNG. A range of gastropods, crustaceans, bivalves, birds, fish and echinoderm were recorded across the four locations. From the top left the fauna are a starfish, fiddler crab, hermit crab, sand dollar, (juvenile) trigger fish, shorebirds and land hermit crab. Photo source: T. Reimann and E. Saeck.

The abundance of crab holes was recorded at each of the sites as a simple indicator of the interaction between the benthic biodiversity of the forest and ecosystem functioning. Through burrowing and feeding activities, mangrove crabs contribute to recycling of organic matter, changes in surface topography, nutrient cycling and removal, oxygenation of mangrove sediments and the success of mangrove propagules[110]. Degraded mangrove forests typically have lower abundances of mangrove crabs which results in poor ecosystem functioning.

Across all locations, a wide range of crab hole sizes was observed, with four out of five of the location harbouring five different crab hole sizes (Figure 47). The sites in West New Britain Province exhibited the highest abundance of 0-5 mm and 5-10 mm crab hole size, while Central Province sites had the highest abundance of 10-20 mm and 20-50 mm crab hole size (Figure 47). In contrast, Milne Bay Province had the highest abundance of large holes larger than 50mm. Overall Western Province exhibited the lowest abundance of crab hole sizes (Figure 47), however the abundances and size distributions of crab holes at the New Ireland and Western sites was difficult to record during the assessments owing to the predominance of high tides over the period of sampling.

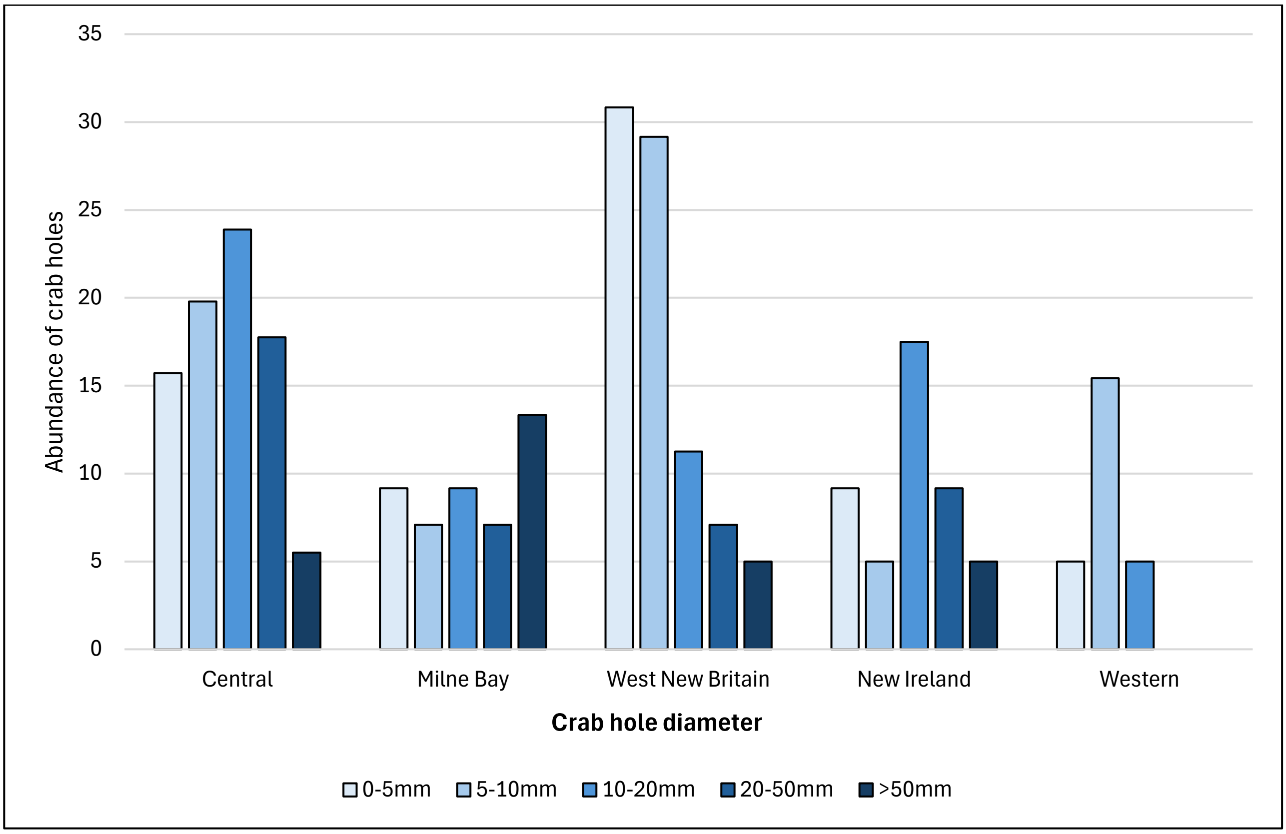

Figure 47. Average abundance of crab holes at each of the four locations sampled in PNG, across five crab hole size categories (0-5mm, 5-10mm, 10-20mm, 20-50mm, >50mm). Note that for some sites in New Ireland and Western, there was missing data due to tidal inundation preventing crab hole observations during surveys.

[110] Lee SY (1998) "Ecological role of grapsid crabs in mangrove ecosystems: a review," *Marine and Freshwater Research*, 49(4):335.

4.6 Summary

The SaM ecosystems of PNG provide essential services like biodiversity enhancement, coastal protection, carbon sequestration, food production, as well as sources of firewood and construction materials. The results of this rapid assessment found that, despite the presence of significant catchment scale threats at each location, the SaM systems across PNG maintain significant biodiversity, remain resilient and continue to support essential ecosystem functions, likely sustaining high levels of services.

Key findings:

Seagrass Ecosystems

- PNG is host to eleven (11) recorded species of seagrass and this study observed seven (7) of those eleven. Four seagrass species were consistently observed at all locations, these were: *Enhalus acoroides, Cymodoceae rotundata, Halodule pinifolia/ Halodule uninervis* and *Halophila ovalis*. *Enhalus acoroides* was the most commonly recorded species in the assessment, found at 80% of the sites. However, seagrass meadows across all locations were more typically mixed species meadows with 4-6 species present. Seagrass meadows were typically located on the lee side of reefs, often adjacent to mangroves on the mainland or islands.
- West New Britain and New Ireland Provinces exhibited the highest average seagrass cover (~65%), whereas seagrass cover in Central Province was lowest (37%).
- The rapid biodiversity assessment found a very large range of species that inhabit seagrass communities, including anecdotal evidence of IUCN-listed Dugong reported in West New Britain and Central Province.

Mangrove Ecosystems

- Based on past studies PNG is estimated to have approximately 592,900 ha of mangrove forests, with 47 species recorded, which is a significantly larger area and higher diversity compared to other countries. A total of 29 of the 47 mangrove species known to inhabit PNG were recorded in this study. Western Province and Milne Bay Province study sites had the most diverse mangroves forests in the study.
- Larger trees in forests contribute a disproportionate level of reproductive components, habitat for other species[111], and therefore significantly contribute to the resilience and biodiversity of mangrove forests. The largest trees recorded in this study were typically found at the West New Britain and New Ireland Province sites. Western and Central Province sites had relatively fewer large trees.
- The range in tree Diameter at Breast Height (DBH) reflects varying levels of environmental threats and biodiversity value. When compared to undisturbed (intact) mangrove sites, disturbed (degraded) mangrove sites can often have a higher DBH because only the hardiest, larger trees survive the adverse conditions. This pattern was noted in Milne Bay, New Ireland and Western Provinces where degraded sites were found to have higher average DBH than intact sites in the same location. Suggesting that despite the threats present, these sites retain large trees which contribute to longer term resilience, biodiversity and also carbon storage.
- Seedlings densities were highest on average in Central and Western Province sites. This likely reflects the relatively fewer larger trees at the sites in these locations, resulting in more space and sunlight available to support seedling growth. This would suggest that the mangrove forests in these locations maintain their productivity and retain the capacity to recover from disturbances.

[111] D.B. Lindenmayer, W.F. Laurance, J.F. Franklin. (2012). Global decline in large old trees. Science, 338 (6112), pp. 1305-1306

- All locations had similar benthic diversity and abundance, with the exception of higher abundances of crab holes in Central and West New Britain. As such, the benthic biodiversity of the mangrove forest and ecosystem functioning appeared relatively similar between locations
- Overall, this study found that the mangrove forests at each study location had evidence of impacts due to natural and anthropogenic pressures. Each location varied in their response to these pressures, however at all locations there were indications that the forests remained productive, supporting high biodiversity and maintaining an ability to recover from existing and future disturbances.

Threat Assessment

- The threat assessments indicated that all locations were relatively equally impacted by both human activities and natural events.
- Threats to the blue carbon ecosystems within each of the study locations were found to include coastal and catchment clearing for oil palm plantations and other agriculture, wood harvesting, sediment runoff, extreme weather events, boat activity and intensive fishing. Historical chemical (herbicide) spill at a site in New Ireland Province.

SOLOMON ISLANDS

5 Seagrass and mangroves of the Solomon Islands

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5.1 Seagrass past studies

The most extensive survey conducted on seagrass in the nation remains the *Solomon Islands Marine Assessment* (McKenzie et al. 2006[112]), which spanned 6,633 hectares of seagrass across 1,428 sites and seven provinces. Seagrass meadows in the Solomon Islands are extensive throughout Malaita Province, Choiseul and Isabel Provinces. Surveys recorded 3607.62 hectares of seagrass in the Malaita Province, with 99% of meadows demonstrating continuous cover. Other prominent seagrass meadows were found in Roviana Lagoon and Marovo Lagoon in the Western Province, as well as Komimbo in north-western Guadalcanal. Seagrasses were typically situated within sheltered bays and lagoons, as well as on the leeward side of islands, and often found on intertidal reef/mud flats, adjacent to mangroves and reefs. They are also typically only found at depths up to 10 m.

There are nine recorded species of seagrass, belonging to the Cymodoceaceae and Hydrocharitaceae families, in the Solomon Islands (Table 18). McKenzie et al. (2006) also found *Thalassia hemprichii* nearshore in 42% of the 6,633 hectares surveyed, while *Enhalus acoroides* typically occurred in monospecific meadows further offshore. However, seagrass meadows with the greatest coverage were dominated by *Cymodea* spp. However, subsequent molecular studies have shown that *Halophila minor* is conspecific with *H. ovalis*[113]. Additionally, there is contradictory evidence to support that *Halodule uninervis* and *H. pinifolia* are distinct species, due to being indistinguishable using molecular markers and morphological differences possibly being caused by environmental factors[114]. This reduces the confirmed number of seagrass species in the Solomon Islands from eleven to nine (the complete list can be viewed in Seagrass results Table 18).

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112 McKenzie, L., Campbell, S. and Lasi, F. 2006. Seagrass and Mangroves. In: Green, A., Lokani, W., Atu, W., Ramohia, P., Thomas, P. and Almany, J. (eds.) 2006. Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No 1/06.
113 McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. Marine pollution bulletin, 160, 111636.
114 Wagey, B. T., & Calumpong, H. P. (2013). Genetic analysis of the seagrass Halodule in Central Visayas, Philippines. Asian Journal of Biodiversity, 4(1), 241-257.

In 2020, the Allen Coral Atlas program[115] also released benthic and geomorphic maps of the region, utilising high-resolution satellite imagery from PlanetScope, which include mapped seagrass distributions.

Other efforts include the Dugong and Seagrass Conservation Project[116], commencing in 2016, where many aspects included monitoring, mapping, and conserving selected seagrass meadows. This included key seagrass fisheries habitats in Lau Lagoon (Malaita Province), as well as important dugong and seagrass habitat in Vonavona Lagoon (Western Province). In collaboration with WorldFish Centre, the Dugong and Seagrass Conservation Project also hosted capacity-building workshops with local communities in North Malaita and Lau Lagoon to educate the communities about seagrass ecosystems and to share Seagrass Watch survey and mapping techniques.

Current threats to seagrasses in the Solomon Islands include sediment run-off due to logging, agriculture, mining, and development, which negatively impact water quality (McKenzie et al. 2006). Destructive fishing practices are also noted as damaging seagrass meadows in the region (Brodie and N'Yeurt 2018[117]; WorldFish 2018[118]). Furthermore, with rising global temperatures, sea-level rise may become an increasing threat to seagrasses globally (Brodie and N'Yeurt 2018).

5.2 Mangrove past studies

The mangrove forests of Solomon Islands span an estimated 52,651 hectares (Bunting et al. 2022[119]), representing approximately 2% of the total land area. The Malaita Province, located east of the Indispensable Strait, is renowned for its extensive, dense, and highly biodiverse mangrove forests, particularly in Lau Lagoon in the northeast, Langalanga Lagoon on the western coastline, and Maramasike in the southeast. Other important mangrove forests are located in Western Province (Marovo Lagoon), Guadalcanal Province (Marau Sound), Isabel Province (northwest islands), as well as Choiseul Province (southeast) (Figure 48) (Albert and Schwarz 2013[120]).

Mangrove forests in the Solomon Islands are home to 33 recorded mangrove species. These include species from the genera *Acanthus, Aegiceras, Avicennia, Brugeria, Ceriops, Cymnometra, Exoecaria, Heriteria, Lumnitzera, Nypa, Osbornia, Scyphiphora, Sonneratia,* and *Xylocarpus.* The most common species found in these regions are *Rhizophora stylosa, R. apiculata,* and *Bruguiera gymnorhiza* (Table 20).

The earliest large-scale mangrove mapping study was conducted by Hansell and Wall (1976[121]), where they mapped 64,200 ha of mangroves using aerial photography as part of mapping land resources of Solomon Islands. Subsequently, Green et al. (2006[122]) published the Solomon Islands Marine Assessment, surveying 1,426 sites to identify coastal fringing mangrove species and assessing their habitat quality and threats. In 2011, another study was conducted using Landsat satellite imagery to assess the coverage of mangrove forests in the Pacific (Bhattarai and Chandra 2011[123]).

[115] Allen Coral Atlas (2022). Imagery, maps and monitoring of the world's tropical coral reefs. doi.org/10.5281/zenodo.3833242
[116] The Dugong and Seagrass Conservation Project, Mapping critical seagrass fisheries habitats in Lau Lagoon, Solomon Islands (SB3). Solomon Islands: Lau Lagoon. https://www.dugongconservation.org/project/mapping-critical-seagrass-fisheries-habitats-lau-lagoon-solomon-islands-sb3-solomon-islands-lau-lagoon/
[117] Brodie, G. and N'Yeurt, A.D.R. 2018. Effects of Climate Change on Seagrasses and Seagrass Habitats Relevant to the Pacific Islands. PACIFIC MARINE CLIMATE CHANGE REPORT CARD Science Review 2018: pp 112-131
[118] WorldFish. 2018. Conservation strategy for dugongs and seagrass habitats in Solomon Islands. Penang, Malaysia: WorldFish. Strategy: 2018-22.
[119] Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T. A., Spalding, M., Murray, N. J., & Rebelo, L.-M. (2022). Global mangrove extent change 1996–2020: Global Mangrove Watch Version 3.0. Remote Sensing, 14(15), 3657.
[120] Albert, J.A. and Schwarz, A.J. (2013) Mangrove management in Solomon Islands: Case studies from Malaita Province. CGIAR Research Program on Aquatic Agricultural Systems. Penang, Malaysia. Policy Brief: AAS-2013-14.
[121] Hansell, J.R.F. and Wall J.R.D. (1976). Land resources of the Solomon Islands. Published by Surbiton, Surrey : Land Resources Division, Ministry of Overseas Development. Great Britain. Land Resources Division.
[122] Green, A., P. Lokani, W. Atu, P. Ramohia, P. Thomas and J. Almany (eds.) (2006). Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No. 1/06.
[123] Bhattarai, B. and Chandra, P.G. (2011). Assessment of mangrove forests in the Pacific region using Landsat imagery. Journal of Applied Remote Sensing, Vol. 5, Issue 1, 053509 (January 2011). https://doi.org/10.1117/1.3563584

Subsequent studies, research programs, and initiatives in the Solomon Islands have been geographically limited, with most efforts being focused on the Malaita Province. The Mangrove Ecosystems for Climate Change Adaptations and Livelihoods (MESCAL) project, coordinated by the IUCN Oceania Regional Office in collaboration with the SPREP, commenced in 2009 (MESCAL 2012[124]). They filmed 9.5 km of fringing mangroves and identified 24 mangrove species along the Teile and We'a Rivers. Rapid fauna sampling caught 45 identifiable species (which made up 28% of the total catch of 173 individuals) and most finfish caught were juveniles, indicating an important fish nursery. Their report established a baseline for the biodiversity and overall health of the ecosystem.

In October 2012, MangroveWatch conducted a second study for the MESCAL Project in Maramasike Passage, using video surveys of fringing mangroves to evaluate ecosystem health (Mackenzie et al. 2013[125]). Overall, mangroves in this region were reported to be in very good or good condition (90% of the shoreline), with minimal dieback and dense to full leaf cover, and an average canopy height of approximately 17.5 m. Furthermore, 24% of the fringing mangrove shoreline had saplings present, indicating growth and expansion, while 8% showed signs of anthropogenic disturbance (cutting or clearing).

Mangroves in the Solomon Islands experience ongoing pressures due to high demand for timber for firewood and construction (FAO 2005[126]) and is exacerbated by population growth, and climate change impacts like sea-level rise (Albert and Schwarz 2013[127]). Mangroves are key to supporting a variety of seafood for communities, which is their primary source of dietary protein. Projects that support community engagement and livelihoods, establish long-term monitoring, and strategic mangrove planting and rehabilitation, such as the Solomon Ports Mangrove Restoration and Livelihood Project[128], are key to helping secure mangrove conservation and sustainable livelihoods for local communities.

This MACBLUE study seeks to build on the existing knowledge and then extend the assessment to other locations. Being able to compare multiple locations across the Solomon Islands will enhance understanding of the unique characteristics and vulnerabilities of these ecosystems. This broad spatial coverage facilitates comparative analyses, helping to identify patterns and trends that may not be apparent in smaller-scale studies. This study focused on some of these known key areas of mangrove in the Solomon Islands, specifically Malaita Island, Marovo Lagoon and North West Isabel province.

[124] MESCAL (2012). Biodiversity Assessment Report Maramasike Passage, Malaita Province, Solomon Islands. Mangrove Ecosystems for Climate Change Adaptation & Livelihoods (MESCAL), IUCN, Solomon Islands Government, Federal Ministry for the environment, Nature Conservation and Nuclear Safety.
[125] Mackenzie, J, NC Duke & A. Wood (2013), 'MangroveWatch assessment of shoreline Mangroves in the Solomon Islands', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 13/52, James Cook University, Townsville, 31 pp.
[126] FAO 2005. GLOBAL FOREST RESOURCES ASSESSMENT 2005, THEMATIC STUDY ON MANGROVES, SOLOMON ISLANDS, COUNTRY PROFILE. Food and Agriculture Organization of the United Nations. Rome, Italy.
[127] Albert, J.A. and Schwarz, A.J. (2013) Mangrove management in Solomon Islands: Case studies from Malaita Province. CGIAR Research Program on Aquatic Agricultural Systems. Penang, Malaysia. Policy Brief: AAS-2013-14.
[128] World Ports Sustainability Program, 2024, Solomon Ports – Mangrove Restoration and Livelihood Project. https://sustainableworldports.org/project/solomon-ports-mangrove-restoration-and-livelihood-project/

5.3 Solomon Island study sites

Seagrass meadows and mangrove forests were surveyed across four provinces in the Solomon Islands, which included Isabel, Western, Malaita and Guadalcanal Provinces. The survey locations for both mangroves and seagrass are shown below in (Figure 48), including Marovo (Western Province), Lau Lagoon (Malaita Province), Honiara (Guadalcanal Province), and Santa Isabel and Papatura Islands (Isabel Province). A total of 21 mangrove sites and eleven (11) seagrass sites were surveyed across a diversity of geomorphological settings to capture representative data for these dynamic ecosystems (Figure 48 to Figure 52).

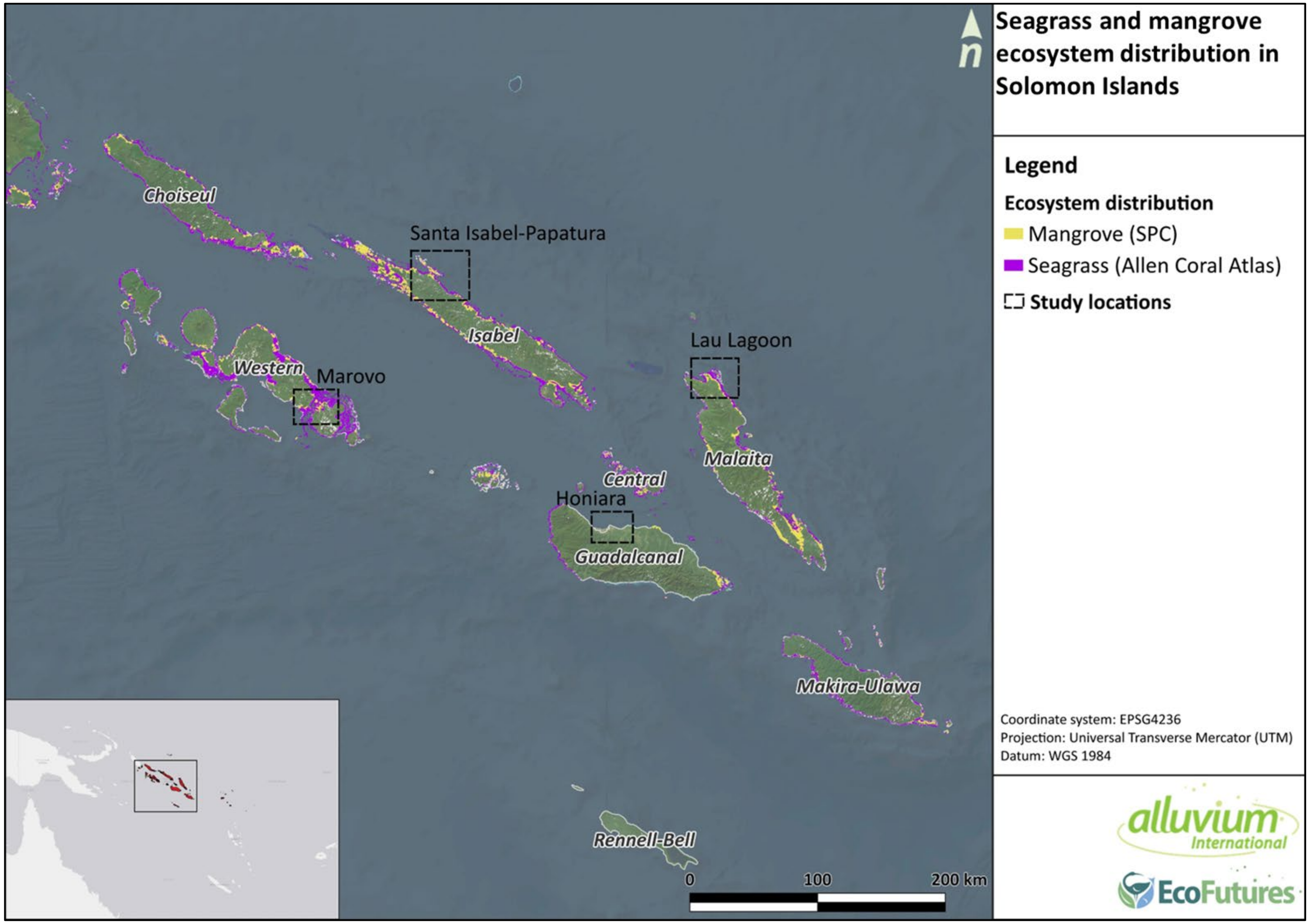

Figure 48. Seagrass and mangrove ecosystem distribution and survey sites in the Solomon Islands.

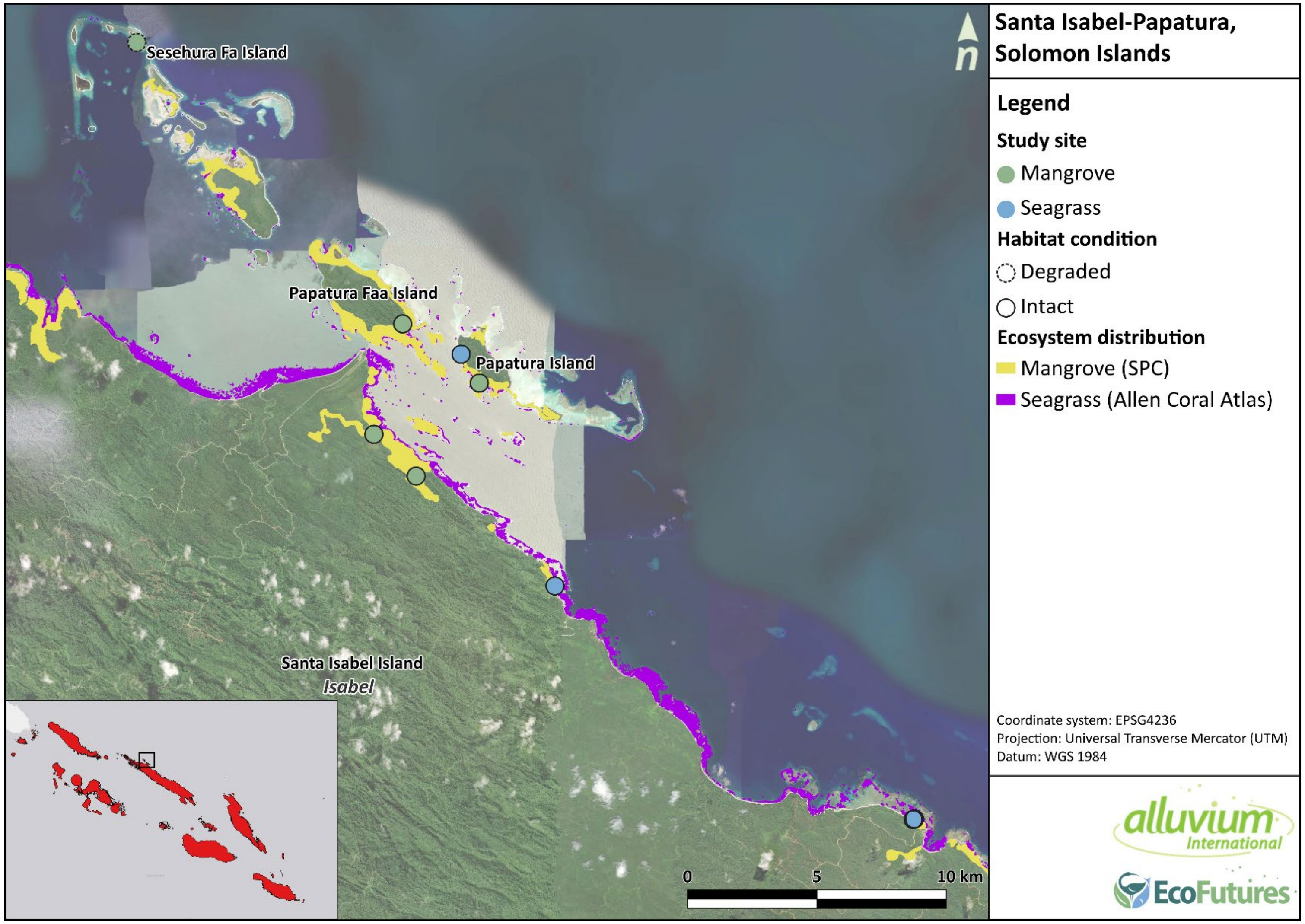

Figure 49. Seagrass and mangrove ecosystem distribution and survey sites at Santa Isabel-Papatura.

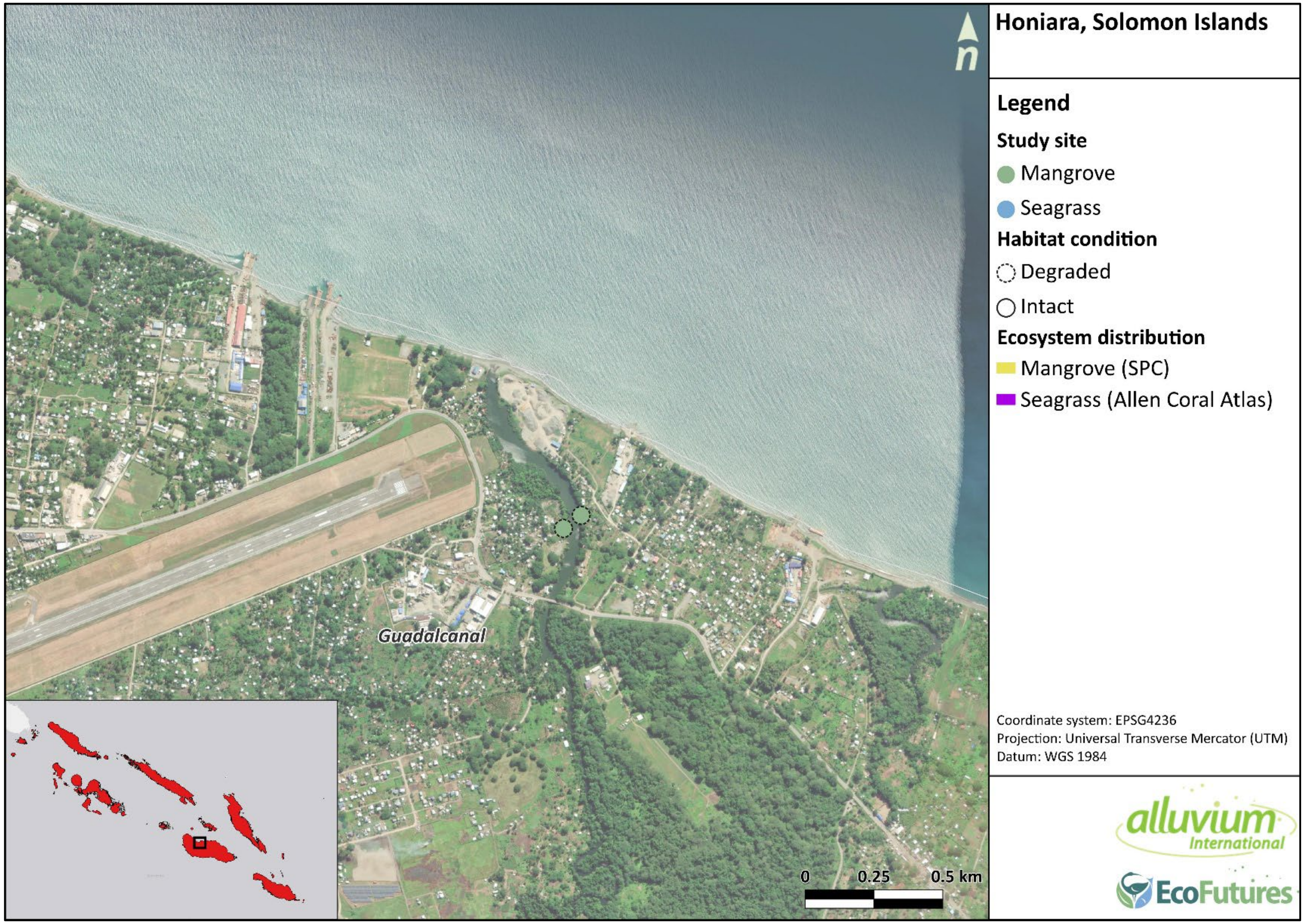

Figure 50. Seagrass and mangrove ecosystem distribution and survey sites at Honiara.

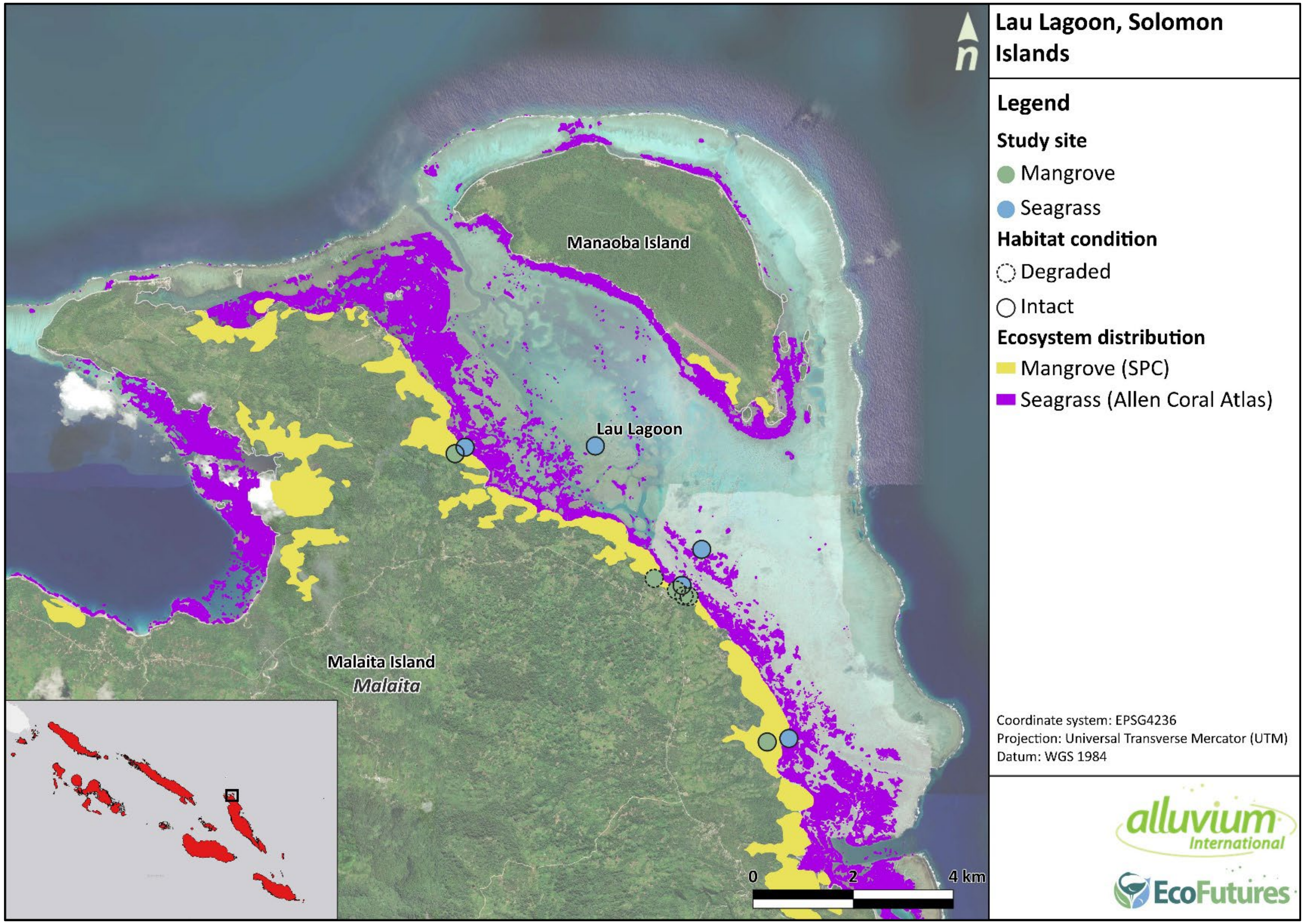

Figure 51. Seagrass and mangrove ecosystem distribution and survey sites at Lau Lagoon.

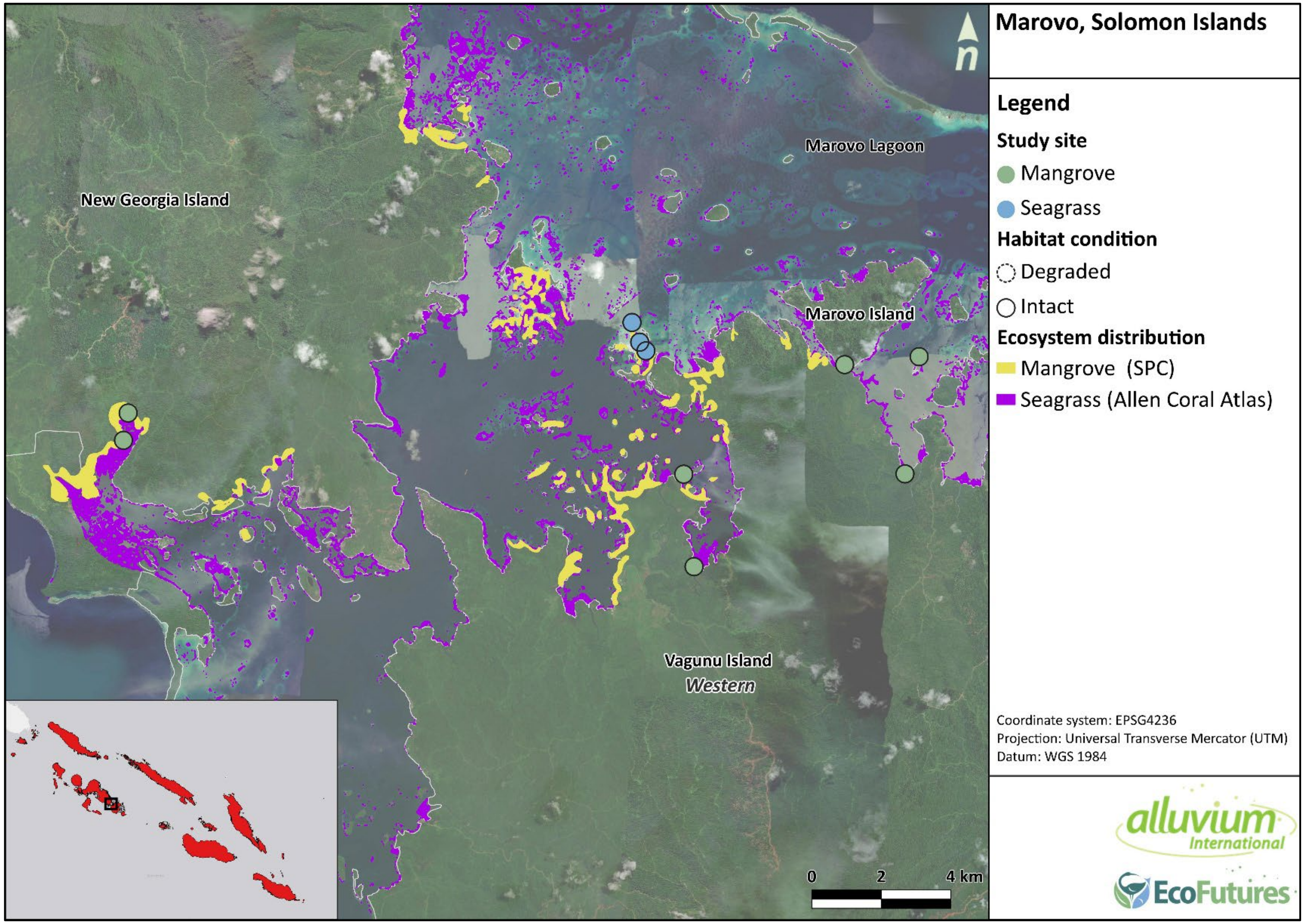

Figure 102. Seagrass and mangrove ecosystem distribution and survey sites at Marovo.

5.4 Solomon Islands ecosystem assessment results

5.4.1 Seagrass results

A total of six of the nine species of seagrass known from the Solomon Islands were recorded from the eleven sites sampled (Table 18). Meadows sampled were predominantly on fringing reef flats or immediately adjacent to mangrove forests. Six of the eleven sites were meadows with multiple species of seagrass, which is common in the Solomon Islands[2]. Of the three locations sampled in the project, Lau Lagoon had the highest species diversity, with five out of the six species found. Marovo and Santa Isabel-Papatura had a lower species diversity (Table 18).

Table 78. Seagrass species found in the MACBLUE compared to previous seagrass species lists described for the Solomon Islands

Species	Lau Lagoon	Marovo	Santa Isabel-Papatura	Past studies in the Solomon Islands[129]
Cymodocea rotundata	X	X	X	X
Cymodocea serrulata		X		X
Enhalus acoroides	X	X	X	X
Halodule pinifolia / Halodule uninervis *	X			X
Halophila decipiens				X
Halophila ovalis / Halophila minor **	X		X	X
Syringodium isoetifolium				X
Thalassia hemprichii	X			X
Thalassodendron ciliatum				X

* For the purpose of this study the sets of species and/or sub-species that require molecular analysis to correctly identify and differentiate, were binned together and not analysed separately [130] ** Note that molecular studies have found *H. minor* is conspecific with *H. ovalis*[131]

Lau Lagoon had the highest average seagrass coverage of 68% (± 4% SE), followed by Marovo at 57% (± 8% SE) coverage, while Santa-Isabel had the least coverage of 41% (± 7% SE) (Figure 53). This is likely reflecting the predominance of *Enhalus acoroides* in the meadows sampled in Lau Lagoon compared to the two other locations. Meadows dominated by *E. acoroides* assessed in this study typically had a higher % coverage than those dominated by other species.

[129] McKenzie, L., S. Campbell and F. Lasi. 2006. Seagrasses and Mangroves. In: Green, A., P. Lokani, W. Atu, P. Ramohia, P. Thomas and J. Almany (eds). 2006. Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No 1/06.
[130] McKenzie, L.J., & Yoshida, R.L. (2007). Seagrass-Watch: Guidelines for Monitoring Seagrass Habitats in the Fiji Islands. Proceedings of a training workshop, Corpus Christi Teachers College, Laucala Bay, Suva, Fiji, 16th June 2007. Seagrass-Watch HQ Cairns.
[131] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. Marine pollution bulletin, 160, 111636.

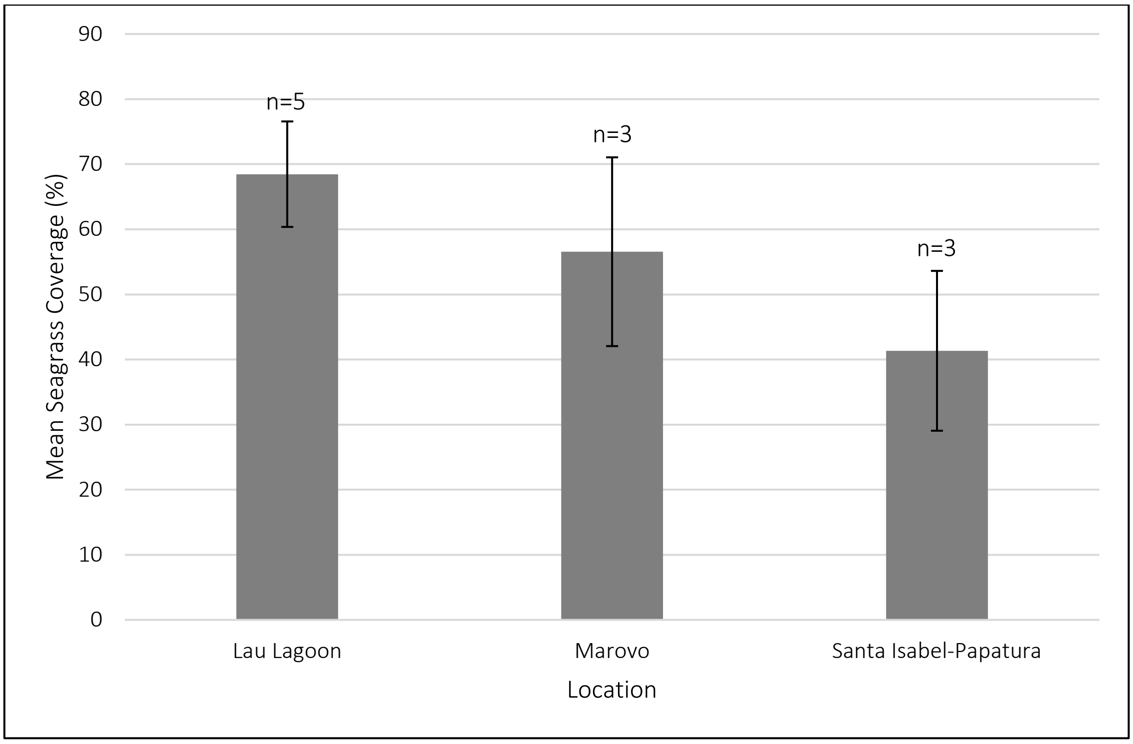

Figure 53. Mean seagrass coverage (%) (± SE) across three locations at the Solomon Islands

Threats to the seagrass meadows of the Solomon Islands are typically from sediment plumes related to erosion associated with catchment clearing (e.g. logging and mining); sewage discharge; industrial pollution; and overfishing[2]. Most of the sites assessed in this project were found to have low levels of threats; however, extreme events (e.g. cyclones and floods), along with inflow from land activity and sediment resuspension, were identified as key potential threats (Table 19).

Overall, the seagrass sites assessed in this study generally experience low levels of threat. Among them, seagrass sites in Marovo were the least threatened, followed by Lau Lagoon and Santa Isabel-Papatura, which had similar threat scores. The high percentage of seagrass cover recorded at most sites reflects the low level of threats experienced at the sites assessed (Figure 53).

Table 19. Rapid threat assessment results for the seagrass sites in the Solomon Islands showing total scores and individual threat scores averaged across sites within a location. The maximum total score for habitat scale and landscape scale is 40 and 35, respectively, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Lau Lagoon	Cyclone damage, boating	*Habitat*	33	NA	5	4	5	NA	4	4	4	5	3
		Landscape	30	5	NA	NA	NA	5	4	4	4	5	3
Marovo	Fishing, logging, wind exposure	*Habitat*	38	NA	5	4	4	NA	5	5	5	5	5
		Landscape	35	5	NA	NA	NA	5	5	5	5	5	5
Santa Isabel-Papatura	Wind exposure, high energy, harvesting village, fishing and boating, sea-level rise and cyclones.	*Habitat*	31	NA	5	4	2	NA	4	5	4	5	4
		Landscape	29	5	NA	NA	NA	4	4	5	4	5	4

E. acoroides was the most commonly recorded species in the assessment, found at 81% of the sites. Four of the eleven sites were monospecific *E. acoroides* meadows. The next most common species were *Cymodocea rototunda*, *Thalassia hemprichii* and *Halodule pinifolia/uninervis*, recorded at 60% of the sites sampled.

Photos of each site surveyed were captured and can be found in Appendix **Error! Reference source not found.**.

5.4.2 Mangroves results

A total of 17 of the 33 mangrove species known to inhabit the Solomon Islands were recorded in the assessments, with the distribution of the species amongst the four locations outlined in Table 20. Overall, *Rhizophora apiculata* was the most abundant species recorded across the locations (n = 595), followed by *Bruguiera gymnorhiza* (n = 358), *Ceriops tagal* (n = 232), *Nypa fruticans* (n = 158), *Lumnitzera littorea* (n = 122) and *Bruguiera hainesii* (n = 86). The least abundant species were *Avicennia marina* (n = 1), *Rhizophora X lamarckii* (n = 4) and *Xylocarpus moluccensis* (n = 7), which were found at one site in Lau Lagoon and Marovo, respectively (Table 20).

Mangrove forests that have a greater species diversity have been found to have enhanced biomass production and soil carbon storage[132] so protecting forests with a higher diversity of species and restoring degraded forests with multiple species is important for maximising carbon storage. Lau Lagoon and Marovo had the highest species diversity with a total of 10 species, while Santa Isabel-Papatura had eight (8), and Honiara had the least diversity with five (5) mangrove species (Table 20). Photos of each site surveyed were captured and can be found in Appendix A.

Table 20. Mangrove species list for Solomon Islands found in the MACBLUE assessment compared with past studies on mangroves in the Solomon Islands (A = Associate mangrove, T = True mangrove, H = Hybrid/Variant).

Species	Category	Recorded during MACBLUE assessment				Past studies in the Solomon Islands[133,134,135]
		Lau Lagoon	Honiara	Marovo	Santa Isabel-Papatura	
Acanthus ebracteatus	A					X
Acanthus ilicifolius	A					X
Acrostichum aureum	A					X
Acrostichum speciosum	A					X
Aegiceras corniculatum	T	X				X
Avicennia alba	T					X
Avicennia marina	T	X				X
Avicennia marina var. *rumphiana*	H					X
Barringtonia racemosa	A					X
Bruguiera cylindrica	T					X
Bruguiera gymnorhiza	T	X	X	X	X	X
Bruguiera X hainesii	H				X	X
Bruguiera parviflora	T	X				X
Bruguiera sexangula	T					X
Ceriops tagal	T	X		X	X	X
Cynometra ramiflora	T					X
Dolichandrone spathacea	A			X		X

[132] Bai J, Meng Y, Gou R, et al. Mangrove diversity enhances plant biomass production and carbon storage in Hainan island, China. *Funct Ecol*. (2021); 35: 774–786. https://doi.org/10.1111/1365-2435.13753
[133] Pillai, G and Sirikolo, Q. M., (2001). Mangroves of the Solomon Islands. USP Marine Studies, Suva, Fiji.
[134] Duke, NC, J. Mackenzie & A. Wood (2012), 'A revision of mangrove plants of the Solomon Islands, Vanuatu, Fiji, Tonga and Samoa', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 12/13, James Cook University, Townsville, 22 pp.
[135] FAO (2005). GLOBAL FOREST RESOURCES ASSESSMENT 2005, THEMATIC STUDY ON MANGROVES, SOLOMON ISLANDS, COUNTRY PROFILE. Food and Agriculture Organization of the United Nations. Rome, Italy.

Species	Category	Recorded during MACBLUE assessment				Past studies in the Solomon Islands[133,134,135]
		Lau Lagoon	Honiara	Marovo	Santa Isabel-Papatura	
Excoecaria agallocha	T					X
Heritiera littoralis	T			X		X
Lumnitzera littorea	T	X		X	X	X
Nypa fruticans	A		X			X
Osbornia octodonta	T					X
Pemphis acidula	A					X
Rhizophora apiculata	T	X	X	X	X	X
Rhizophora mucronata	T					X
Rhizophora stylosa	T		X	X	X	X
Rhizophora X lamarckii	H	X				X
Scyphiphora hydrophylacea	T			X		X
Sonneratia alba	T	X	X		X	X
Sonneratia caseolaris	T					X
Sonneratia X gulngai	H					X
Xylocarpus granatum	T	X		X	X	X
Xylocarpus moluccensis (syn. *X. mekongensis*)	T			X		X

Across the four locations surveyed in the Solomon Islands, Honiara had the highest level of threat at both the habitat and landscape scale (Table 21). Mangrove clearing around Honiara, driven by development, agriculture, and village housing were the main threatening processes. Although mangroves had been planted along the waterway margins by the village at one of the Honiara sites, all sites had been significantly impacted by mangrove clearing and reclamation (Figure 54).

Figure 54. Degraded site near Honiara.

The remaining three locations exhibited lower threat levels at both the habitat and landscape scales (Table 21). In Lau Lagoon, many of the mangrove sites assessed were impacted by harvesting for firewood, construction, and food production. At Santa Isabel-Papatura one site (Sesehura Fa Island) had experienced severe cyclone damage, with significant destruction observed across the area (Figure 55).

Figure 55. Cyclone damaged site at Santa Isabel-Papatura, Solomon Islands.

Table 21. Rapid threat assessment results for the mangrove sites in the Solomon Islands showing total scores and individual threat scores averaged across sites within a location. The maximum total score for habitat scale and landscape scale is 40 and 35 respectively, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Lau Lagoon	Harvesting and food production	*Habitat*	33	NA	5	4	5	NA	3	4	4	5	4
		Landscape	30	5	NA	NA	NA	5	3	4	4	5	4
Marovo	Logging, shell harvesting, shellfish harvesting, wind exposure, fishing, sediment runoff.	*Habitat*	37	NA	5	3	4	NA	5	5	4	5	5
		Landscape	34	5	NA	NA	NA	5	5	5	4	5	5
Honiara	Sand mobilised during cyclones smoothers seagrass.	*Habitat*	20	NA	2	3	3	NA	3	2	4	3	2
		Landscape	17	2	NA	NA	NA	2	3	1	4	3	2
Santa Isabel-Papatura	Wind exposure, swell, sea-level rise, tsunami, waves, shell harvesting, erosion, fishing, logging, high energy.	*Habitat*	36	NA	4	5	4	NA	5	5	5	5	3
		Landscape	32	4	NA	NA	NA	5	5	5	5	5	3

Locations and sites with higher threat levels typically had fewer large trees compared to less threatened sites, likely due to less tree removal for firewood and construction. Larger trees in forests play a keystone role[136] by contributing a disproportionate level of reproductive components, habitat for other species, and above ground biomass for carbon storage. The largest trees recorded in the Solomons Islands were typically found in Marovo Lagoon, followed by Santa Isabel-Papatura (Table 22). The most heavily impacted sites in Honiara had no large trees, indicating removal for construction and firewood.

Table 22. The distribution of larger trees across the four (4) locations assessed in the Solomon Islands. Numbers refer to the percentage (%) of trees recorded in that location. DBH refers to Diameter at Breast Height.

Tree size	Lau Lagoon	Honiara	Marovo	Santa Isabel-Papatura
<20cm DBH	88	91	63	72
>20cm DBH	11	9	31	25
>50cm DBH	1	0	5	2

[136] D.B. Lindenmayer, W.F. Laurance, J.F. Franklin. (2012) Global decline in large old trees. Science, 338 (6112), pp. 1305-1306

At Lau Lagoon, *Lumnitzera littorea* had the largest average Diameter at Breast Height (DBH) of 26 cm (Figure 56), followed by *Rhizophora X lamarckii* (21 cm), *Xylocarpus granatum* (DBH = 19 cm), *Sonneratia alba* (DBH = 14 cm), *Bruguiera parviflora* (DBH = 13 cm), *Bruguiera gymnorhiza* (11 cm), and *Rhizophora apiculata* (DBH = 11 cm). *Bruguiera gymnorhiza* displayed multiple outliers, representing larger trees (maximum DBH 67 cm). *Sonneratia alba* had an outlier that denoted one large tree with a DBH of 124.5 cm. *Lumnitzera littorea* demonstrated the least variability in comparison to all other species (Figure 56). Only one *Avicennia marina* was identified in the field, and it had the smallest DBH across Lau Lagoon (DBH = 2 cm).

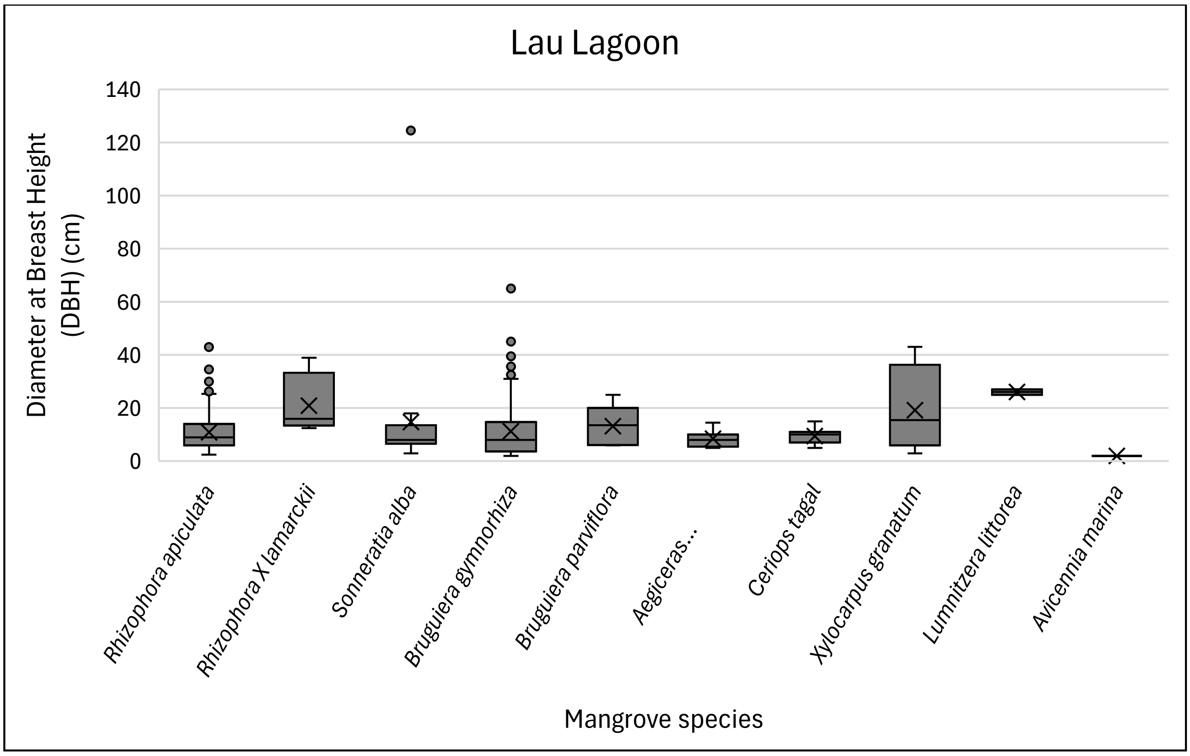

Figure 56. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Lau Lagoon. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

At Marovo the DBH across species was greater in comparison to mangroves found at Lau Lagoon, with *Lumnitzera littorea* having an average DBH of 38 cm (Figure 57). *Heritiera littoralis* had an average DBH of 28 cm, which was skewed due to one outlier (DBH = 114 cm). These species were followed by *Xylocarpus granatum* (DBH = 26 cm), *Rhizophora apiculata* DBH = 22 cm and *Bruguiera gymnorhiza* (DBH = 22 cm). All other species had a DBH <12 cm.

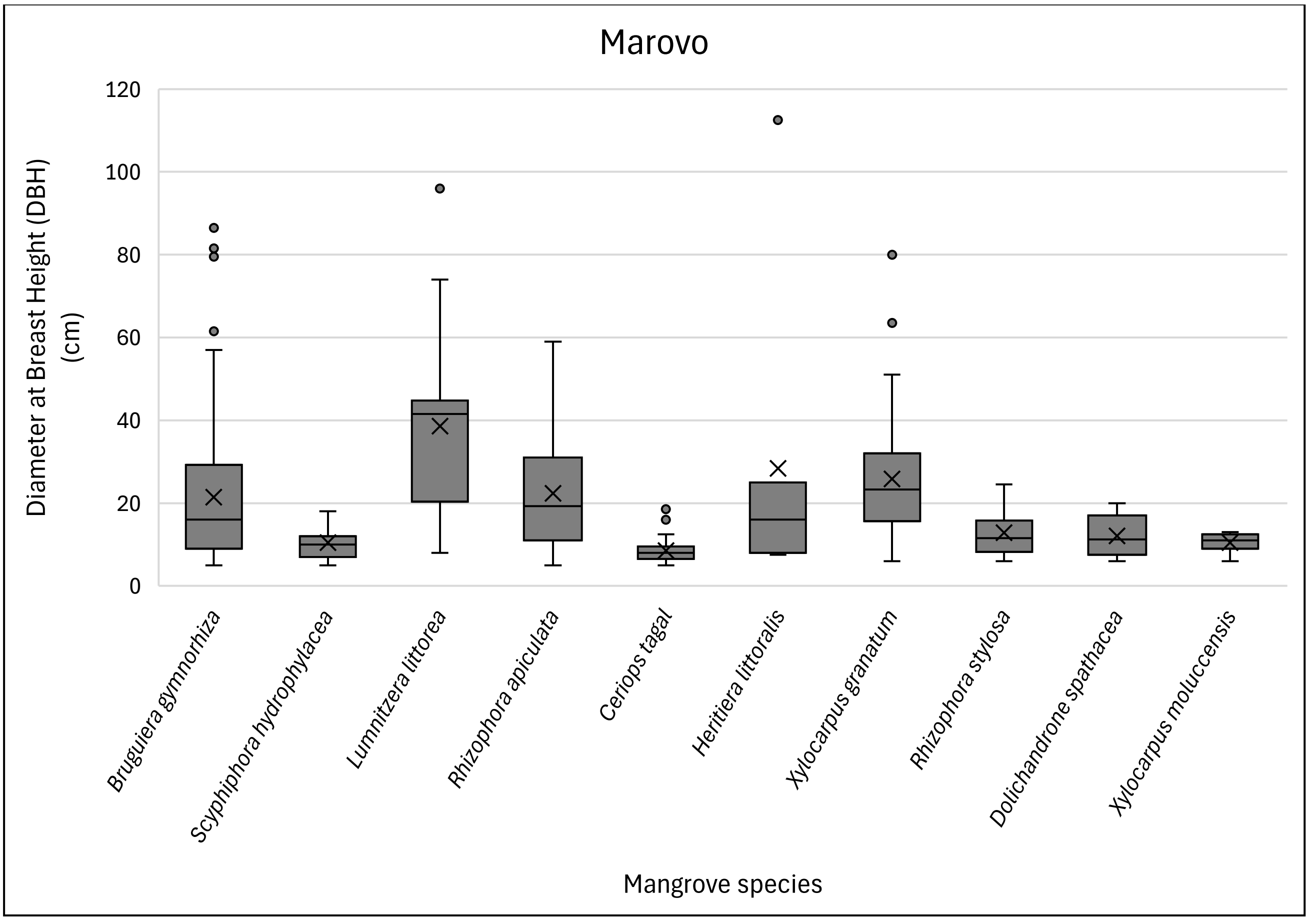

Figure 57. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Marovo. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

At Santa Isabel-Papatura, *Sonneratia alba* had the largest average DBH of 46 cm, with a maximum DBH of 95 cm (Figure 58). This species also exhibited the widest size range (DBH 6 – 95 cm) compared to the other species (Figure 58). *Lumnitzera littorea, Bruguiera hainesii*, and *Bruguiera gymnorhiza* followed with an average DBH of 17 cm, while *Rhizophora stylosa* had a DBH of 16 cm and *R. apiculata* had a DBH of 15 cm (Figure 58). All other species had a DBH of less than 13 cm (Figure 58).

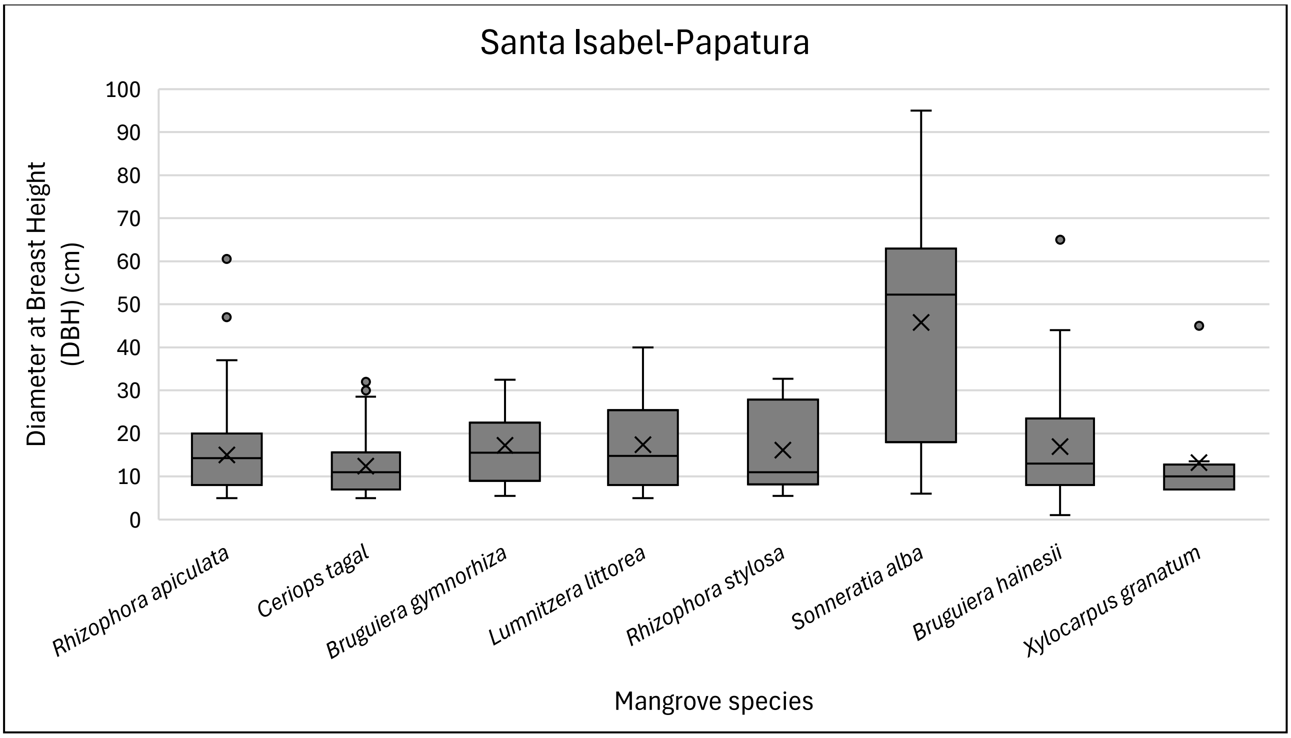

Figure 58. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Santa Isabel Papatura. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

At Honiara, *Sonneratia alba* had the largest average DBH of 25 cm, with a maximum DBH of 48 cm (Figure 59). This species also had the greatest range in size (DBH 6 – 95 cm) in comparison to other species (Figure 12). *Lumnitzera littorea* and *Rhizophora apiculata* also exhibited the second largest DBH of 15 cm. All remaining species had a DBH of less than 7 cm (Figure 59).

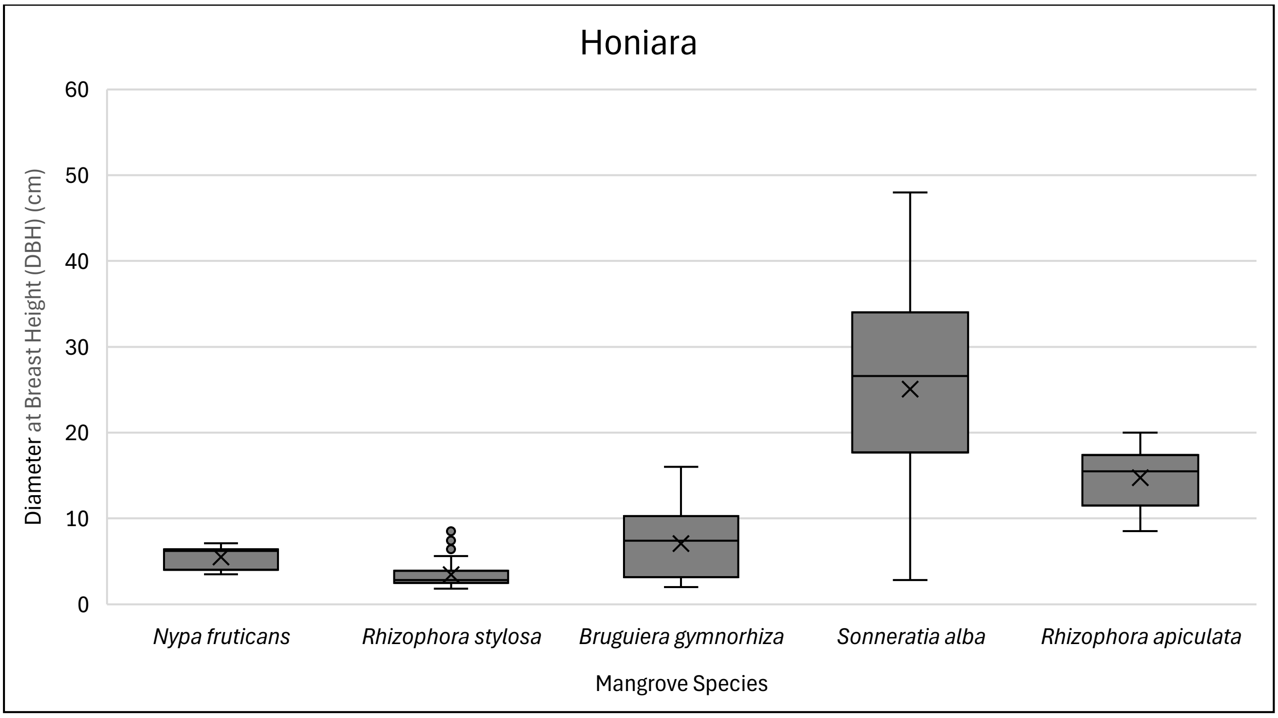

Figure 59. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Honiara. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Across the four locations, mangrove trees in Marovo had the largest average DBH of 20 cm, followed by Santa Isabel-Papatura (DBH = 16 cm), Lau Lagoon (DBH = 11 cm), and Honiara (DBH = 8 cm). All sites had considerable variability, with some outliers being greater than 80 cm DBH. This reflects the complexity of intact mangrove ecosystems and outlines their variability due to multiple factors such as extreme weather conditions, anthropogenic influences, tidal inundation, and stratification.

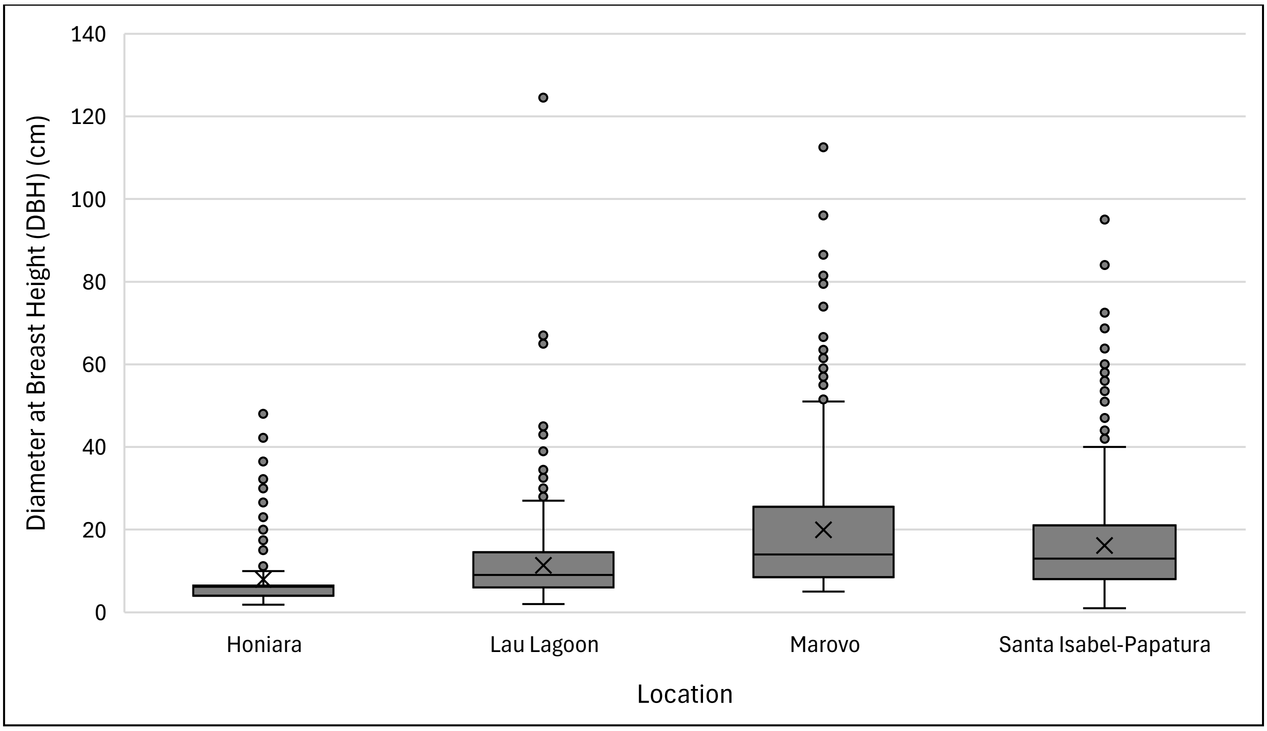

Figure 60. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) across the locations in Solomon Islands. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Degraded sites typically demonstrate lower mangrove DBH records, likely due to the removal of large trees for firewood or construction. Honiara consisted entirely of degraded sites, with an average DBH of 8 cm. Santa Isabel-Papatura had the largest DBH across the degraded sites (DBH = 15 cm), while the degraded sites at Lau Lagoon had an average DBH of 10 cm (Figure 61). It is important to note that only intact sites were sampled in Marovo, while only degraded sites were sampled in Honiara.

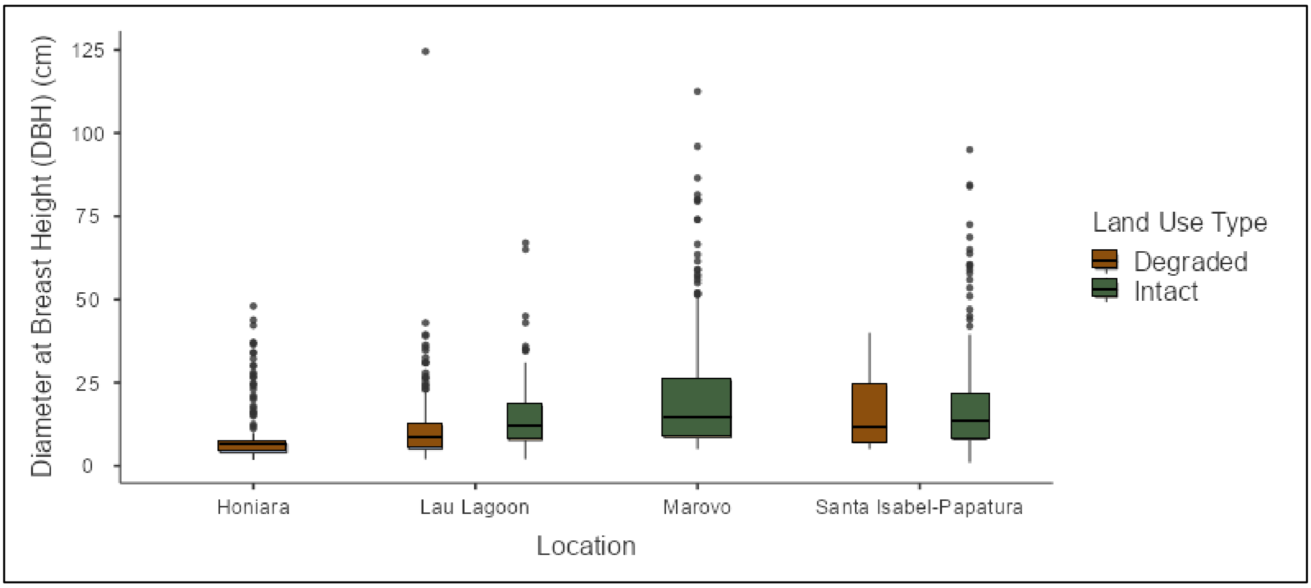

Figure 61. A box plot displaying Diameter at Breast Height (DBH) (cm) compared between land use type (degraded v. intact) and locations across the Solomon Islands. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Marovo had the highest mangrove canopy cover, with an average coverage of 83% (± 3 SE), followed by Santa Isabel-Papatura at 74% (± 2 SE) (Figure 62). The locations with the most degraded sites had lower average canopy cover, with Lau Lagoon at 48% (± 8 SE) and Honiara at 34% (± 29 SE). Honiara showed considerably variability between the two sites surveyed, resulting in a large SE (Figure 62). It should be noted that mangrove canopy cover was collected as range data. The mid-point from this range data were averaged across each site and averaged again for each location. This analysis further suggests that both Marovo and Santa Isabel-Papatura have high mangrove canopy cover and are associated with better ecosystem health when compared to the other locations.

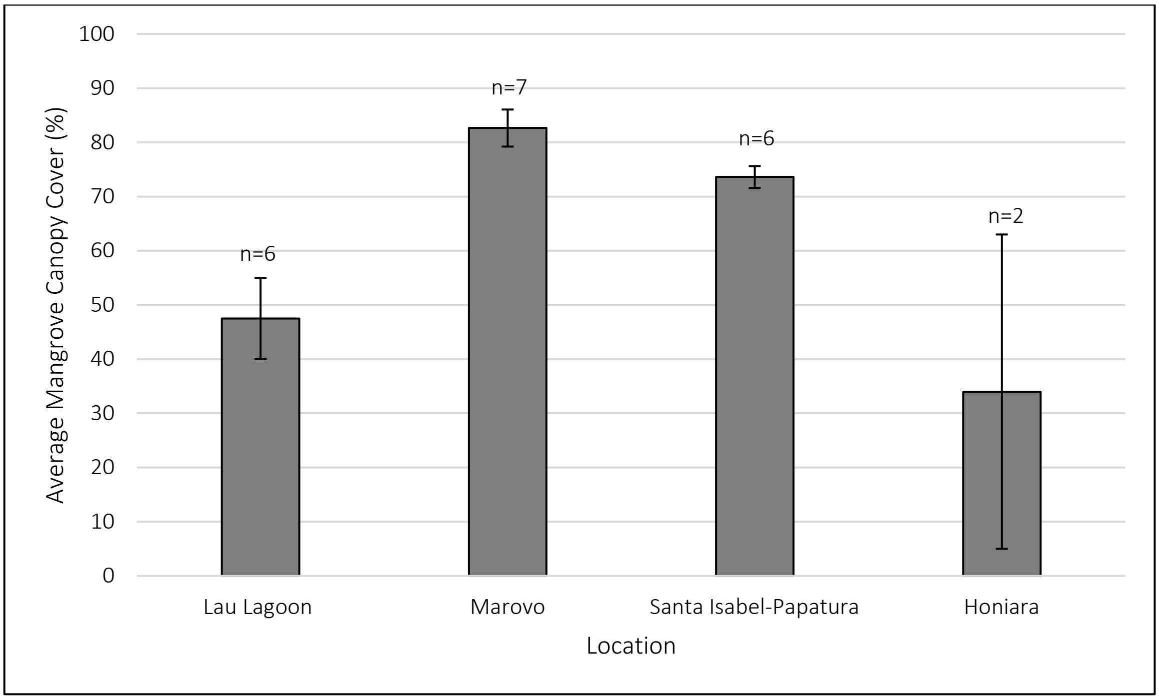

Figure 62. Average mangrove canopy cover (%) (±SE) across locations in Solomon Islands (where n is the number of sites surveyed at each location).

Across the locations, intact sites had a higher average mangrove canopy cover than degraded sites (Figure 63). Among degraded sites, Lau Lagoon had the highest average canopy cover at 36%, followed by Honiara at 34%, and Santa Isabel-Papatura at just 5%. In contrast, intact sites at Santa Isabel-Papatura had the greatest canopy coverage at 87%, followed by Marovo (83%), and Lau Lagoon (71%) (Figure 63). Notably, only intact sites were sampled in Marovo, while only degraded sites were sampled in Honiara (Figure 63).

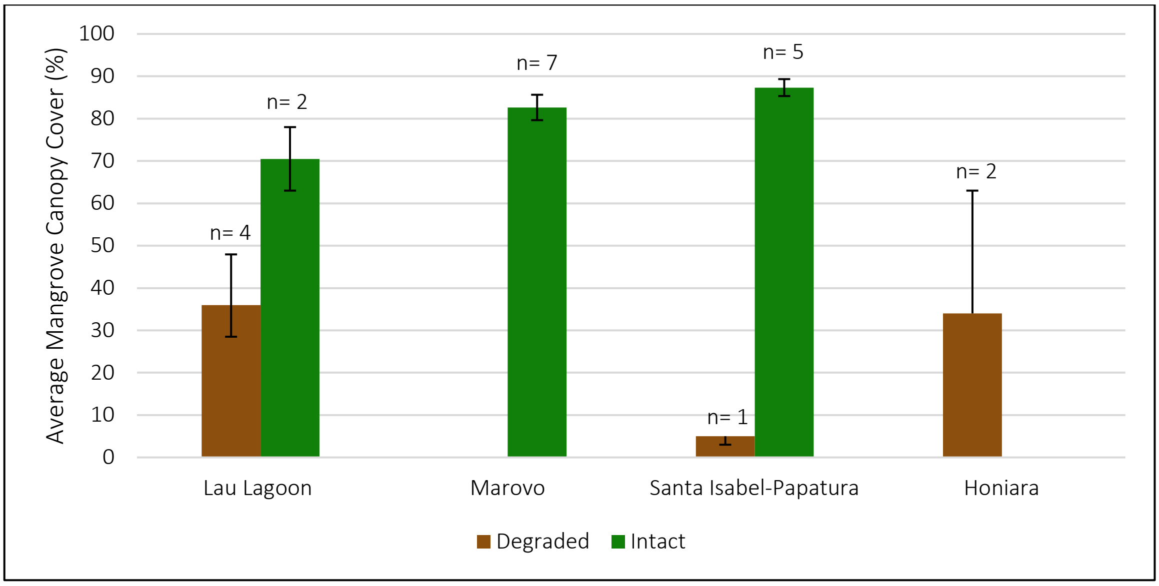

Figure 63. Average mangrove canopy cover (%) (± SE) across intact and degraded locations. n = the number of sites surveyed at each location.

Seedling abundance was collected at each site as an indicator of forest productivity and the capacity for a forest to recover from disturbance. If resilient, a disturbed forest may have high seedling abundance compared to an equivalent intact forest, due to increased sunlight to the forest floor. Seedling abundance was assessed at each site as one of three categories (0-10, 10-50 and >50 seedlings). The seedling density/m^2 for each site was calculated using the mid-point of the categories and standardised by the area of each plot.

Lau Lagoon had the highest seedling density when compared to the other locations, with 0.65 seedlings/m^2 (Figure 64). This location also had the largest range in seedling density (Figure 64). This location was followed by Marovo and Santa Isabel-Papatura, which had a seedling density of 0.49 and 0.33 seedlings/m^2, respectively (Figure 64). Honiara had the lowest density across the locations (0.18 seedlings/m^2) (Figure 64).

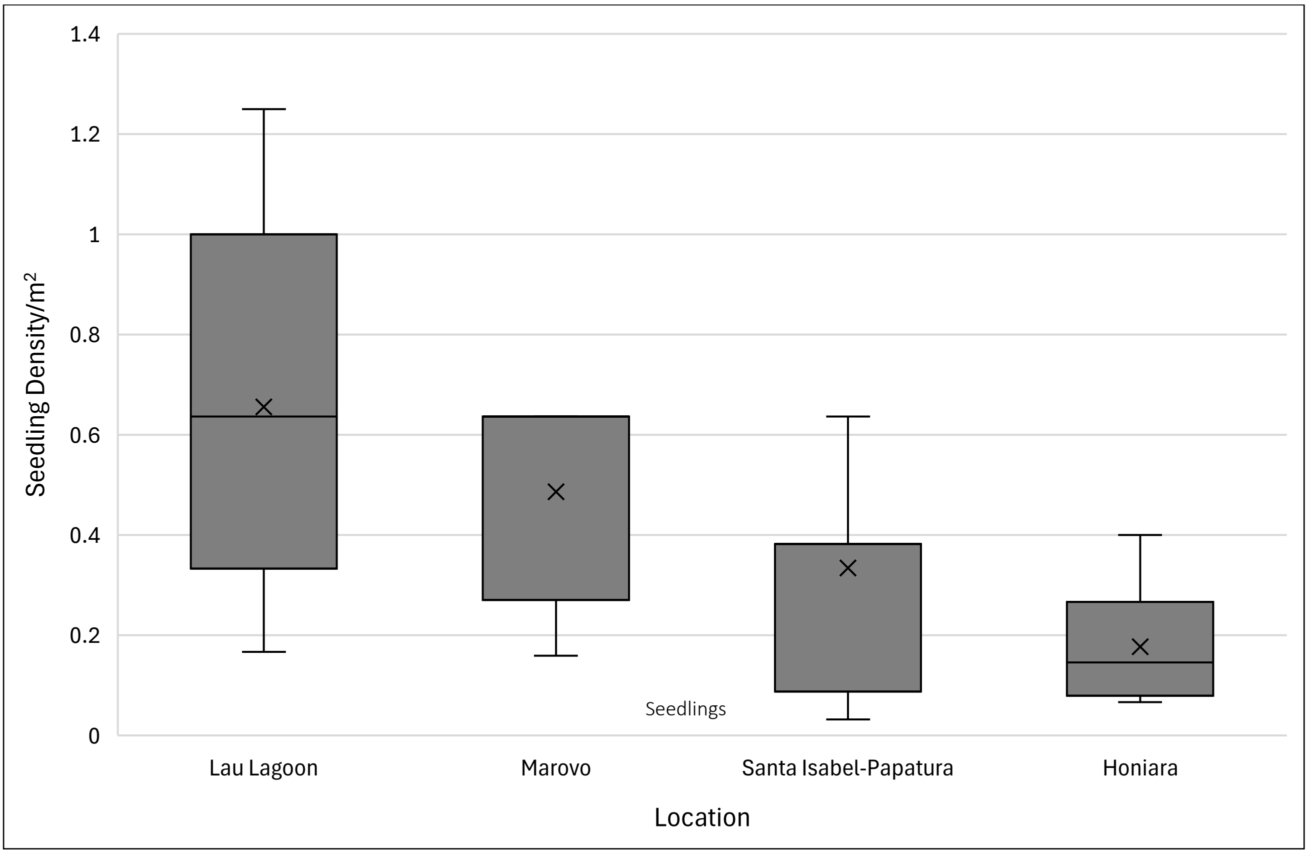

Figure 64. Seedling density/m^2 at each location in the Solomon Islands. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Comparing degraded and intact sites across locations intact sites typically had higher seedling density (Figure 65). Lau Lagoon had the highest seedling density for intact sites with 0.898 seedlings/m^2 (Figure 65). This was followed by Marovo (0.487 seedlings/m^2) and Santa Isabel-Papatura (0.393 seedlings/m^2). For degraded sites, Santa Isabel-Papatura had the lowest seedling density of 0.043 seedlings/m^2 (Figure 65). This low seedling density is likely due to the significant cyclone damage and the presence of downed dead wood on the degraded site, which reduces the available space for seedlings to establish and germinate. The degraded site in the Lau Lagoon had been cleared for *Bruguiera gymnorhiza* planting for food production, resulting in the highest seedling density for the degraded sites (0.544 seedlings/m^2) (Figure 65). The site is surrounded by an intact forest so has a ready supply of seeds. Honiara only had degraded sites and had a seedling density of 0.177 seedlings/m^2.

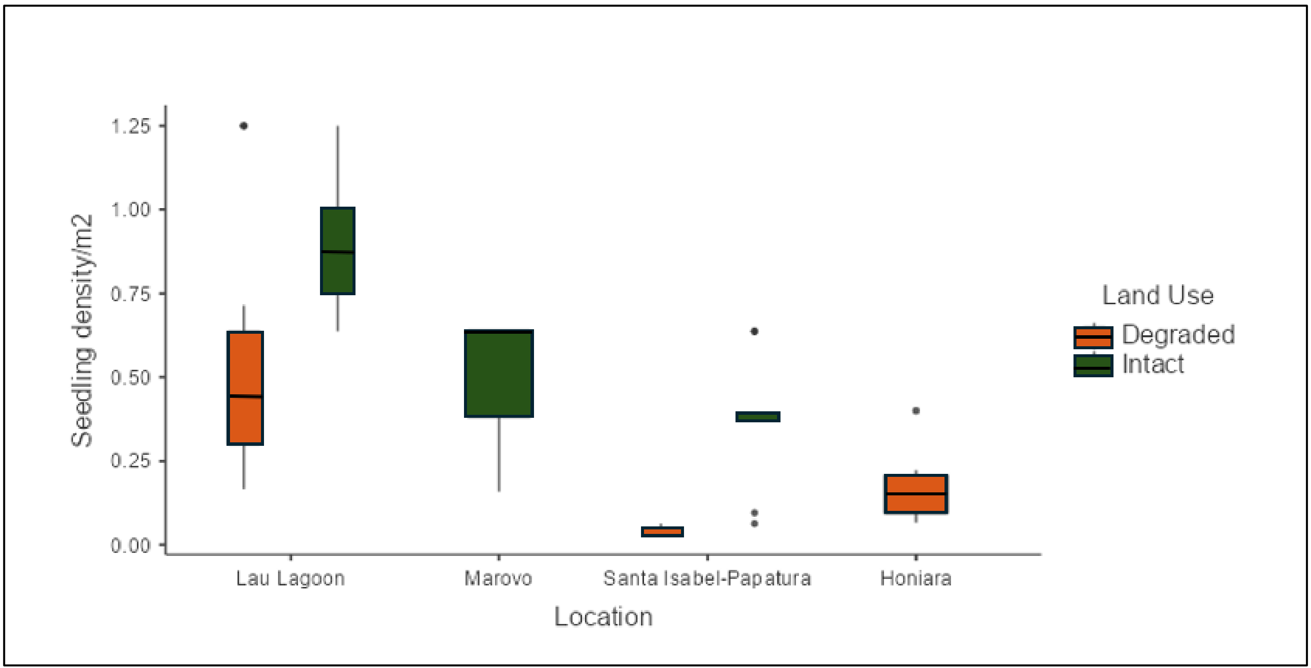

Figure 65. Seedling density/m^2 at each location in the Solomon Islands compared between intact, degraded and converted sites. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

5.4.3 Biodiversity results

Seagrass meadows represent vital habitats characterised by high biodiversity and play a crucial role as feeding ground for threatened species such as Dugongs and turtles[137]. Additionally, one third of all known whale and dolphin species worldwide are found in the Solomon Island Seas[138], and many prey fish species depend on SaM habitats as nurseries for juveniles.

The rapid biodiversity assessment completed at the eleven seagrass sites for the Solomon Islands found a range of species present. The assessment was based on opportunistic observations while on-site and was not comprehensive. The focus was on recording any evidence of IUCN-listed species observed at each seagrass site (e.g. Table 23). Green Sea Turtles were sighted at two sites in Lau Lagoon, along with anecdotal evidence of dugongs at the same site. Fishermen in Lau Lagoon reported that a herd of thirteen Dugongs were once common in the lagoon, but numbers have declined in recent years to three individuals (two adults and a calf). The presence of both species, which rely on seagrass for food, highlights the importance of protecting seagrass meadows in the Solomon Islands.

Table 23. Examples of threatened species previously recorded in seagrass meadows in the Solomon Islands.

Habitat	Organism	Species	Common name	IUCN status	Reference
Seagrass	Reptile	*Chelonia mydas*	Green Sea Turtle	Endangered	McKenzie et al. 2006[139] Seminoff 2023[140]
	Mammal	*Dugong dugon*	Dugong	Vulnerable	McKenzie et al. 2006 Marsh and Sobtzick 2019[141]
	Fish	*Astreopora cucullata*	Orange Spotted Filefish	Vulnerable	GBIF Occurrence Download [142]
		Plectropomus areolatus	Passionfruit Coral Trout/Square-tailed Coral Grouper	Vulnerable	GBIF Occurrence Download

Green Turtles were observed during the assessments and anecdotal descriptions of Dugongs in the Lau Lagoon were recorded.

Incidental observations of fauna biodiversity were made in each of the seagrass and mangrove sites assessed. A range of fauna species were recorded as per Table 24 and Figure 66.

[137] Green, A., P. Lokani, W. Atu, P. Ramohia, P. Thomas and J. Almany (eds.) (2006). Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No. 1/06.
[138] Green, A., P. Lokani, W. Atu, P. Ramohia, P. Thomas and J. Almany (eds.) (2006). Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No. 1/06.
[139] McKenzie, L., S. Campbell and F. Lasi. 2006. Seagrasses and Mangroves. In: Green, A., P. Lokani, W. Atu, P. Ramohia, P. Thomas and J. Almany (eds). 2006. Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No 1/06.
[140] Seminoff, J.A. (Southwest Fisheries Science Center, U.S.). 2023. *Chelonia mydas* (amended version of 2004 assessment). *The IUCN Red List of Threatened Species* 2023: e.T4615A247654386. https://dx.doi.org/10.2305/IUCN.UK.2023-1.RLTS.T4615A247654386.en. Accessed on 04 February 2025.
[141] Marsh, H. & Sobtzick, S. 2019. *Dugong dugon* (amended version of 2015 assessment). *The IUCN Red List of Threatened Species* 2019: e.T6909A160756767. https://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T6909A160756767.en. Accessed on 04 February 2025.
[142] GBIF.org (4 February 2025) GBIF Occurrence Download https://doi.org/10.15468/dl.36mjtu

Table 24. Species recorded in the seagrass meadows and mangrove forests assessed in the Solomon Islands.

Habitat	Organism type	Species	Common name
Seagrass	Bird	*Tringa brevipes*	Grey-tailed Tattler
		Fregata ariel	Lesser Frigatebird
		Butorides striata	Striated Heron
	Cnidarian	*Cassiopea sp.*	Upside-down Jellyfish
	Mammal	*Dugong dugon*	Dugongs
	Reptile	*Chelonia mydas*	Green Sea Turtle
Mangrove	Bird	*Vini margarethae*	Duchess Lorikeet
		Ducula pistrinaria	Island Imperial Pigeon
		Todiramphus tristrami	Melanesian Kingfisher
		Aplonis metallica	Metallic Starling
		Cacatua ducorpsii	Solomons Corella
		Butorides striata	Striated Heron
	Bivalve		Assorted bivalves (not identified)
	Crustacean		Hermit crab (multiple species)
			Mangrove crabs (multiple species)
		Gelasimus vomeris	Orange Clawed Fiddler Crab
		Uca perplexa	Yellow Clawed Fiddler Crab
	Fish	Zenarchopterus dispar	Feathered River-garfish
		Thalassina sp.	Mud Lobster
		Periophthalmus argentilineatus	Mud Skipper
		Family: Mugilidae	Mullet (multiple species)
		Tylosurus punctulatus	Spotted Long Tom
	Gastropod		Mud Shell (Deo/Ropi)
		Family: Neiritidae	Nerites (multiple species)
		Strombus luhuanus	Red-lipped Stromb
		Family: Trochidae	Top snails (Multiple species)
	Mammal		Dugong
	Reptile	*Crocodylus porosus*	Estuarine Crocodile
		Acrochordus granulatus	Little File Snake

Figure 66. Observed fauna across the Solomon Islands. A range of reptiles, gastropods, crustaceans, bivalves, birds, fish and mammals were recorded across the four locations.

The abundance of crab holes were recorded at each of the sites as a simple indicator of the interaction between the benthic biodiversity of the forest and ecosystem functioning. Through burrowing and feeding activities, mangrove crabs contribute to recycling of organic matter, changes in surface topography, nutrient cycling and removal, oxygenation of mangrove sediments and the success of mangrove propagules[143]. Degraded mangrove forests typically have lower abundances of mangrove crabs which results in poor ecosystem functioning.

The abundance and size distribution of crab holes recorded in each of the locations broadly reflects the threat profile of each location. Honiara had lower abundances and smaller crab holes than the other three locations which corresponds to the poorer condition and higher level of threat recorded at those sites. Crab hole abundances and size distributions were higher at Santa Isabel-Papatura which reflects the better condition and lower threat levels at those sites. The

[143] Lee SY (1998) "Ecological role of grapsid crabs in mangrove ecosystems: a review," *Marine and Freshwater Research*, 49(4):335.

abundances and size distributions of crab holes at the Marovo sites was difficult to record during the assessments owing to the predominance of high tides over the period of sampling.

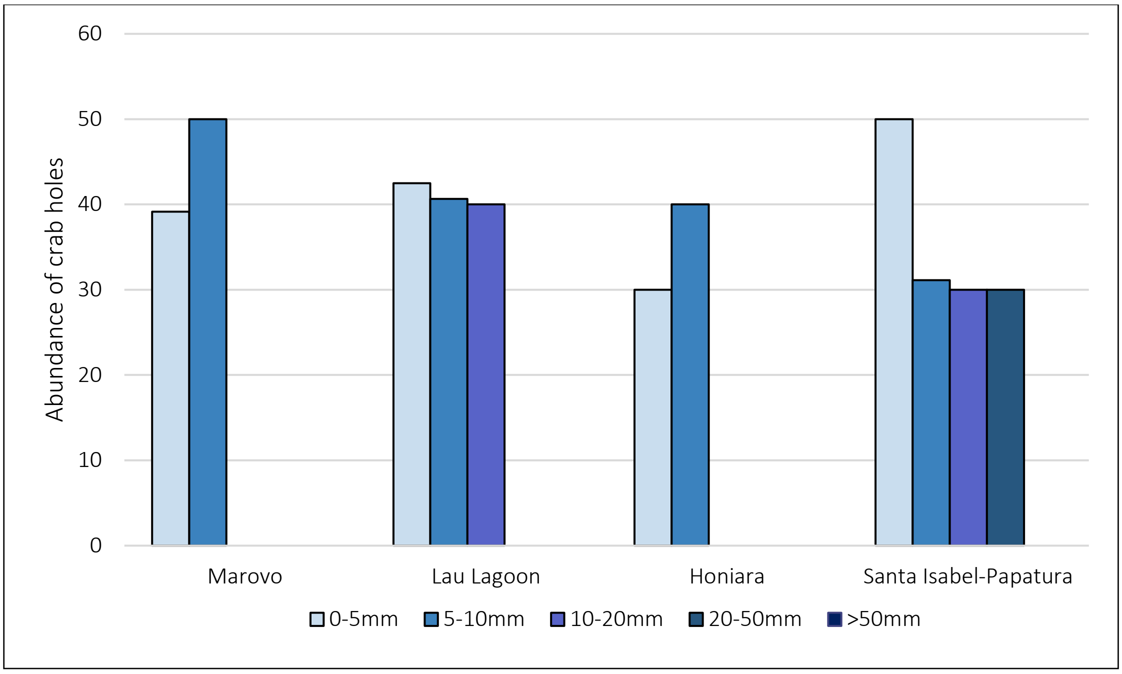

Figure 67. Average abundance of crab holes at each of the four locations sampled in the Solomon Islands, across five crab hole size categories (0-5mm, 5-10mm, 10-20mm, 20-50mm, >50mm). Note that for some sites, predominantly in Marovo and Santa Isabel-Papatura, there was missing data due to tidal inundation preventing crab hole observations during surveys.

5.5 Summary

The SaM ecosystems of the Solomon Islands provide essential services like biodiversity enhancement, coastal protection, carbon sequestration, food production, as well as sources of firewood and construction materials. The results of this rapid assessment found that, despite varying between sites and locations, many SaM systems across the Solomon Islands remain resilient and continue to support essential ecosystem functions, likely sustaining high levels of services. However, there was an indication that ecosystem function and associated services were measurably reduced at sites and locations exposed to high levels of threats.

Key findings:

Seagrass Ecosystems

- The Solomon Islands are host to ten recorded species of seagrass, with extensive meadows found in provinces like Malaita, Choiseul, and Isabel. This project recorded six of those ten. Seagrass meadows are typically located in sheltered bays and lagoons, often adjacent to mangroves and reefs.
- Current threats to seagrasses include sediment run-off from logging, agriculture, mining, and development, as well as destructive fishing practices. However, all sites had relatively high levels of seagrass cover (40-70%), with the highest levels in Lau Lagoon. This indicates that seagrass ecosystems in all study locations were exposed to relatively low levels of threats overall.
- The rapid biodiversity assessment found a range of species that inhabit seagrasses, including endangered green turtles and vulnerable dugongs.

Mangrove Ecosystems

- The Solomon Islands have approximately 52,651 hectares of mangrove forests, with 33 recorded species. A total of 17 of the 33 mangrove species known to inhabit the Solomon Islands were recorded at the study locations.
- The range in tree Diameter at Breast Height (DBH) reflects varying levels of environmental threats and biodiversity value. Specifically, degraded sites with lower DBH values suggest significant removal of large trees, leading to reduced biodiversity. This pattern is evident in Honiara and Lau Lagoon, where the average DBH and variation in DBH were low and moderate, respectively, suggesting the forests here are exposed to higher levels of environmental threat and have lower diversity of structure and potentially lower biodiversity and ecosystem resilience. For Honiara, relatively lower levels of benthic biodiversity and seedling counts indicate that there is likely lower biodiversity and ecosystem resilience in mangrove forests in this region. However, for Lau Lagoon, benthic biodiversity and seedling abundances suggest the system remains resilient despite existing pressures.
- In contrast, Santa Isabel and Marovo had the highest mean DBH and largest variation in DBH, suggesting greater levels of biodiversity and ecosystem resilience. Higher benthic biodiversity, abundances, and seedling counts also suggest that there were relatively lower threats to biodiversity and ecosystem resilience across these locations.
- The rapid biodiversity assessment also recorded a wide range of fauna species, including estuarine crocodiles, island imperial pigeons, mangrove crabs and banded archer fish.

Threat Assessment

- Threats to mangroves include high demand for timber, population growth, and climate change impacts like sea-level rise.
- Intact sites had higher DBH, mangrove canopy cover and seedling abundances, reflecting better ecosystem health, biodiversity and resilience, whereas degraded sites typically had lower DBH, canopy cover and seedling abundances, often due to the removal of large trees for firewood or construction.
- The threat assessments indicated that while some areas are relatively intact, others are significantly impacted by human activities and natural events.

- Honiara had the highest level of threat at both the habitat and landscape scale, primarily due to mangrove clearing for development, agriculture, and village housing.
- Marovo had the highest mangrove canopy cover and seedling abundances, indicating lower threats and better ecosystem health compared to other locations.

VANUATU

6 Seagrass and mangroves of Vanuatu

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6.1 Seagrass past studies

There are few previous studies carried out across Vanuatu to understand the extent, species distribution and condition of seagrasses across Vanuatu, as highlighted by McKenzie & Yoshida (2017[144]). One of the earliest and most extensive surveys on seagrass distribution and habitat conditions in Vanuatu was conducted by Chambers et al. (1990[145]). The study spanned 60 sites across 11 major locations, from the southern region of Aneityum to Ureparapara in the north, including key areas such as Efate, Malekula, and the Reef (Rowa) Islands. Seagrass was present at 39 of the 60 sites, with a total of nine species identified. Overall, the highest diversity and abundance of seagrasses were observed in sandy, sheltered intertidal habitats. The most extensive seagrass meadows documented during this survey were surrounding the Maskelyne Islands, southeast of Malekula. Other expeditions to assess seagrass have been undertaken in Efate and Espiritu Santo (2001), Amal/Crab Bay on the east coast of Malekula (2004-2005), and Luganville in southern Espiritu Santo (2006) (McKenzie & Yoshida 2017). In addition to these studies, Seagrass-Watch[146], an international organisation that collaborates with local communities to undertake long-term seagrass monitoring, has established four on-going monitoring sites in Vanuatu (Lamen Bay, Epi; Lamap, Malekula; Paonangisu, Efate; Erakor Lagoon, Efate).

These past studies state that Vanuatu is home to thirteen species of seagrasses, including species from the genera *Cymodocea, Enhalus, Halodule, Halophila, Thalassia, Syringodium* and *Ruppia* (Mckenzie & Yoshida 2017; McKenzie et al. 2021[147]). According to McKenzie et al. (2021), the most common species in the region are *Thalassia hemprichii, Cymodocea rotunda, Enhalus acoroides, Halodule uninervis*, and *Halophila ovalis.* Meanwhile, *Ruppia martimia* was least commonly identified and was recorded in river mouths at Anelgauhat (Aneityum) and Adisone River (Santo) (Hashimoto et al. 2002[148]; McKenzie et al. 2021; Mukai, 1993 [149]). However, subsequent molecular studies have shown that *Halophila*

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[144] McKenzie, L. J. & Yoshida, R.L. (2017). Seagrass - Watch: Proceedings of a workshop for monitoring and mapping seagrass habitats in Vanuatu, Port Vila, 7-9 August 2017. Seagrass – Watch HQ, Cairns. 48pp.
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[147] McKenzie, L. J., Yoshida, R. L., Aini, J. W., Andréfouet, S., Colin, P. L., Cullen-Unsworth, L. C., Hughes, A. T., Payri, C. E., Rota, M., Shaw, C., Skelton, P. A., Tsuda, R. T., Vuki, V. C., & Unsworth, R. K. F. (2021). Seagrass ecosystems of the Pacific Island Countries and Territories: A global bright spot. Marine Pollution Bulletin, 167, 112308. https://doi.org/10.1016/j.marpolbul.2021.112308
[148] Hashimoto, T., Sugimura, K., Tanaka, N., Kokubugata, G., Konishi, T., Chanel, S., & Iwashina, T. (2002). A list of herbarium specimens (Angiosperms) from Vanuatu, Collected in 2000 and 2001 (No. 21; pp. 1–23). Ann. Tsukuba Bot. Gard. https://www.kahaku.go.jp/research/publication/tsukuba/download/21/ATBG21_1.pdf
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minor is conspecific with *H. ovalis*[150]. Additionally, there is contradictory evidence to support that *Halodule uninervis* and *H. pinifolia* are distinct species, due to being indistinguishable using molecular markers and morphological differences possibly being caused by environmental factors[151]. This reduces the confirmed number of seagrass species in Vanuatu from thirteen to eleven (the complete list can be viewed in Seagrass results Table 25).

The exact area and species distributions of seagrass across Vanuatu is highly uncertain, as no comprehensive on-ground mapping study has been carried out. Pascal et al. (2015) suggested that Vanuatu's seagrass area is 1,500 ha, however the referenced source does not verify this. Other area estimates come from remotely sensed data, which have significant limitation for seagrass mapping. An estimate of 124,000 ha intact seagrass across Vanuatu (Mackey et al. 2017[152]), was used for ecosystem services estimates, based on 2005 global seagrass mapping using remote sensing (Short 2005[153]), however Allen Coral Atlas mapping (2018-2021)[154] estimates that Vanuatu seagrass at only 469 ha.

The density of seagrass cover typically relates to site specific characteristics as well as species composition. Few past studies in Vanuatu have specifically reported seagrass percent cover, however it is noted to range from patchy meadows with less than 20% cover, through to highly dense meadows with estimates of larger than 50% cover (Lincoln et al. 2021[155]; Seagrass-Watch 2022[156]). These estimates were observed both within and between locations, highlighting this natural variation in seagrass density.

Seagrass habitats of Vanuatu are vulnerable to cyclones, tectonic uplift (shallowing effect), overfishing and sedimentation and nutrient pollution from development, rapid population growth and logging (Hickey 2007[157]; Brodie & De Ramen 2018[158]). These threats have specifically been observed in studies of nearshore habitats in Efate (Lincoln et al. 2021[159]), Malekula (Hickey, 2007) and likely impact other locations with high population densities such as Espiritu Santo.

Seagrass habitats of Vanuatu support a diversity of species of significant value to culture, livelihood, economy and biodiversity, including marine turtles, marine mammals, fishes (including sharks), invertebrates (including endangered species such as giant clams (*Tridancna spp*.) and commercialised shellfish such as trochus (*Trochus niloticus*) and green snail (*Turbo marmoratus*) (Komugabe-Dixen et al. 2019[160]; Hickey 2007). Ecosystem services delivered by Vanuatu coastal seagrass is considered very high per hectare, despite covering relatively smaller areas than other habitat types (Mackey et al. 2017[161]).

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[150] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. Marine pollution bulletin, 160, 111636.
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[154] Allen Coral Atlas (2020). Imagery, maps and monitoring of the world's tropical coral reefs. Zenodo. doi:10.5281/zenodo.3833242
[155] Lincoln, S., Vannoni, M., Benson, L., Engelhard, G. H., Tracey, D., Shaw, C., & Molisa, V. (2021). Assessing intertidal seagrass beds relative to water quality in Vanuatu, South Pacific. *Marine Pollution Bulletin*, *163*, 111936.
[156] Seagrass-Watch. (2022). Vanuatu Seagrass Monitoring. Retrieved March 6, 2025, from https://www.seagrasswatch.org/vanuatu/
[157] Hickey, F. (2007). *Marine ecological baseline report for Amal/Crab Bay Tabu Eria, Malekula Island, Vanuatu* (IWP-Pacific Technical Report No. 45). Secretariat of the Pacific Regional Environment Programme. ISBN: 978-982-04-0368-0.
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[160] Komugabe-Dixson, A. F., de Ville, N. S., Trundle, A., & McEvoy, D. (2019). Environmental change, urbanisation, and socio-ecological resilience in the Pacific: Community narratives from Port Vila, Vanuatu. *Ecosystem Services*, *39*, 100973.
[161] Mackey, B., Ware, D., Nalau, J., Buckwell, A., Sahin, O., Fleming, C., ... & Hallgren, W. (2017). *Vanuatu Ecosystem and Socio-economic Resilience Analysis and Mapping (ESRAM)*. SPREP.

6.2 Mangrove past studies

Estimates of mangrove coverage in Vanuatu vary widely, and few ground-truthed surveys have been conducted on a national-scale. One of the earliest field surveys studying mangrove distributions in Vanuatu was conducted by David (1985)[162]. Their survey identified almost 2,000 ha of mangroves on Malekula (Malakula) Island, followed by 210 ha on Hiu (Hiw) Island, then 100 ha on Efate Island. Across the remaining six islands surveyed, mangrove coverage totalled approximately 235 ha. The largest mangrove stands identified by David (1985) were located in Malekula in the Port Stanley-Crab Bay area (approximately 950 ha) and Port-Sandwich-Lamap-Maskelyne area (approximately 725 ha). Similarly, the Department of Forests estimate that Vanuatu's mangrove forests cover between 2,500 and 3,000 ha (Department of Forests 2021[163]). However, a remote sensing approach employed by MangroveWatch, suggests that mangrove coverage as of 2020 may be significantly lower at approximately 1,584 ha (Bunting et al. 2022[164]; Global Mangrove Watch 2011[165]), and another recent source of Mangrove spatial data (GIZ 2018[166]) suggests mangroves as spanning only 865 ha.

Mangrove forests in Vanuatu support 25 species, representing approximately 32% of global mangrove diversity. This includes species from the genera *Acanthus, Acrostichum, Avicennia, Barringtonia, Bruguiera, Ceriops, Dolichandrone, Excoecaria, Heritiera, Lumnitzera, Pemphis, Rhizophora, Sonneratia*, and *Xylocarpus* (Baereleo et al. 2013[167]; Duke et al. 2012[168], FAO 2005[169], Saenger et al. 1983[170]). The most common mangrove species recorded by Baerelo et al. (2013) in Amal/Crab Bay (Malekula Island) and Eratap (Efate Island) were the following*: Rhizophora* spp.*, Avicennia marina, Ceriops tagal, Bruguiera gymnorhiza, and Xylocarpus granatum.*

The most notable research on mangrove ecosystems in Vanuatu have formed part of the MESCAL project, which produced several reports on mangroves in the region between 2012 and 2013. These studies were conducted in Amal/Crab Bay (Malekula Island) and Eratap (Efate Island) with the objective of establishing a national baseline information on mangroves ecosystems, their uses and values, as well as educating local communities and guide management practices (Baereleo et al. 2013). This project included:

- developing standardised mapping practices of mangroves
- conducting mangrove floristic and biomass surveys
- as well as rapid fauna assessments.

Surveys in Amal and Crab Bay mapped approximately 136.5 ha of mangrove forest, identifying 11 mangrove species, along with three (3) and five (5) major vegetation types, respectively. The dominant species in these areas were *Cerips tagal* and *Xylocarpus granatum*. In Eratap, approximately 312 ha of mangrove forest were mapped, with three (3) major vegetation types and 12 mangrove species identified, with *Rhizophora stylosa* being the most dominant. A key outcome

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[162] Tari, T., & Naviti, W. (2001). Inventory of the status of mangrove wetlands in Vanuatu. In proceedings of the Regional workshop: Mangrove Wetland Protection & Sustainable Use. Marine Studies Centre, USP Suva, June 12-16, 2001. Retrieved March 6, 2025, from https://www.sprep.org/att/IRC/eCOPIES/Countries/Vanuatu/2.pdf
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[165] Global Mangrove Watch. (2011). Vanuatu Mangrove Habitat Extent and Change. Retrieved March 6, 2025, from https://www.globalmangrovewatch.org/country/VUT
[166] Mangrove spatial data supplied by GIZ, dated 2018
[167] Baereleo, R., Kalfatak, D., Kanas, T., Bulu, M., Ham, J., Kaltavara, J., Sammy, E., Dovo, P., Duke, N., Mackenzie, J., Sheaves, M., Johnston, R., & Yuen, L. (2013). Biodiversity Assessments Technical Report (Eratap and Amal/Crab Bay). Mangrove EcoSystems for Climate Change Adaptation and Livelihoods (MESCAL). https://vanuatu-data.sprep.org/system/files/mangroves_biodiversity_assessment_report_vanuatu.pdf
[168] Duke, N. C., Mackenzie, J., & Wood, A. (2012). A revision of mangrove plants of the Solomon Islands, Vanuatu, Fiji, Tonga, and Samoa. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University. Retrieved March 6, 2025, from https://vanuatu-data.sprep.org/system/files/a_revision_of_mangrove_plants.pdf
[169] FAO 2005, GLOBAL FOREST RESOURCES ASSESSMENT 2005, THEMATIC STUDY ON MANGROVES, VANUATU COUNTRY PROFILE. Food and Agriculture Organization of the United Nations. Rome (Italy).
[170] Saenger, P., Hegerl, E.J. & Davie, J.D.S. 1983. Global status of mangrove ecosystems. Commission on ecology papers No. 3. Gland, Switzerland, IUCN.

of this survey was the identification of eight new mangrove species in Vanuatu, increasing the previous record from 15 to 24 (Baereleo et al. 2013).

In addition to floristic assessments, MangroveWatch evaluated ecosystem health and condition of fringing mangroves in Crab Bay and Eratap using video record assessments (McKenzie et al. 2013[171]). In Crab Bay, mangroves were in good to very good condition (90% of mangroves on the 7.72 km shoreline), with minimal dieback and dense to full leaf cover, and an average canopy height of approximately 5 m. Their report primarily identified non-anthropogenic factors such as wave action and wind as the main factors driving mangrove dieback and damage. There was some evidence of cutting or clearing, although this was typically to improve accessibility for local communities. By comparison, Eratap Lagoon had much more significant levels of anthropogenic disturbance, with over 1.7 km of the 5.71 km of fringing mangroves surveyed being impacted by human clearing or cutting. C. tagal was noted as a tree species commonly harvested for construction (McKenzie et al. 2013; Baereleo et al. 2013).

The rapid fauna assessment conducted as part of the MESCAL project identified a general pattern of greater species diversity across all fauna groups in the Amal-Crab Bay area, in comparison to Eratap. The greatest disparity between the sites was most notable among avifauna and reptiles, where 15 bird and eight (8) reptile species were recorded in Amal-Crab Bay area, meanwhile eight (8) bird and three (3) reptile species were identified in Eratap. Gastropods found in Amal-Crab Bay were generally more abundant and larger than those found in Eratap. The most notable recording in this study was the first sighting of the endemic Scaly-toed Gecko (*Lepidodactylus vanuatuensis*) on Malekula Island (Baereleo et al. 2013[172]). Environmental threats recorded during this assessment included harvesting/clearing of mangrove trees, leasing of land adjacent to mangroves, overharvesting of Giant Mangrove Whelks (*Terebralia palustris*), and waste/litter disposal.

This MACBLUE study seeks to build on the existing knowledge and then extend the assessment to other locations. Being able to compare multiple locations across Vanuatu will enhance understanding of the unique characteristics and vulnerabilities of these ecosystems. This broad spatial coverage facilitates comparative analyses, helping to identify patterns and trends that may not be apparent in smaller-scale studies. This study focused on some of these known key areas of mangrove in Vanuatu, specifically Malekula and Efate, in addition to areas assessed for the first time on Espiritu Santo and Malo Island.

[171] Mackenzie, J., Duke, N. C., & Wood, A. (2013). MangroveWatch assessment of shoreline Mangroves in Vanuatu (No. 13/50). TropWATER. https://vanuatu-data.sprep.org/system/files/mangrovewatch_svam_report_vanuatu.pdf

[172] Baereleo, R., Kalfatak, D., Kanas, T., Bulu, M., Ham, J., Kaltavara, J., Sammy, E., Dovo, P., Duke, N., Mackenzie, J., Sheaves, M., Johnston, R., & Yuen, L. (2013). Biodiversity Assessments Technical Report (Eratap and Amal/Crab Bay). Mangrove EcoSystems for Climate Change Adaptation and Livelihoods (MESCAL). https://vanuatu-data.sprep.org/system/files/mangroves_biodiversity_assessment_report_vanuatu.pdf

6.3 Vanuatu study sites

Seagrass meadows and mangrove forests were surveyed across three Islands in Vanuatu, including Efate, Malekula and Espiritu Santo. The survey locations for both mangroves and seagrass are shown in Figure 68, including: Moso-Undine Bay and Port Vila-Eratap (Efate Island, Shefa Province), Santo and Malo-Aore (Espiritu Santo Island, Sanma Province) and Malekula and Maskelyne (Malekula Island, Malampa Province). A total of 19 mangrove sites and 14 seagrass sites were surveyed across a diversity of geomorphological settings in order to capture representative data for these dynamic ecosystems. Locations and sites are shown in detail in Figure 68 to Figure 75.

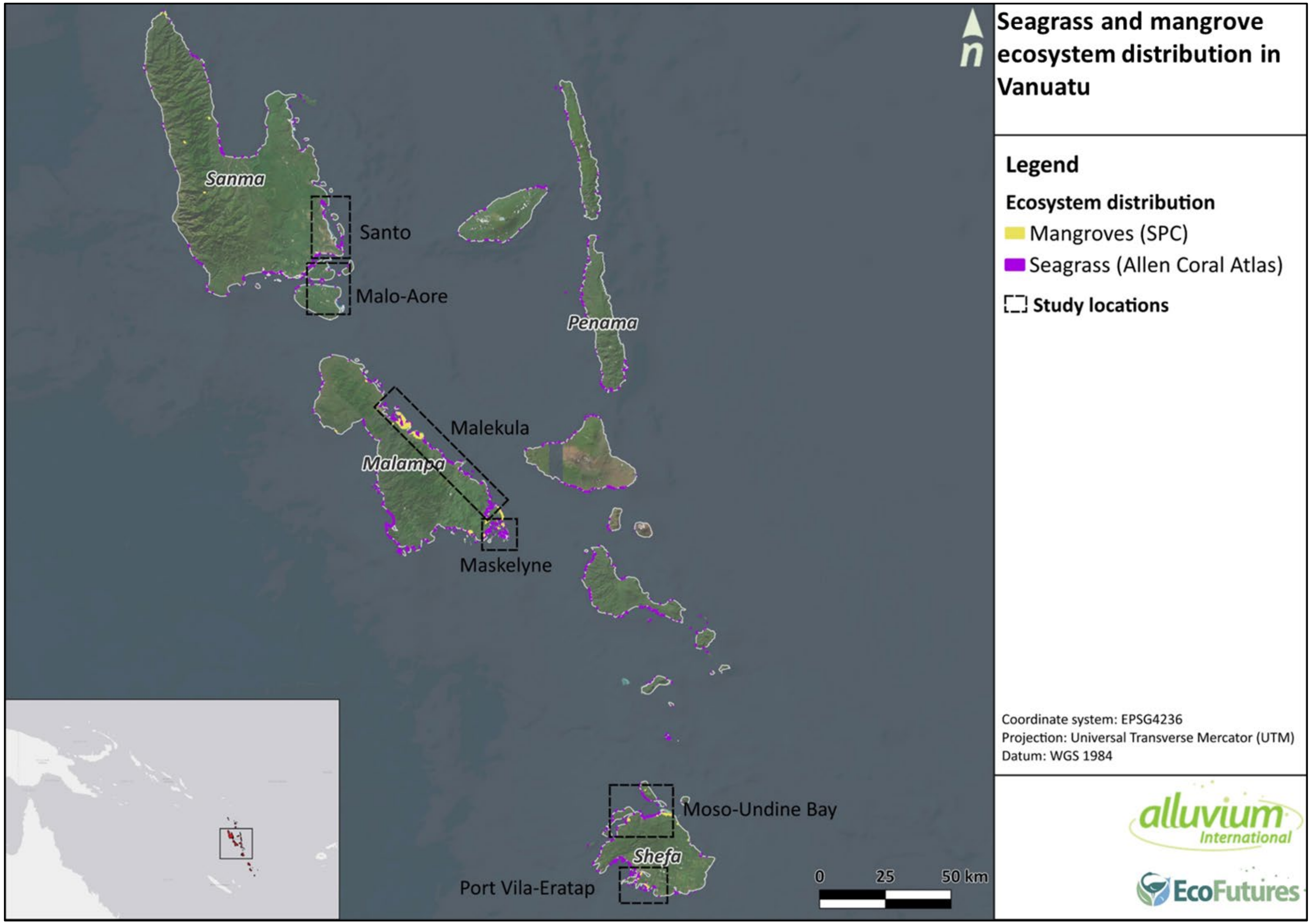

Figure 68. Seagrass and mangrove ecosystem distribution and survey locations in Vanuatu.

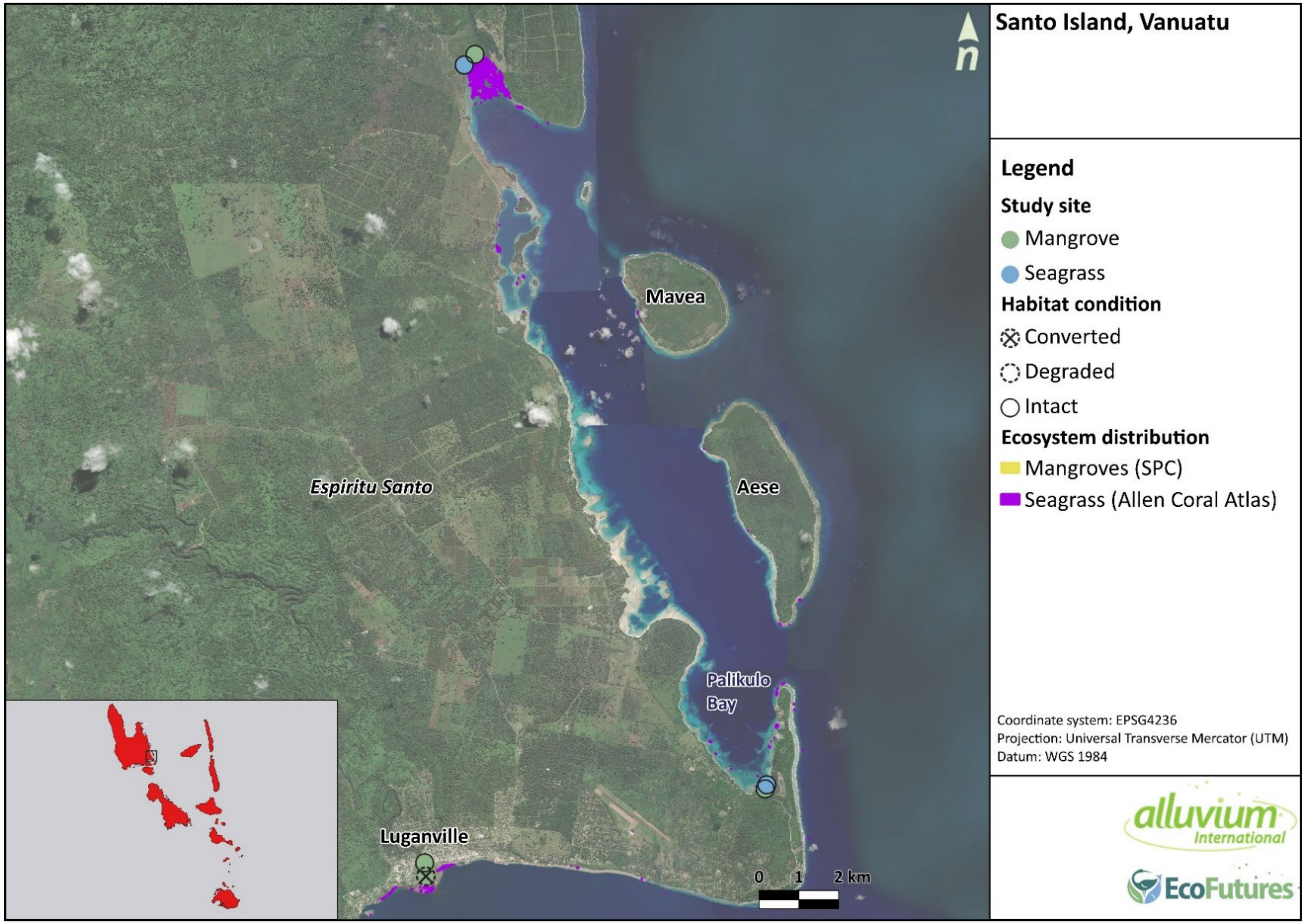

Figure 69. Seagrass and mangrove ecosystem distribution and survey sites at Santo. At this location, three (3) intact and one (1) converted mangrove sites and two (2) intact seagrass sites were assessed.

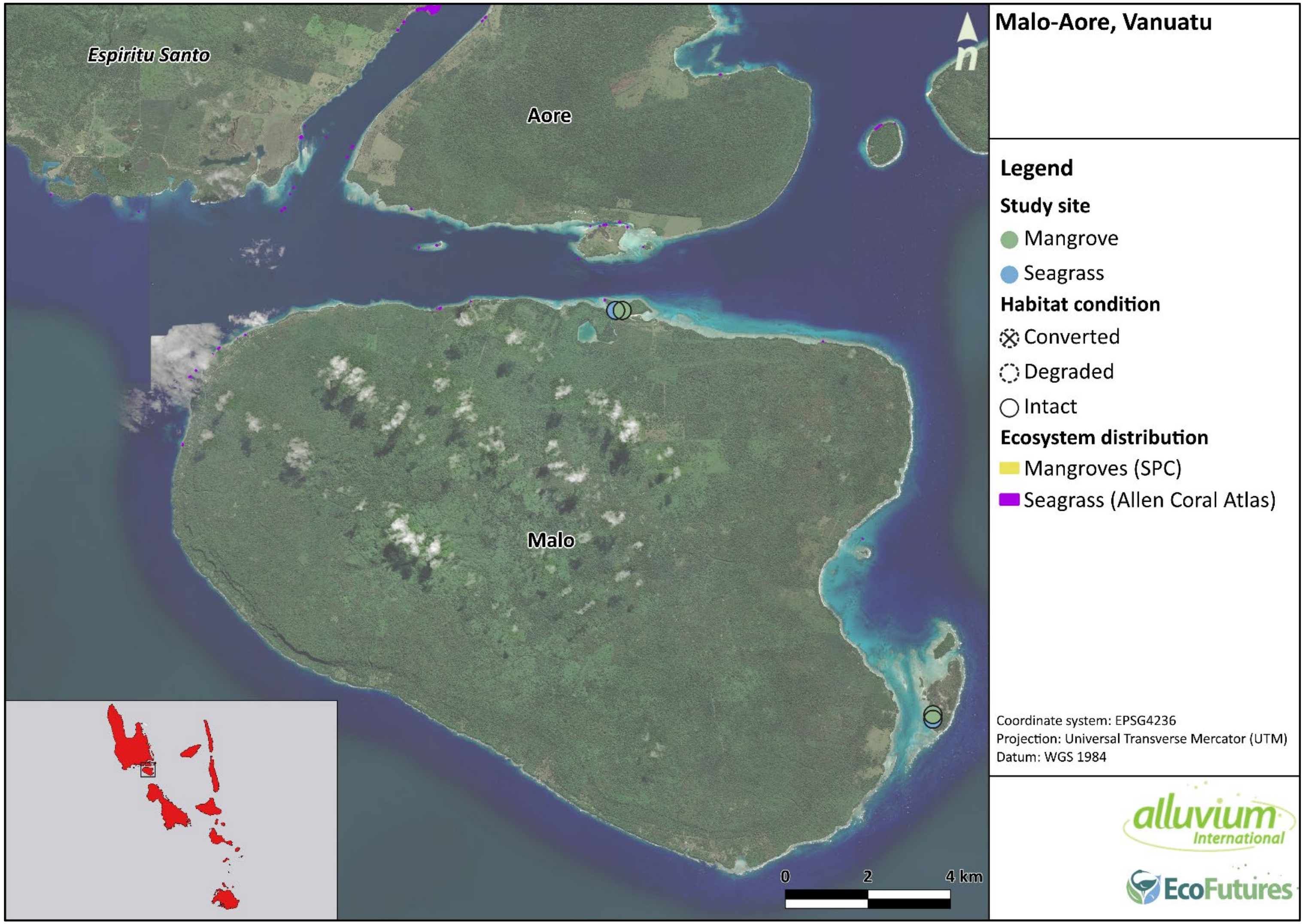

Figure 70. Seagrass and mangrove ecosystem distribution and survey sites at Malo-Aore. At this location, two (2) intact mangrove sites and two (2) intact seagrass sites were assessed.

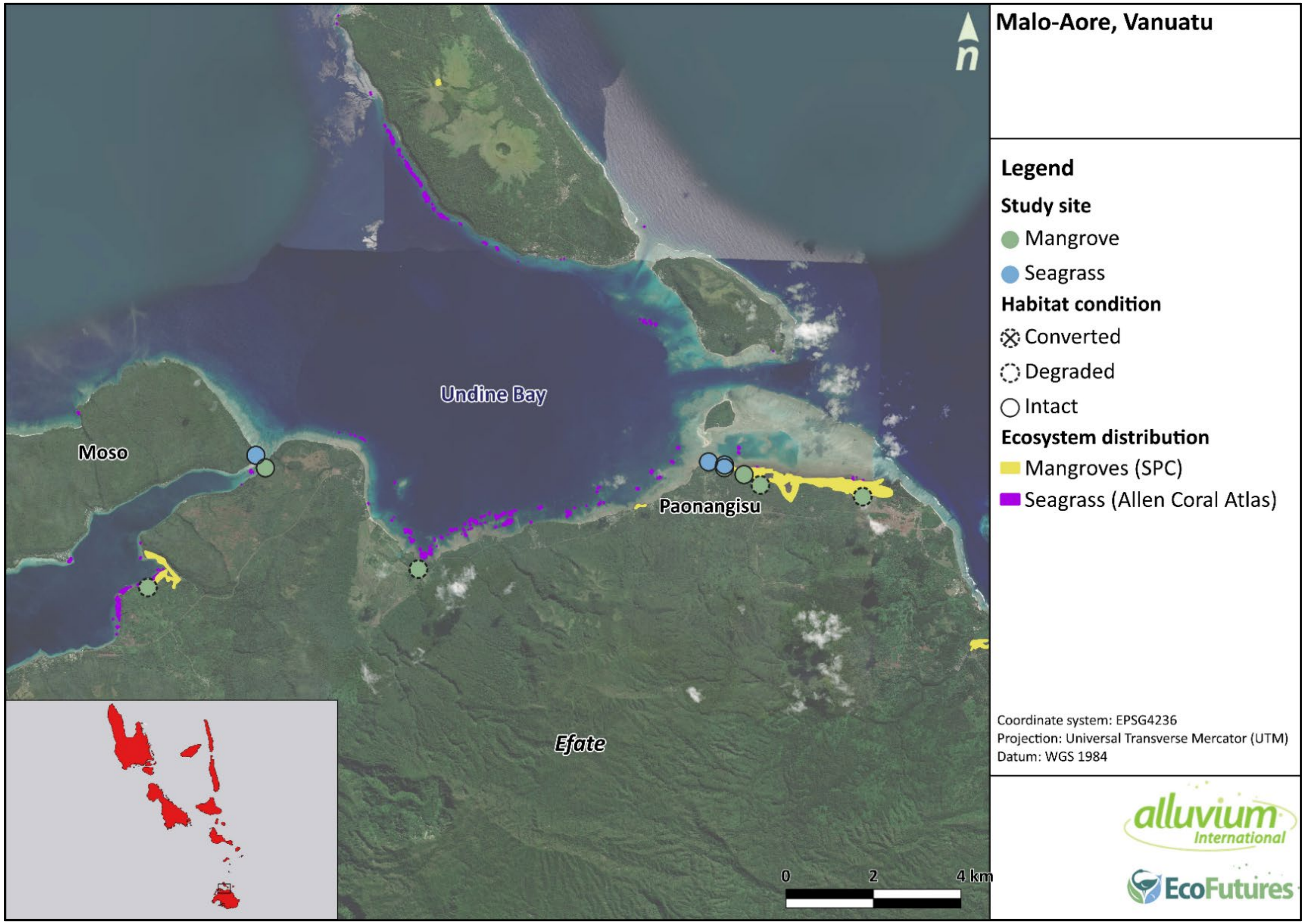

Figure 71. Seagrass and mangrove ecosystem distribution and survey sites at Moso-Undine Bay. At this location, three (3) intact and four (4) degraded mangrove sites and two (2) intact seagrass sites were assessed.

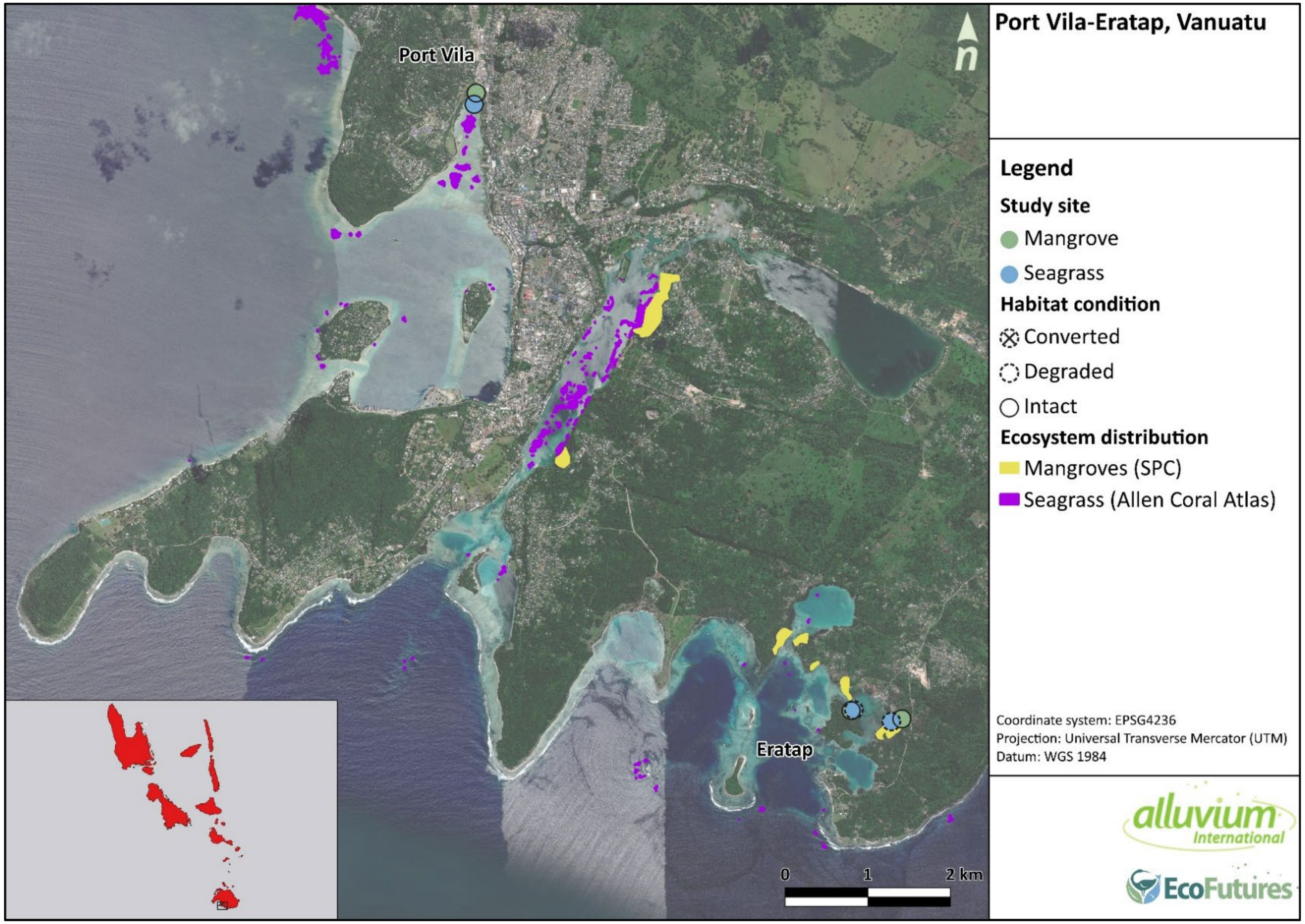

Figure 72. Seagrass and mangrove ecosystem distribution and survey sites at Port Vila-Eratap. At this location, one (1) intact and two (2) degraded mangrove sites and three (3) intact seagrass sites were assessed.

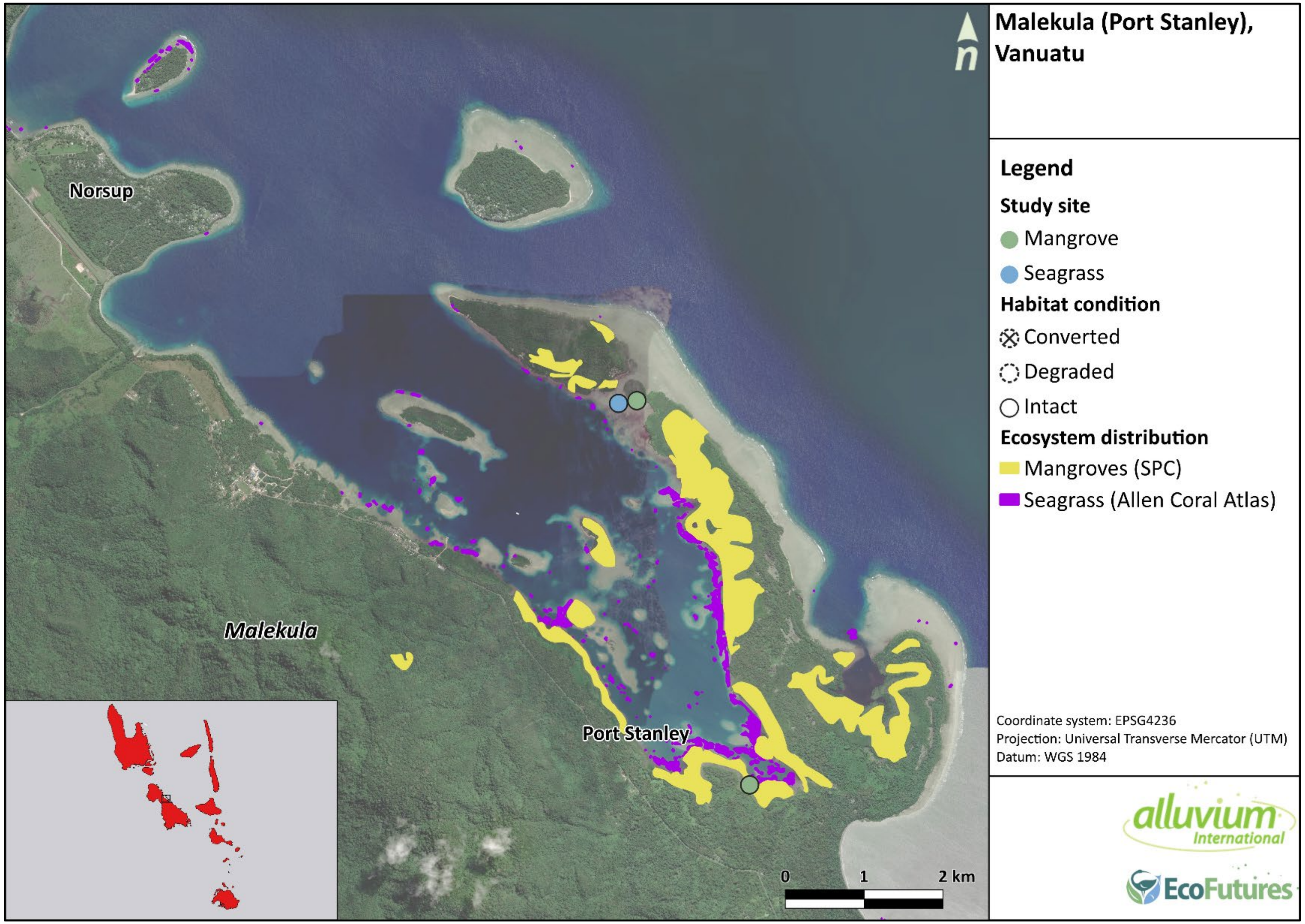

Figure 73. Seagrass and mangrove ecosystem distribution and survey sites at Malekula (Port Stanley section). At this location two (2) intact mangrove sites and one (1) intact seagrass site were assessed.

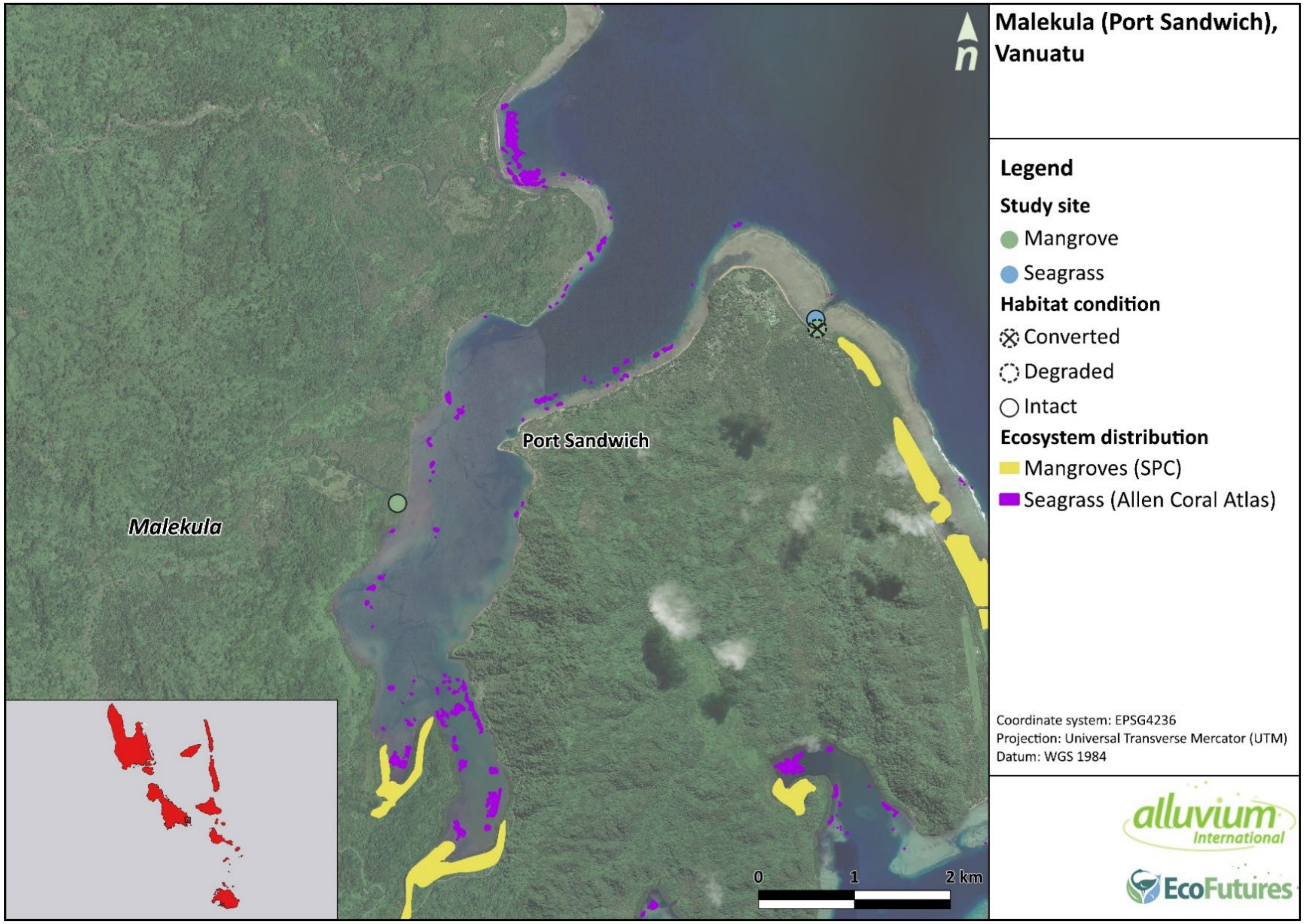

Figure 114. Seagrass and mangrove ecosystem distribution and survey sites at Malekula (Port Sandwich section). At this location, one (1) intact mangrove site, one (1) converted mangrove site, and one (1) intact seagrass site were assessed.

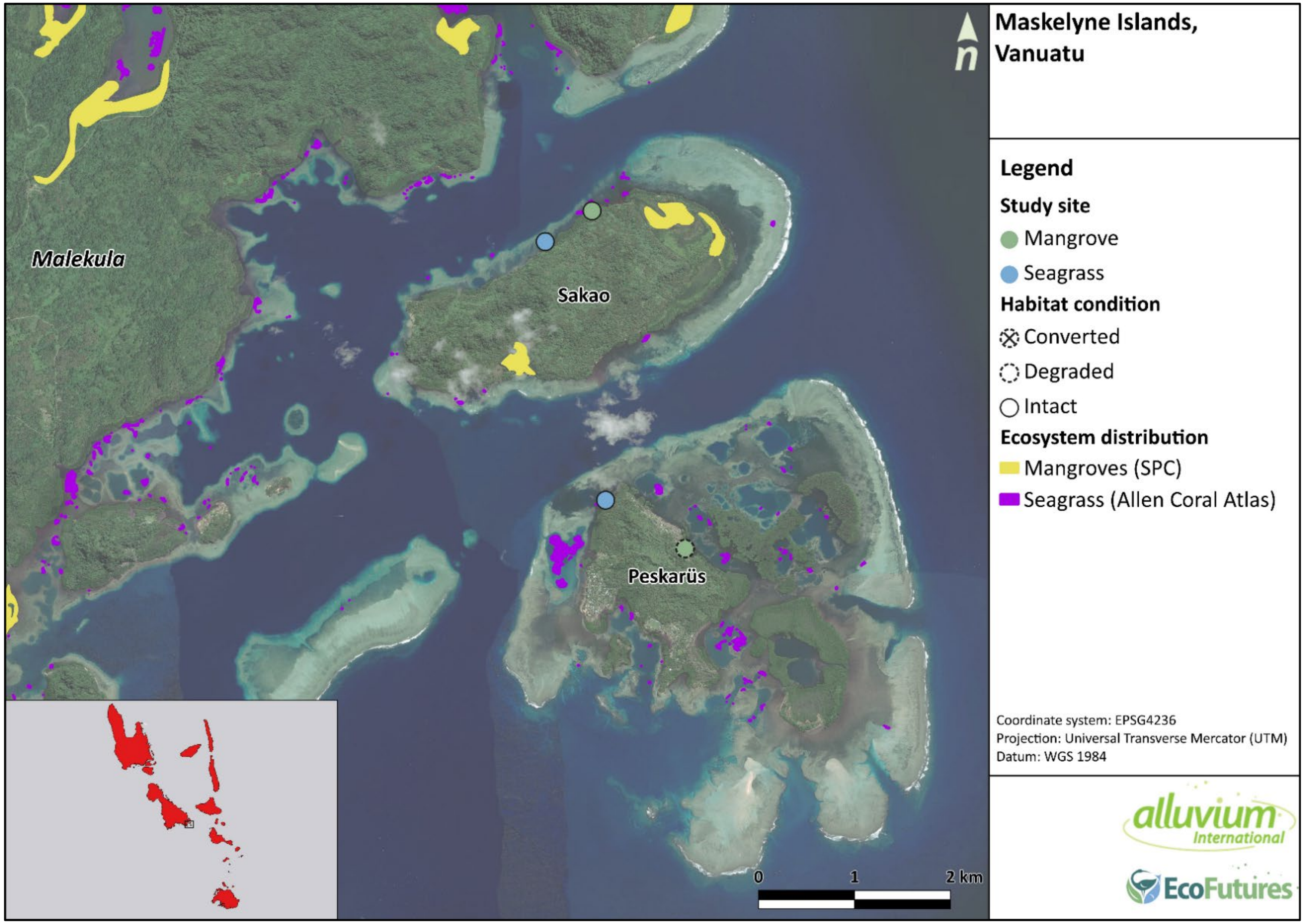

Figure 75. Seagrass and mangrove ecosystem distribution and survey sites in the Maskelyne Islands. At this location, one (1) intact and one (1) degraded mangrove site and two (2) intact seagrass sites were assessed.

6.4 Vanuatu ecosystem assessment results

6.4.1 Seagrass results

A total of seven (7) of the eleven species (11) of seagrass known from Vanuatu were recorded from the fourteen seagrass sites sampled (Table 25). Meadows sampled were predominantly on fringing reef flats or islands. Eight of the thirteen sites were meadows with multiple species of seagrass which is common in Vanuatu. Of the six locations sampled in the project, Moso-Undine Bay and Port Vila-Eratap had the highest species diversity with four out of the seven species found. Malo-Aore had the lowest species diversity (Table 25). Photos of each site surveyed were captured and can be found in Appendices.

Table 25. Seagrass species found in the MACBLUE compared to previous seagrass species lists described for Vanuatu

Species	Moso-Undine Bay	Port Vila-Eratap	Santo	Malo-Aore	Malekula	Maskelyne	Past studies in the Vanuatu [173, 174]
Cymodoceae rotundata	X		X	X	X	X	X
Cymodoceae serrulate							X
Enhalus acoroides	X	X				X	X
*Halodule pinifolia / Halodule uninervis **	X	X	X		X		X
Halophila capricorni							X
Halophila decipiens							X
*Halophila ovalis / Halophila minor ***	X	X			X		X
Ruppia maritima							X
Syringodium isoetifolium							X
Thalassia hemprichii		X					X
Thalassodendron ciliatum							X

* For the purpose of this study the sets of species and/or sub-species that require molecular analysis to correctly identify and differentiate, were binned together and not analysed separately [175] ** Note that molecular studies have found *H. minor* is conspecific with *H. ovalis*[176]

Cymodocea rotundata was the most commonly recorded species in the assessment, found at 62% of the sites. Two of the thirteen sites were monospecific *C. rotundata* meadows, while another two sites were monospecific *Enhalus acoroides* meadows. The next most common species were *Enhalus acoroides, Halodule uninervis* and *Halophila minor*, which were recorded at 38%, 31% and 23% of the sites sampled, respectively.

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[173] Hickey, F. 2007. Marine ecological baseline report for Amal/Crab Bay Tabu Eria, Malekula Island, Vanuatu. Apia, Samoa. Secretariat of the Pacific Regional Environment Programme (SPREP).
[174] McKenzie, L. J. & Yoshida, R.L. (2017). Seagrass - Watch: Proceedings of a workshop for monitoring and mapping seagrass habitats in Vanuatu, Port Vila, 7-9 August 2017. Seagrass – Watch HQ, Cairns. 48pp.
[175] McKenzie, L.J., & Yoshida, R.L. (2007). Seagrass-Watch: Guidelines for Monitoring Seagrass Habitats in the Fiji Islands. Proceedings of a training workshop, Corpus Christi Teachers College, Laucala Bay, Suva, Fiji, 16th June 2007. Seagrass-Watch HQ Cairns.
[176] McKenzie, L. J., & Yoshida, R. L. (2020). Over a decade monitoring Fiji's seagrass condition demonstrates resilience to anthropogenic pressures and extreme climate events. Marine pollution bulletin, 160, 111636.

Port Vila-Eratap had the highest average seagrass coverage of 54% (± 20 SE), followed by Moso-Undine Bay at 46% (± 23 SE) coverage, while Malekula had the least coverage of 29% (± 12 SE) (Figure 82). This is likely reflecting the predominance of *Enhalus acoroides* in the meadows sampled in Port Vila-Eratap compared to the other locations. Meadows dominated by *E. acoroides* assessed in this study typically had a higher % coverage than those dominated by other species.

Port Vila-Eratap was the only location with degraded sites and had an average seagrass coverage of 39% (± 24 SE) (Figure 83). Overall, the degraded sites had a similar seagrass coverage to the intact sites at Santo (41%), Male-Aore (41%), Malekula (29%) and Maskelyne (41%) (Figure 83).

Threats to the seagrass meadows of Vanuatu are typically from sediment plumes related to erosion associated with catchment clearing (e.g. logging and mining); sewage discharge; industrial pollution; and overfishing (Table 26). Most of the sites assessed in this project were found to have low levels of threats; however, extreme events (e.g. cyclones and floods), along with invasive species, species collection and harvesting using seine/dragnet methods were identified as key potential threats (Table 26).

Overall, most of the seagrass sites assessed in this study generally experience low levels of threat. However, Santo did result with a high threat level at the landscape scale (Table 26). This location had a multitude of threats which were mostly related to anthropogenic activities. Seagrass sites in Moso-Undine Bay and Maskelyne were the least threatened, followed by Malo-Aore, Malekula and Port Vila-Eratap, which had similar threat scores.

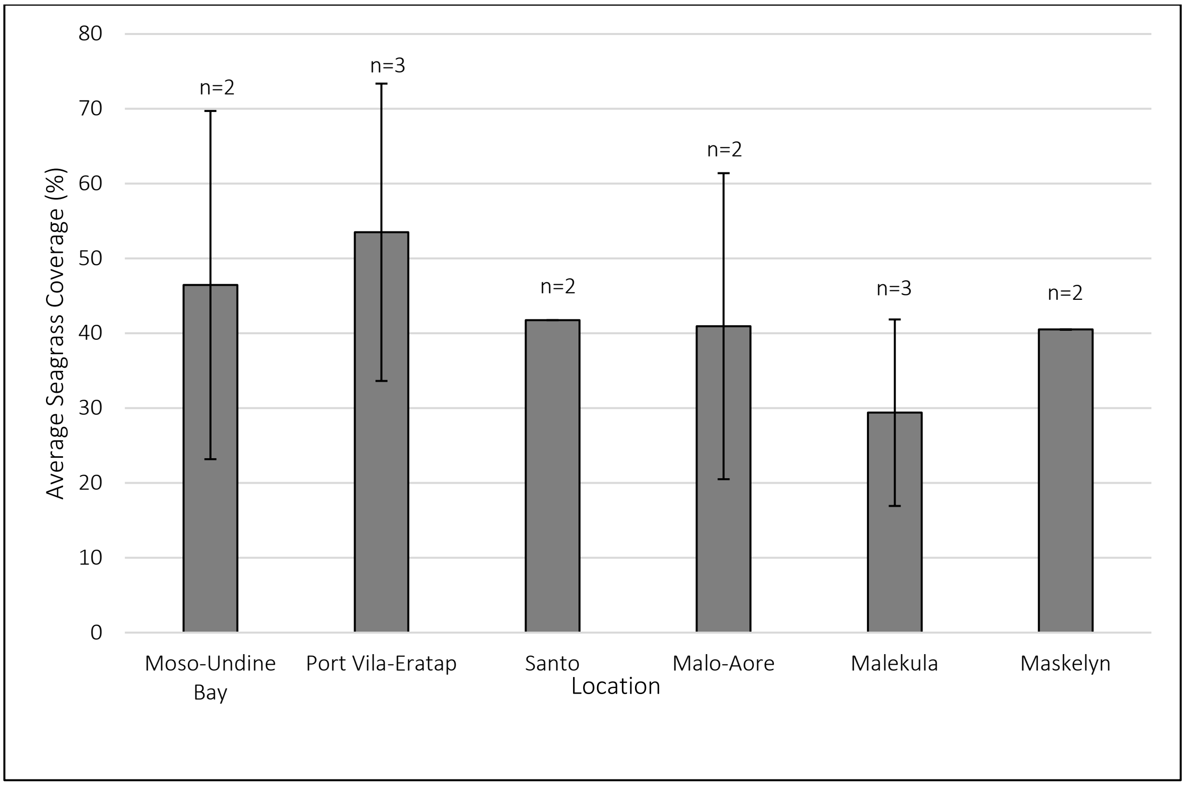


Figure 76. Average seagrass coverage (%) (± SE) across six locations in Vanuatu, where n is the number of sites surveyed at each location.

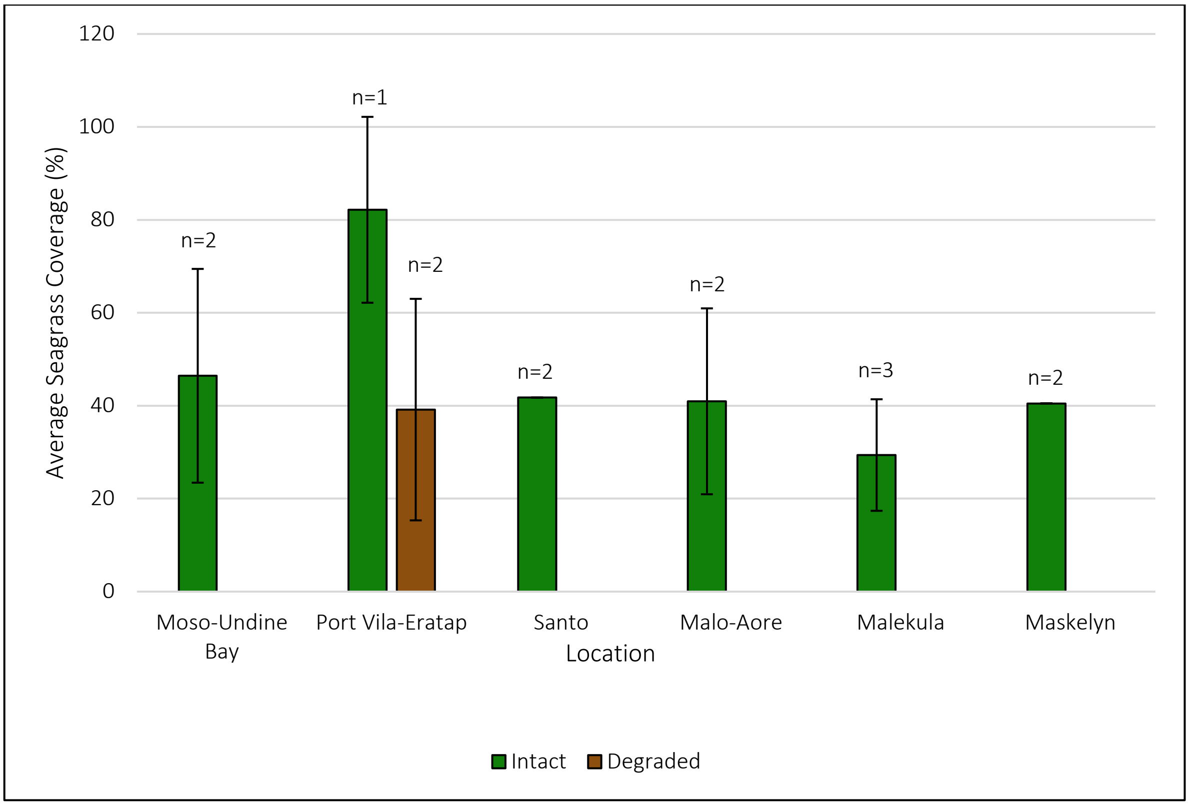


Figure 77. Average seagrass cover (%) (± SE) across intact and degraded locations, where n is the number of sites surveyed at each location.

Table 86. Rapid threat assessment results for the seagrass sites in the Vanuatu showing total scores and individual threat scores averaged across sites within a location. The maximum total score for habitat scale and landscape scale is 40 and 35 respectively, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in the Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Moso-Undine Bay	Shell harvesting, mobile sand bank, sand mobilisation during cyclone.	*Habitat*	34	NA	5	5	4	NA	5	5	5	4	1
		Landscape	30	5	NA	NA	NA	5	5	5	5	4	1
Port Vila-Eratap	Development in surroundings	*Habitat*	26	NA	5	4	3	NA	5	5	4	0	4
		Landscape	22	5	NA	NA	NA	3	5	5	4	3	2
Santo	Road parallel restricting tidal flow, fishing by seine, unsealed roads, high-level of harvesting for seagrass and mangrove fauna, cyclones, sea-level rise.	*Habitat*	26	NA	4	4	4	NA	3	3	1	4	4
		Landscape	16	4	NA	NA	NA	1	4	3	0	4	2
Malo-Aore	Fishing by seine, cyclones, boating.	*Habitat*	28	NA	4	4	5	NA	4	5	1	5	1
		Landscape	21	5	NA	NA	NA	3	4	4	1	4	1
Maskelyne	Fishing from outriggers, reduction in seagrass extent due to increased human population, and subsequent intensity of fishing.	*Habitat*	34	NA	5	5	5	NA	4	5	3	5	2
		Landscape	27	5	NA	NA	NA	4	4	5	3	5	2
Malekula	Constructed berm along sea edge,	*Habitat*	28	NA	4	4	4	NA	4	4	3	4	2
		Landscape	24	5	NA	NA	NA	4	4	4	3	4	2

6.4.2 Mangrove results

A total of seven (7) of the 25 mangrove species known to inhabit Vanuatu were recorded in the assessments, with the distribution of the species amongst the four locations outlined in Table 27. Overall, *Rhizophora stylosa* was the most abundant species recorded across the locations (n = 613), followed by *Sonneratia alba* (n = 247), *Avicennia marina* (n = 230), *Ceriops tagal* (n = 160) and *Bruguiera gymnorhizai* (n = 98). The least abundant species were *Xylocarpus granatum* (n =42) and *Lumnitzera littorea* (n = 8) (Table 27).

Mangrove forests that have a greater species diversity have been found to have enhanced biomass production and soil carbon storage[177] so protecting forests with a higher diversity of species and restoring degraded forests with multiple species is important for maximising carbon storage. Moso-Undine Bay had the highest species diversity with a total of six (6) species, while Santo, Malo-Aore and Malekula had five (5). Port Vila-Eratap and Maskelyne had the least diversity with four (4) mangrove species (Table 27). Photos of each site surveyed were captured and can be found in **Error! Reference source not found.**.

Table 27. Mangrove species list for Vanuatu found in the MACBLUE assessment compared with past studies on mangroves in Vanuatu (T = True Mangrove, A = Associate Mangrove, H = Hybrid/Subspecies/Variant).

Species	Category	Recorded during MACBLUE assessment						Past studies in the Vanuatu[178, 179, 180, 181]
		Moso-Undine Bay	Port Vila-Eratap	Santo	Malo-Aore	Malekula	Maskelyne	
Acanthus ilicifolius	A							X
Acrostichum aureum	A							X
Acrostichum speciosum	A							X
Avicennia marina	T			X	X	X	X	X
Barringtonia racemosa	A							X
Bruguiera gymnorhiza	T	X	X	X	X	X		X
Bruguiera parviflora	T							X
Ceriops tagal	T	X		X	X	X	X	X
Dolichandrone spathacea	A							X
Excoecaria agallocha	T							X

[177] Bai J, Meng Y, Gou R, et al. Mangrove diversity enhances plant biomass production and carbon storage in Hainan Island, China. *Funct Ecol*. 2021; 35: 774–786. https://doi.org/10.1111/1365-2435.13753
[178] Duke, NC, J. Mackenzie & A. Wood 2012, 'A revision of mangrove plants of the Solomon Islands, Vanuatu, Fiji, Tonga and Samoa', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 12/13, James Cook University, Townsville, 22 pp.
[179] Saenger, P., Hegerl, E.J. & Davie, J.D.S. 1983. Global status of mangrove ecosystems. Commission on ecology papers No. 3. Gland, Switzerland, IUCN
[180] Baereleo, R., Duke, N., Chanel, S., Layang, D., Ala, P. and Dovo, P. Section 2. MESCAL Project Mangrove Forestry Surveys of Amal/Crab Bay (Malekula) and Eratap (Efate), Vanuatu. In: Waqalevu, V.P. (ed), 2013, Biodiversity Assessments Technical Report (Eratap and Amal/Crab Bay). Mangrove EcoSystems for Climate Change Adaptation and Livelihoods (MESCAL).
[18] Secretariat of the Pacific Regional Environment Programme. (n.d.). Vanuatu: National Biodiversity Strategy and Action Plan. https://www.sprep.org/att/IRC/eCOPIES/Countries/Vanuatu/2.pdf
[181] FAO 2005, GLOBAL FOREST RESOURCES ASSESSMENT 2005, THEMATIC STUDY ON MANGROVES, VANUATU COUNTRY PROFILE. Food and Agriculture Organization of the United Nations. Rome (Italy).

Species	Category	Recorded during MACBLUE assessment						Past studies in the Vanuatu[178, 179, 180, 181]
		Moso-Undine Bay	Port Vila-Eratap	Santo	Malo-Aore	Malekula	Maskelyne	
Heritiera littoralis	A							X
Lumnitzera littorea	T	X						X
Lumnitzera racemosa	T							X
Pemphis acidula	A							X
Rhizophora apiculata	T							X
Rhizophora mucronata	T							X
Rhizophora samoensis	T							X
Rhizophora stylosa	T	X	X	X	X	X	X	X
Rhizophora X lamarckii	H							X
Rhizophora X selala	H							X
Sonneratia alba	T	X	X	X	X	X		X
Sonneratia caseolaris	T							X
Sonneratia X gulngai	H							X
Xylocarpus granatum	T	X	X				X	X
Xylocarpus moluccensis (syn. *X. mekongensis*)	T							X

Across the six locations surveyed in Vanuatu, Santo had the highest level of threat at the landscape scale (Table 28). This location had an array of threats, which included intensive agriculture, catchment clearing, cyclone damage, coconut plantations, sea-level rise, among other threats (Figure 84).

Port Vila-Eratap also resulted with a high threat level for the landscape scale (Table 28). This threat was mostly related to cyclone damage, fishing, development, clearing for tourism and harvesting. The remaining three locations exhibited lower threat levels at both the habitat and landscape scales (Table 28). The surrounding areas of Malo-Aore had low-level cyclone damage, particularly near Malo Killikilli, where large patches of mangroves had been damaged (Figure 85). Cyclone damage can significantly impact mangrove ecosystem health by causing tree mortality, altering forest structure, and disrupting biogeochemical processes. These changes can lead to prolonged inundation and shifts in salinity, which may result in mangrove diebacks and affect overall ecosystem resilience.

Figure 78. Coastal inundation mitigation measures such as this 10 m sea wall constructed to reduce the impact of sea-level rise to homes and businesses on Santo, impacts natural mangrove functions by hindering tidal inundation, reclamation and natural stratification.

Figure 79. Cyclone damage in a mangrove forest at Malo Killikilli, illustrating uprooted trees, broken branches, and altered forest structure. The disturbance can lead to changes in salinity and prolonged inundation, impacting overall ecosystem health and resilience.

Table 28. Rapid threat assessment results for the mangrove sites in the Vanuatu showing total scores and individual threat scores averaged across sites within a location. The maximum total score for habitat scale and landscape scale is 40 and 35 respectively, and the maximum score for individual threats is 5. Higher scores denote lower threat levels. Refer to Table 5 in the Methods section for a description of each threat.

Location	Observed Key Threats	Scale	Average of total scores for all sites	Average of individual threat scores									
				T1. Major hydrological modifications	T2. Minor hydrological modifications	T3. Inflow from land activity	T4. Sediment resuspension	T5. Land Use	T6. Sea Use	T7. Native habitat conversion	T8. Species collection and harvesting	T9. Non-preferred species	T10. Extreme events
Moso-Undine Bay	Impounded, thermal springs, cattle, cyclone damage, local fishing, rubbish, collection of crabs, dredging, land use change, shell harvest, boat passage, sediment runoff.	*Habitat*	28	NA	4	3	4	NA	4	4	3	4	2
		Landscape	24	4	NA	NA	NA	4	4	4	3	4	2
Port Vila-Eratap	Channels used for fishing, cyclone damage, development in surrounding areas, clearing for tourism, harvesting.	*Habitat*	22	NA	3	3	3	NA	3	3	3	0	3
		Landscape	18	3	NA	NA	NA	2	3	3	3	0	3
Santo	High density of unsealed roads, intensive agriculture, high intensity boating, catchment clearing, cyclone damage, tide restrictions, coconut plantations, sea level rise, increased frequency of extreme high tides.	*Habitat*	23	NA	4	4	3	NA	3	3	1	3	3
		Landscape	16	4	NA	NA	NA	1	3	2	0	4	2
Malo-Aore	Cyclone damage Coconut plantations, cattle grazing, boats, fishing.	*Habitat*	28	NA	4	4	5	NA	4	5	1	5	1
		Landscape	21	5	NA	NA	NA	3	4	4	1	4	1
Maskelyne	Jetty, seawall structures, agriculture, fishing outriggers, human occupation, cyclones.	*Habitat*	32	NA	4	5	5	NA	4	3	3	5	4
		Landscape	26	5	NA	NA	NA	4	4	4	3	4	2
Malekula	Crab and shellfish harvesting, fishing, coconut plantations, settlements, constructed berm along sea edge, inflows from cleared adjacent lands, wind and wave induced sedimentation, mangrove clearing, agriculture, sea-level rise, timber harvesting.	*Habitat*	30	NA	4	5	4	NA	4	4	3	4	2
		Landscape	24	5	NA	NA	NA	4	4	4	3	4	2

Larger trees in forests play a keystone role[182] by contributing a disproportionate level of reproductive components, habitat for other species, and above ground biomass for carbon storage. The largest trees recorded in Vanuatu were typically found in Santo, followed by Malo-Aore (Table 29).

Table 29. The distribution of larger trees across the six (6) locations assessed in Vanuatu. Numbers refer to the percentage (%) of trees recorded in that location. DBH refers to Diameter at Breast Height.

Tree size	Moso-Undine Bay	Port Vila-Eratap	Santo	Malo-Aore	Malekula	Maskelyne
<20cm DBH	86	89	70	81	74	53
>20cm DBH	10	7	23	14	21	44
>50cm DBH	4	4	7	5	3.6	3

In Moso-Undine Bay, *Sonneratia alba* had the largest average Diameter at Breast Height (DBH) of 39 cm (Figure 86), followed by *Xylocarpus granatum* (DBH = 21 cm), *Bruguiera gymnorhiza* (DBH= 10 cm), and *Rhizophora stylosa* (DBH = 9 cm). *Sonneratia alba* displayed the largest range in size and had multiple outliers, which represented the largest trees (maximum DBH 130 cm). *Lumnitzera littorea* demonstrated the least variability in comparison to all other species (Figure 86).

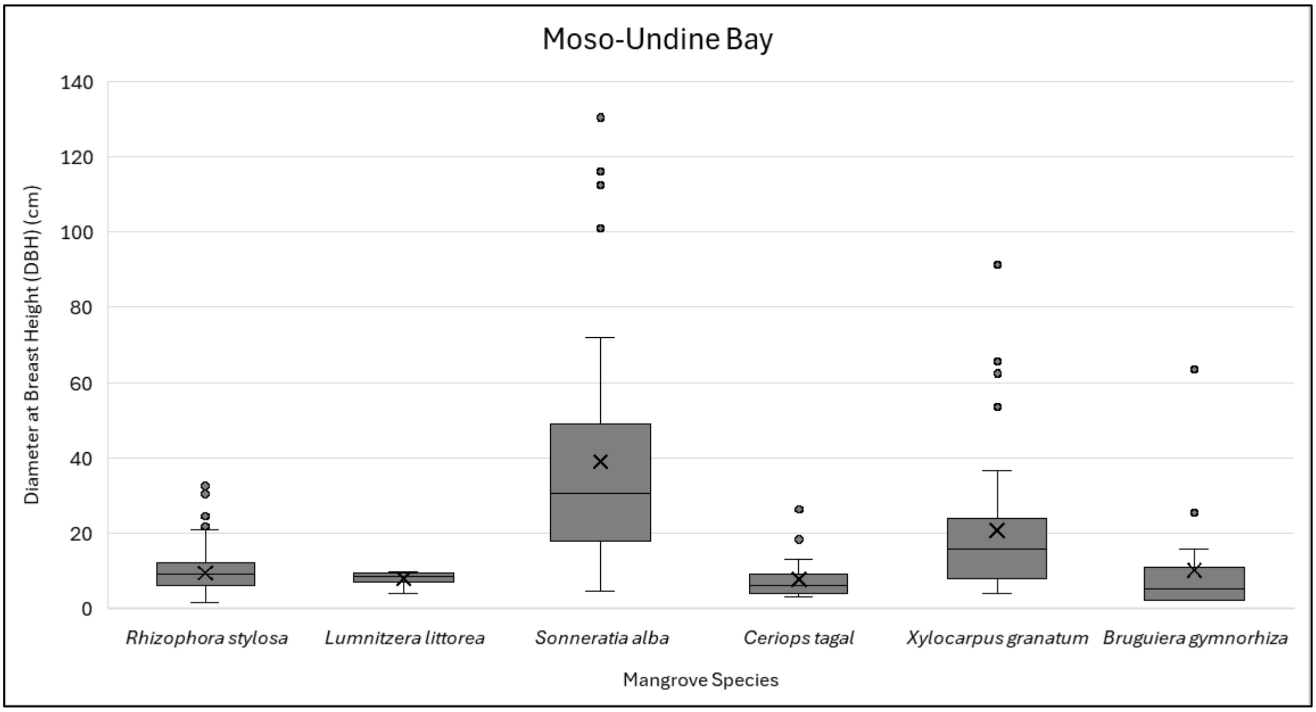


Figure 80. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Moso-Undine Bay. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

[182] D.B. Lindenmayer, W.F. Laurance, J.F. Franklin.(2012). Global decline in large old trees. Science, 338 (6112), pp. 1305-1306

At Port Vila-Eratap the variation in DBH across species was lower in comparison to mangroves found at Moso-Undine Bay, with *Bruguiera gymnorhiza* having an average DBH of 27 cm (Figure 87). *Sonneratia alba* had an average DBH of 18 cm, which was skewed due to two outliers (DBH = 88 cm and DBH = 47 cm). These species were followed by *Rhizophora stylosa* (DBH = 12 and cm) *Xylocarpus granatum* (DBH = 7 cm). *Xylocarpus granatum* had the least variability in DBH size when compared to the other species (Figure 87).

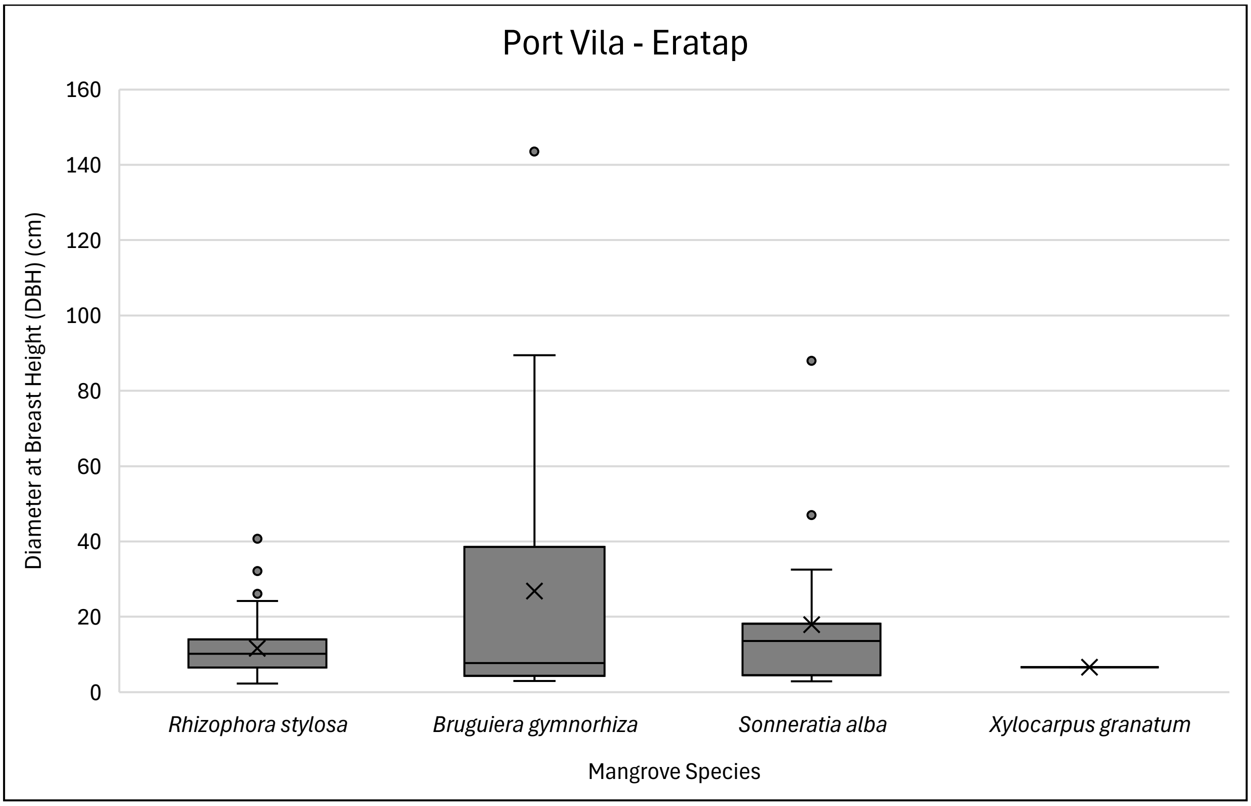


Figure 81. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Port Vila-Eratap. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

In Santo, *Ceriops tagal* had the largest average DBH of 52 cm, with a maximum DBH of 167 cm and also exhibited the widest size range (DBH 17 – 167 cm) compared to the other species (Figure 82). *Sonneratia alba,* had an average DBH of 31 cm, followed by *Bruguiera gymnorhiza* (DBH 16 cm), *Avicennia marina* (DBH = 13 cm) and *Rhizophora stylosa* (DBH = 12 cm). Both *R. stylosa* and *B. gymnorhiza* had the least variability in DBH size when compared to the other species (Figure 82).

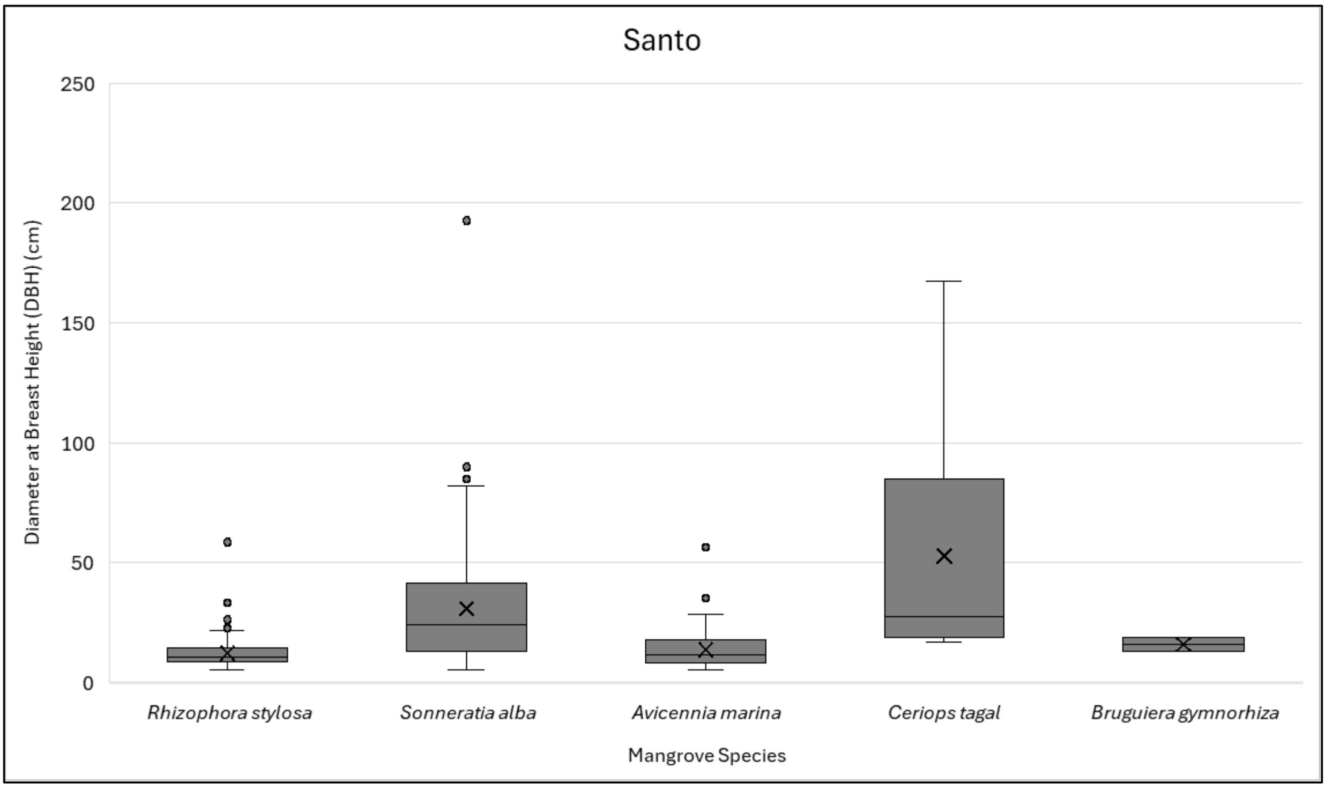


Figure 82. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Santo. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

In Malo-Aore, *Sonneratia alba* trees had the largest average DBH of 53 cm, with a maximum DBH of 84 cm (Figure 83). This species also exhibited the greatest range in size (DBH 15.2 – 84 cm) in comparison to other species (Figure 83). Interestingly, *Bruguiera gymnorhiza* had the same average DBH as *Sonneratia alba* (53 cm); however, it had the smallest range in size at this location (Figure 83). *Avicennia marina* had a DBH of 32 cm, while *Rhizophora stylosa* and *Ceriops tagal* had a DBH of 12 cm and 14 cm, respectively.

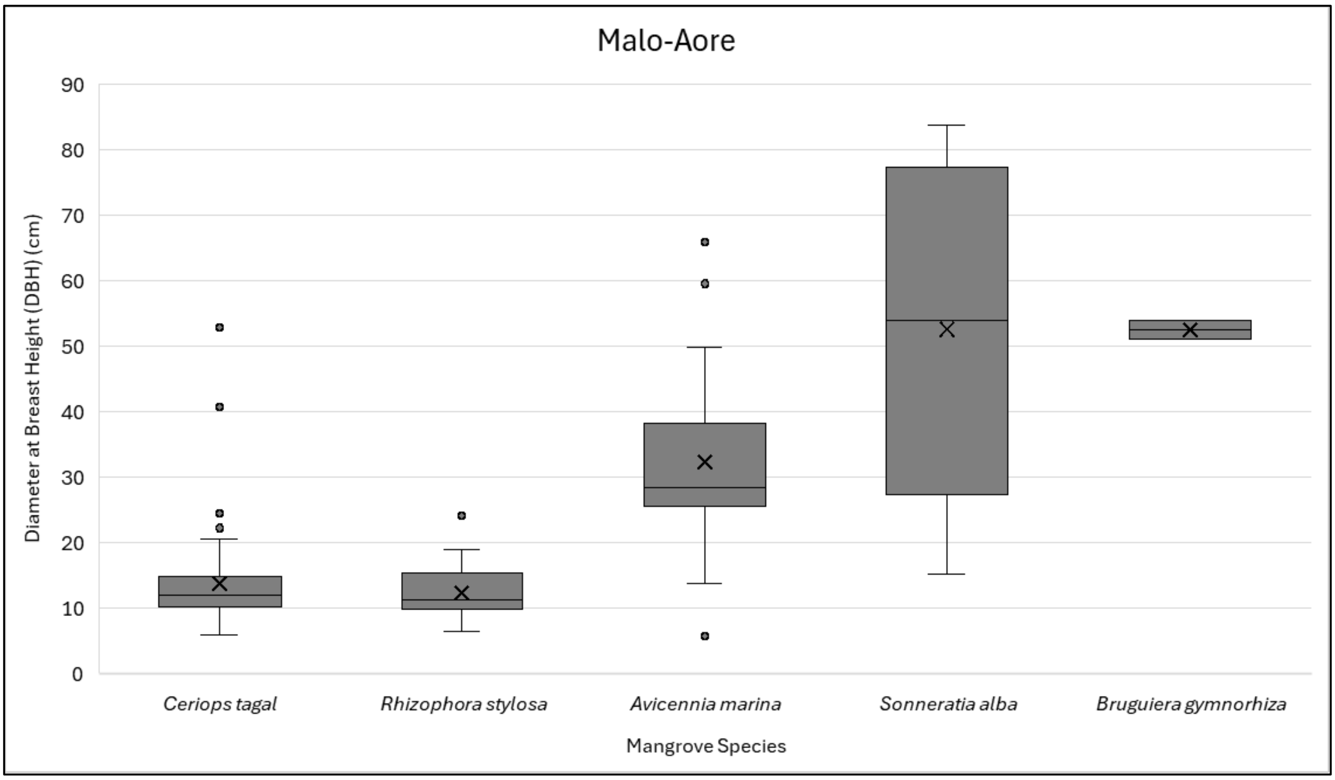


Figure 83. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Malo-Aore. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

In Malekula, *Bruguiera gymnorhiza* had the largest DBH 32 cm and range of size (5 – 78 cm), when compared to the other species (Figure 84). *Avicennia marina* had a DBH of 23 cm and had two outliers, with one being low (6.5 cm) and the other being high (74 cm) (Figure 84). All other species at this location had a DBH < 14 cm.

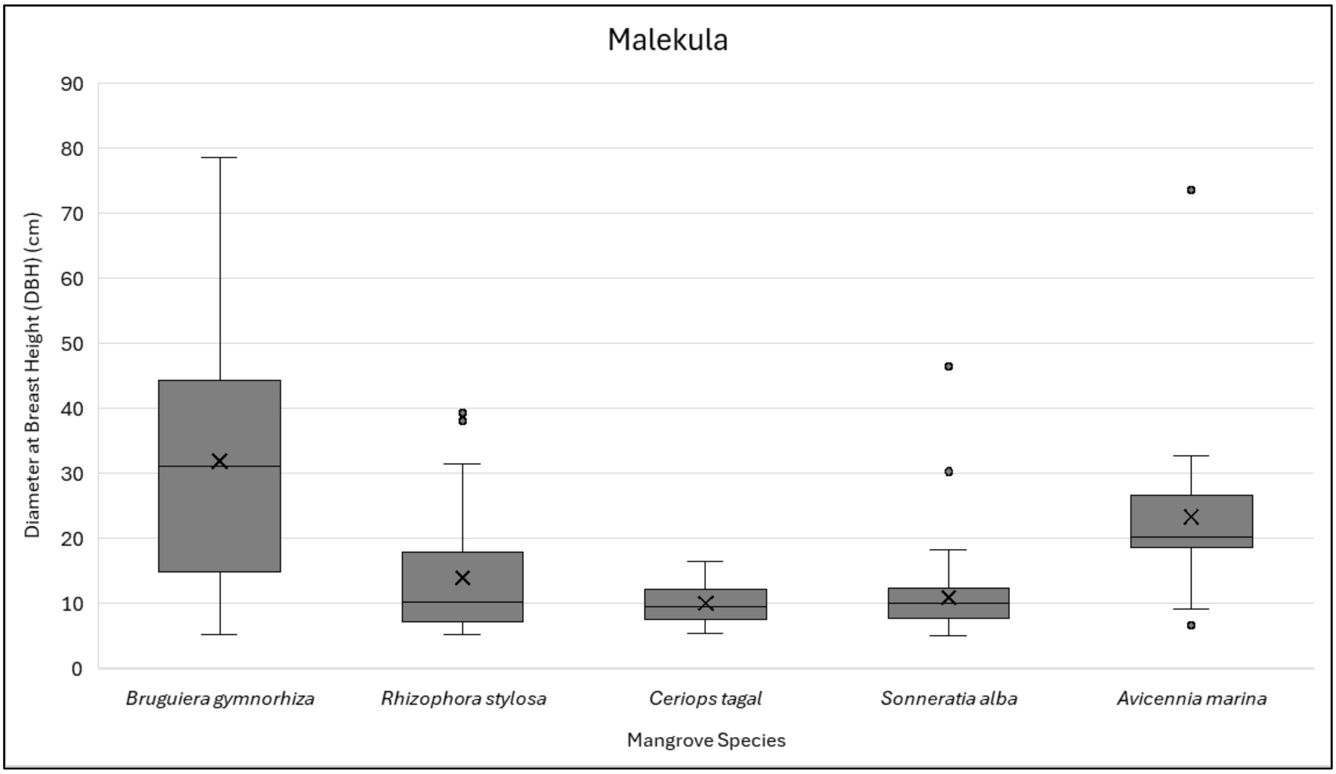


Figure 84. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Malekula. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

In the Maskelyne Islands, *Xylocarpus granatum* had the largest DBH (27 cm) when compared to the other species. Maskelyne is the only location where *X. granatum* trees had a larger DBH than the other species (Figure 85). *Avicennia marina*, closely followed by a DBH of 24 cm. However, this species did display several outliers, with the largest outlier being 58 cm (Figure 85). *Rhizophora stylosa* had the least variability in size range, with an average DBH of 16 cm.

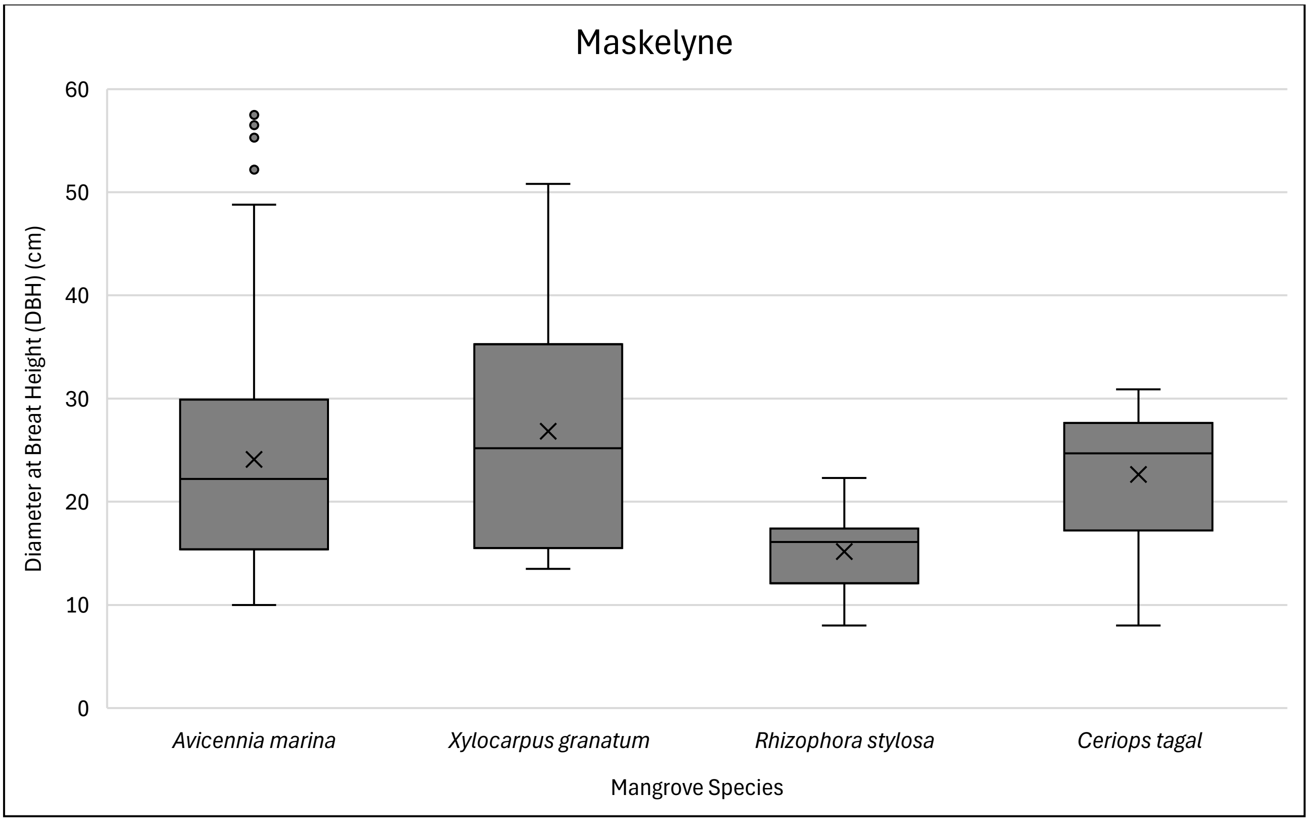


Figure 85. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) of mangrove species at Maskelyne. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Across the six locations, mangrove trees in Maskelyne had the largest average DBH of 22 cm, followed by Santo (DBH = 20 cm), Malekula (DBH = 17 cm), and Malo-Aore (DBH = 17 cm), Port Vila-Eratap (DBH = 15 cm) and Moso-Undine Bay (DBH = 13 cm). All sites had considerable variability, with some outliers reaching a maximum of 167 cm DBH (Figure 86). This reflects the complexity of intact mangrove ecosystems and outlines their variability due to multiple factors such as extreme weather conditions, anthropogenic influences, tidal inundation, and stratification in structural complexity.

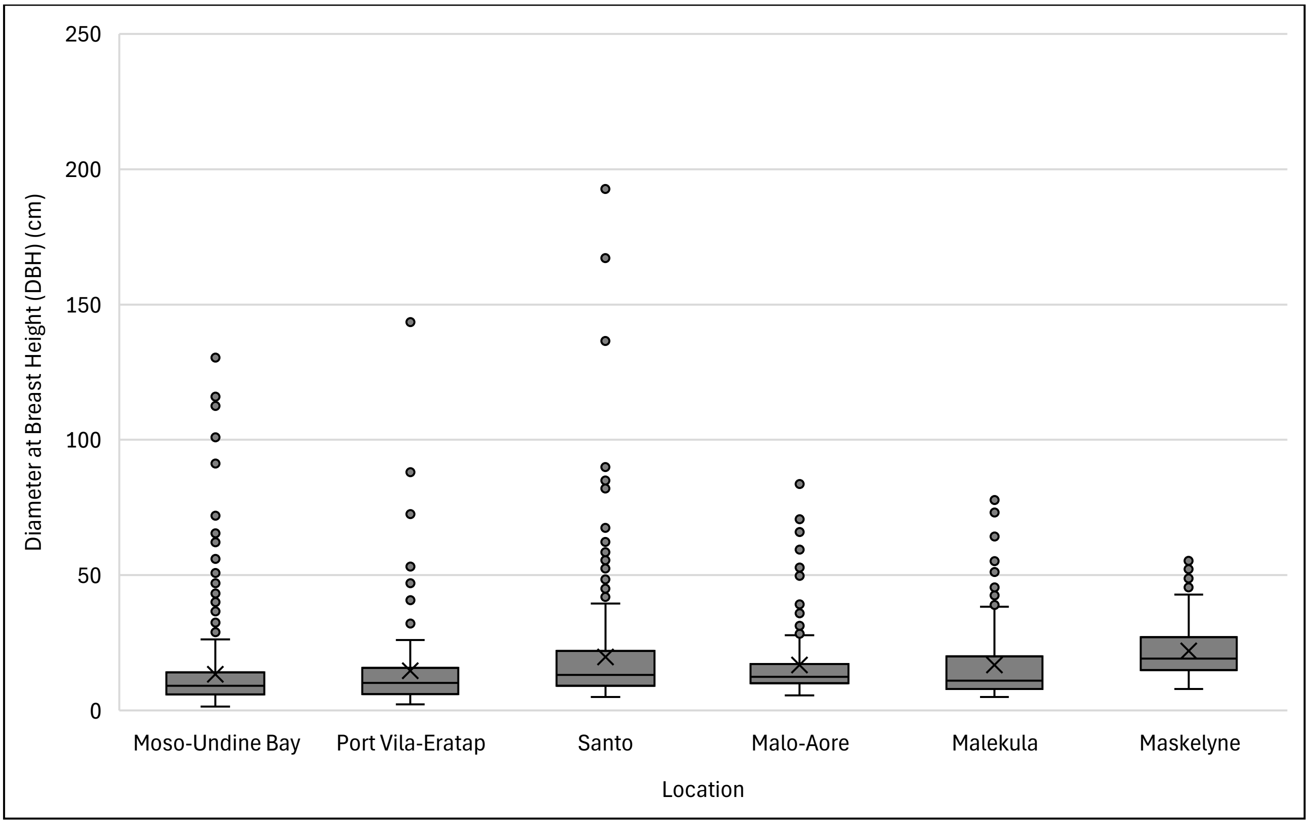


Figure 86. A box plot displaying the distribution of Diameter at Breast Height (DBH) (cm) across the locations in Vanuatu. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

When comparing all degraded and intact sites across Vanuatu, the degraded sites showed no difference in mangrove DBH records compared to intact sites, with the possible exception of a trend towards a wider range of DBH values for degraded sites. The degraded site at Maskelyne had the largest DBH, compared to all other locations and land use (Figure 87). This is likely related to the species composition at this location, where the dominant species, *Avicennia marina*, exhibited a DBH range of 10 to 57.5 cm.

Santo had the largest DBH across the intact sites (DBH = 22.5 cm), while the intact sites at Maskelyne and Malekula had an average DBH of 20 cm and 17 cm, respectively (Figure 87). Moso-Undine Bay resulted with the lowest DBH for both the intact and degraded locations (DBH = 13.5 and 13.3 cm respectively) (Figure 87). It is important to note that only intact sites were sampled in Port Vila-Eratap and Malo-Aore. At Malekula, one site had been completely cleared of mangroves approximately 20 years ago, with no mangroves to measure for DBH, however, revegetation efforts are being made, which is reflected in the seedling density at that site (Figure 87). The remaining sites at Malekula were all intact (Figure 87).

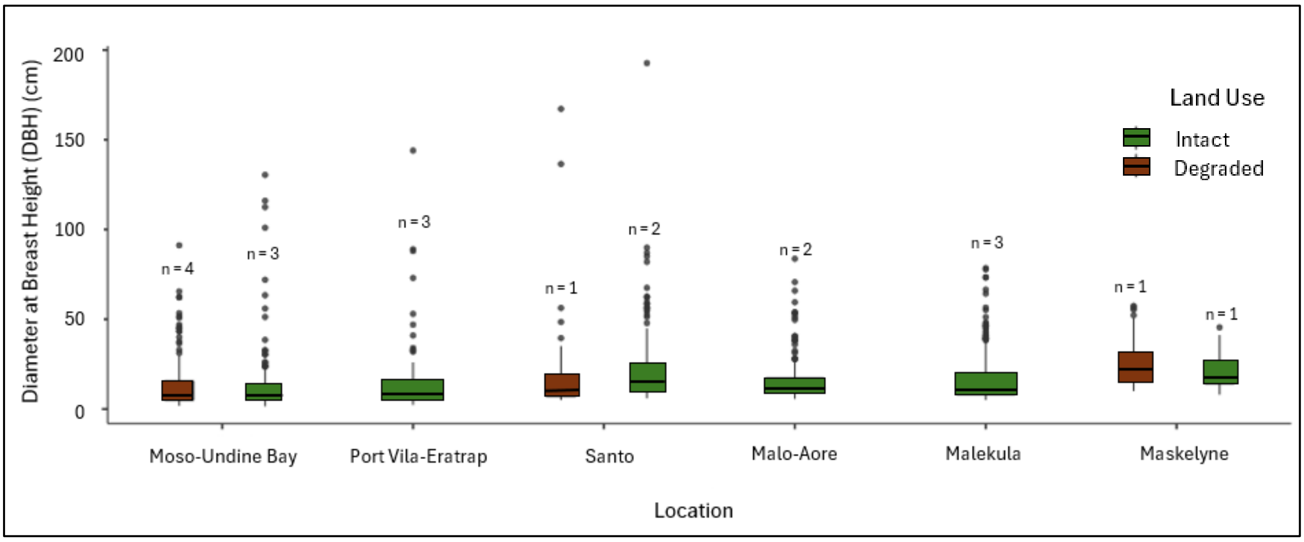


Figure 87. A box plot displaying Diameter at Breast Height (DBH) (cm) compared between land use type (degraded v. intact) and locations across Vanuatu. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Port Vila-Eratap had the highest mangrove canopy cover, with an average coverage of 73% (± 5 SE), followed by Malekula at 64% (± 10 SE) (Figure 88). Malo-Aore had the lowest canopy cover when compared to the other locations (31% ±7 SE) (Figure 88). The lower canopy cover at the site does not necessarily represent poor condition but rather highlights the species composition at the sites. This location was mostly made-up of *Sonneratia alba*, which is large single-stemmed tree, creating more space between the trees, and ultimately leading to the lower canopy cover. All other locations had a mean canopy cover <64% (Figure 88). It should be noted that mangrove canopy cover was collected as categorical data (i.e., 0-10, 11-30, 31-50, 51-75, 76-95, 96-100%). The mid-point of this range data was averaged across each site and averaged again for each location.

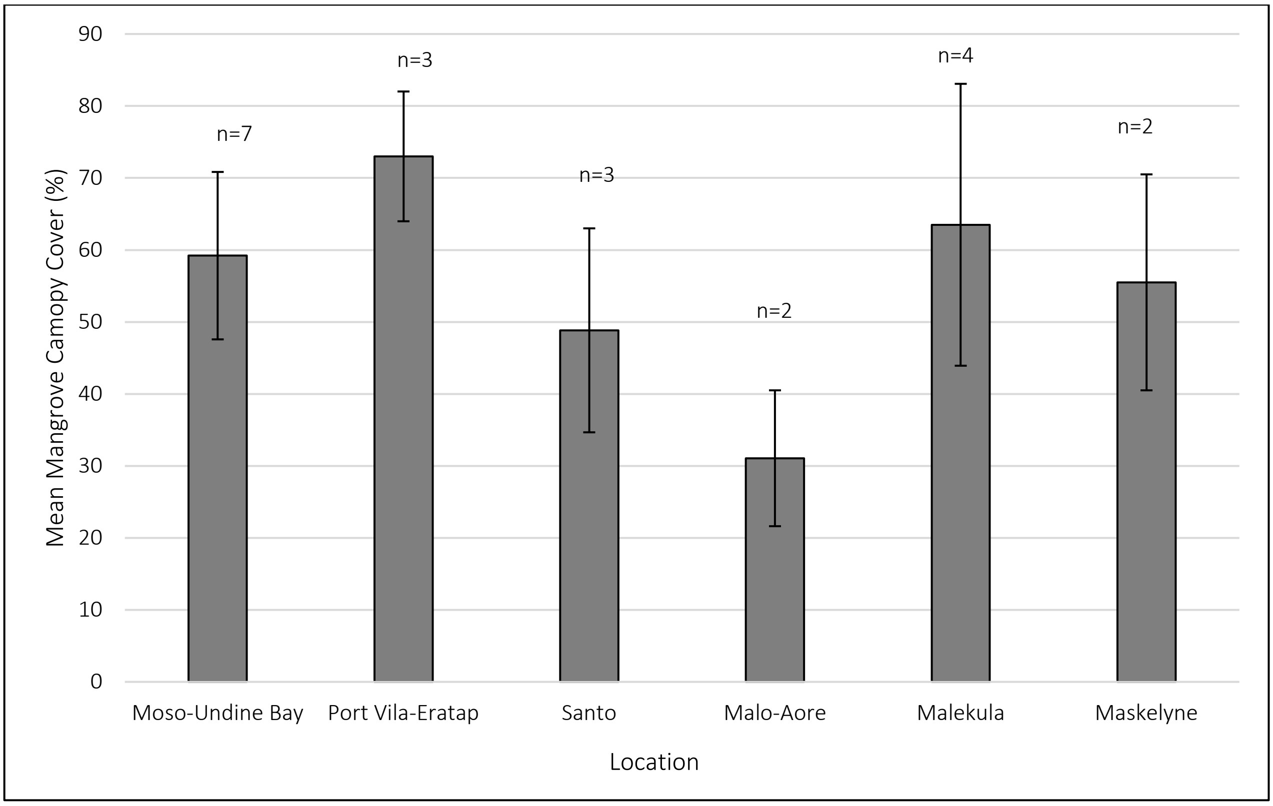


Figure 88. Mean mangrove canopy cover (%) (±SE) across locations in Vanuatu (where n is the number of sites surveyed at each location).

Across all locations, intact sites tended to have higher average mangrove canopy cover than degraded sites (Figure 89). Intact sites at Malekula had the highest canopy cover of 83% (± 3 SE), followed by Port Vila-Eratap (73%) and Maskelyne (71%) (Figure 89). At the degraded sites, Moso-Undine Bay had the highest canopy cover of 58% (± 9 SE), while Santo had the least canopy cover for degraded sites 21% (Figure 89). Notably, only intact sites were sampled in Malo-Aore, Port Vila-Eratap and Malekula (Figure 89).

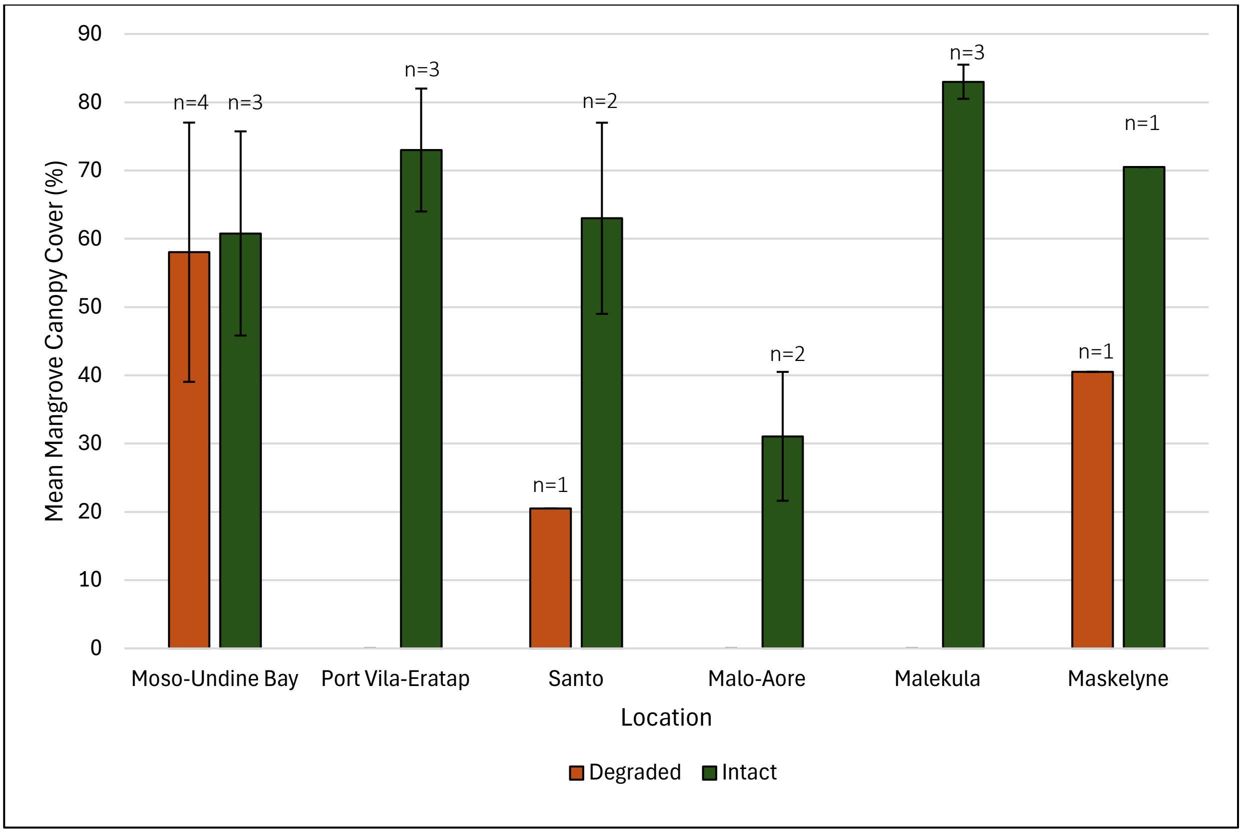


Figure 89. Mean mangrove canopy cover (%) (± SE) across intact and degraded locations. Where n is the number of sites surveyed at each location.

Seedling abundance was collected at each site as an indicator of forest productivity and the capacity for a forest to recover from disturbance. If resilient, a disturbed forest may have high seedling abundances compared to an equivalent intact forest, due to increased sunlight to the forest floor. Seedling abundances was assessed at each site as one of three categories (0-10, 10-50 and >50 seedlings). The seedling density/m^2 for each site was calculated using the mid-point of the categories and standardised by the area of each plot.

Malekula had the highest seedling density when compared to the other locations, with 0.23 seedlings/m^2, with one large outlier of 0.60 seedlings/m^2 (Figure 90). The high seedling density at this location is likely related to the clearing of all mangroves 20 years ago, which provided light and space for seedlings to grow. Additionally, there is a ready supply of mangrove seeds from adjacent forests. This location was followed by Santo and Malo-Aore, which had a seedling density of 0.16 and 0.15 seedlings/m^2, respectively (Figure 90). All other locations had a seedling abundance < 0.11 seedlings/m^2, with Maskelyne having the lowest density across the locations (0.09 seedlings/m^2) (Figure 90).

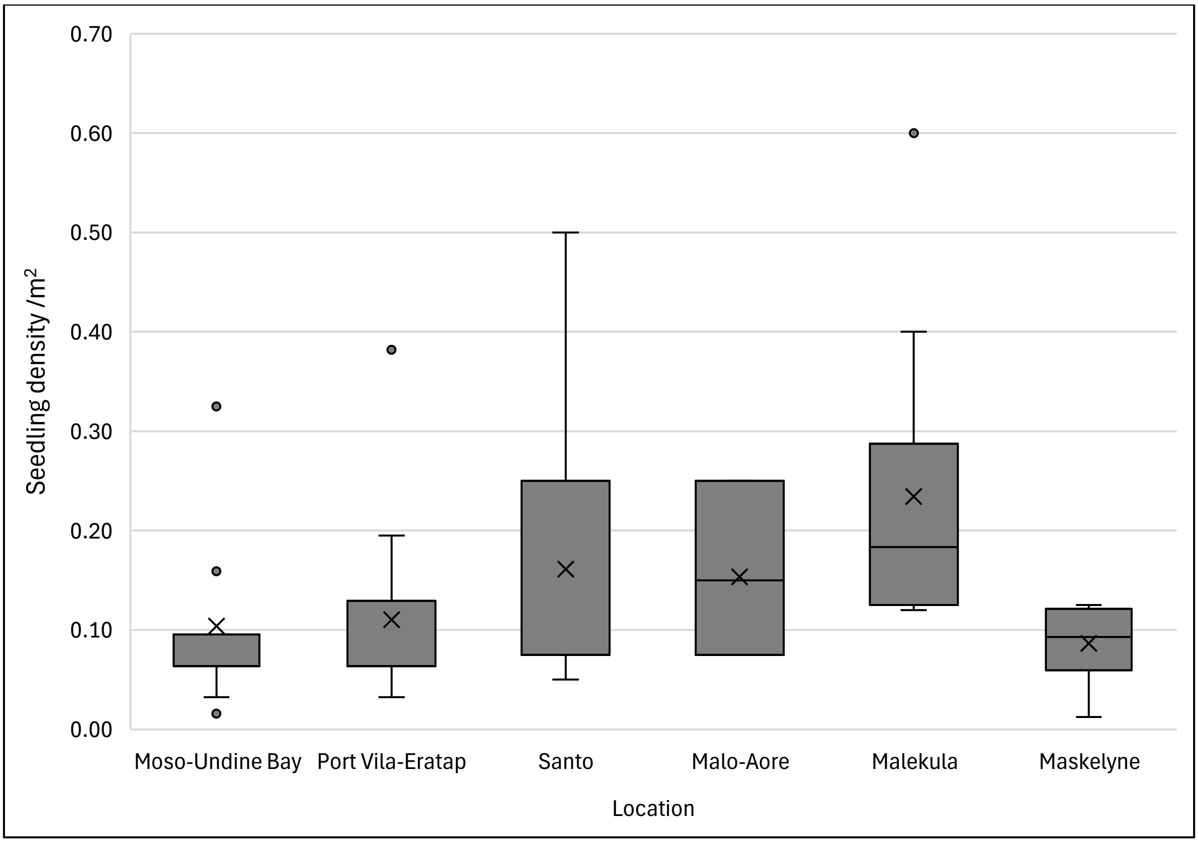


Figure 90. Seedling density/m^2 at each location in Vanuatu. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

Comparing degraded and intact sites across locations (Figure 91), Malekula had the highest seedling density for intact and degraded sites with 0.24 and 0.23 seedlings/m^2, respectively (Figure 91). The degraded site in the Malekula had been cleared of all mangroves and has recently been revegetated by the community to reduce the impact of sea-level rise and cyclones. Port Vila-Eratap, which only had intact sites, had a low seedling density of 0.11 seedlings/m^2, which is likely due to high canopy cover at this location. High canopy cover typically restricts sunlight for seedling germination and also reduces space for seedlings to anchor down. For the remaining degraded sites, Moso-Undine Bay had the highest seedling density after Malekula, with 0.15 seedlings/m^2, while Santo and Maskelyne had 0.13 and 0.12 seedlings/m^2 (Figure 91).

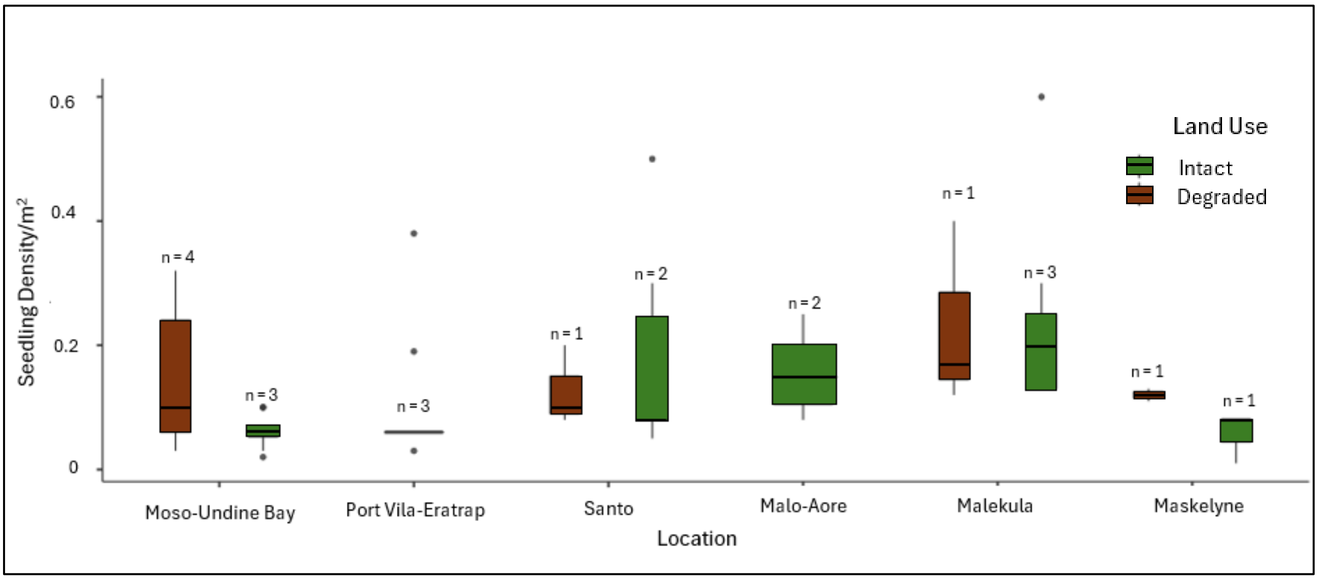


Figure 91. Seedling density/m^2 at each location in Vanuatu compared between intact, degraded and converted sites. The box represents the range between the 25% (lower quartile) and 75% (upper quartile) values. The line inside the box marks the median and the X marks the mean. Whiskers extend to the smallest and largest values within 1.5 times the interquartile range, and dots indicate outliers.

6.4.3 Biodiversity results

The rapid biodiversity assessment completed at the seagrass and mangrove sites for Vanuatu found a range of species present. The assessment was based on opportunistic observations while on-site and should not be considered comprehensive. The focus was on recording any evidence of IUCN-listed species observed at each site. Green Sea Turtles are listed as Endangered by the IUCN and were sighted at four sites across Vanuatu. Meanwhile, Dugongs, classified as Vulnerable by the IUCN, are known to inhabit several of the seagrass sites. The presence of this species, which relies on seagrass for food, highlights the importance of protecting seagrass meadows in Vanuatu.

Incidental observations of fauna biodiversity were made in each of the seagrass and mangrove sites assessed. A range of fauna species were recorded as per Table 30 and Figure 92.

Table 30. Species recorded in the seagrass meadows and mangrove forests assessed in Vanuatu.

Habitat	Organism type	Species	Common name
Seagrass	Mammal	*Dugong dugon*	Dugong
	Reptile	*Chelonia mydas*	Green Sea Turtle
		Sub-Family: Laticaudinae	Sea Snake
	Birds	*Milvus migrans*	Black Kite
		Limosa spp.	Godwit
		Egretta sacra	Pacific Reef Heron
		Thalasseus bergii	Greater Crested Tern
	Fish	Family: Mugilidae	Mullet (multiple species)
		Family: Hippocampus	Seahorse
		Seriola sp.	Kingfish
		Family: Sphyraenidae	Barracuda
		Family: Chaetodontidae	Butterfly Fish
		Family Acanthuridae	Surgeon fish (multiple species)
		Family: Myliobatoidei	Stingray
	Bivalve	Family: Bivalvia	Clam (multiple species)
		Family: Ostreidae	*Crassostrea* sp., Mangrove Oyster
		Family: Cyrenidae	*Geloina* spp.
	Crustacean		Mangrove crabs (multiple species)
		Cardisoma carnifex	White Crab
		Scylla paramamosain	Mud Crab
		Family: Caridea	Shrimp
		Carnifex sp.	Red Crab
	Gastropod	Family: Aplysiidae	Sea Hare
		Family: Cypraeidae	*Cypraea* spp.
		Terebralia palustris	Serwock
		Family: Neritidae	*Nerita* spp.
		Family: Conidae	*Conus* spp.
Mangrove	Reptile	*Emoia caeruleocauda*	Pacific Bluetail Skink
		Caledoniscincus atropunctatus	Speckled Litter Skink
		Lacticauda colubrina	Yellow-lipped Sea Krait
		Emoia impat	Blue-tailed Stripe Skink
	Birds	*Columba palumbus*	Wood Pigeon
		Haliastur sphenurus	Whistling Kite
		Acridotheres tristis	Common Myna
		Hirundo neoxena	Welcome Swallow
		Todiramphus sacer	Pacific Kingfisher
		Ardea alba	Great Egret
		Butorides striata	Striated Heron
		Family: Accipitridae	Sea Eagle
		Ptilinopus greyii	Red-bellied Fruit Dove
		Aerodramus vanikorensis	Uniform Swiftlet
		Family: Psittaculidae	Parrots
	Fish	*Periophthalmus argentilineatus*	Mud Skipper
	Bivalve		Assorted bivalves (not identified)
	Crustacean		Hermit crab (multiple species)

Habitat	Organism type	Species	Common name
		Carnifex sp	Red Crab
		Uca urville	Fiddler Crab
			Mangrove crabs (multiple species)
		Family: Sesarmidae	Sesarmid crabs
	Gastropod	Family: Neiritidae	Nerites (multiple species)
		Family: Trochidae	Top snails (multiple species)
		Family: Strombidae	*Strombus* spp.
		Family: Conidae	*Conus* spp.
		Terebralia palustris	Giant Mangrove Whelk
		Family: Littorinidae	*Littoria* spp.
	Echinoderm	Family: Asteroideae	Starfish (multiple species)
		Family: Holothuriidae	Sea cucumber (multiple species)

Figure 92. Observed fauna across Vanuatu. A range of reptiles, gastropods, crustaceans, bivalves, birds, fish and mammals were recorded across the four locations. From the top left the fauna are a mangrove crab, periwinkle, sea cucumber, brittle star, hermit crab and bivalve.

The abundance of crab holes was recorded at each of the sites as a simple indicator of the interaction between the benthic biodiversity of the forest and ecosystem functioning. Through burrowing and feeding activities, mangrove crabs contribute to recycling of organic matter, changes in surface topography, nutrient cycling and removal, oxygenation of mangrove sediments and the success of mangrove propagules[183]. Degraded mangrove forests typically have lower abundances of mangrove crabs which results in poor ecosystem functioning.

The abundance and size distribution of crab holes recorded in each of the locations broadly reflect the threat profile of each location. Santo had smaller crab holes when compared to the other five locations, which corresponds to the poorer condition and higher level of threat recorded at those sites. Crab hole abundances and size distributions were higher at Moso-Undine Bay; however, Malekula and Maskelyne had the highest diversity in crab hole size (Figure 93), which reflects the better condition and lower threat levels at those sites. The abundances and size distributions of crab holes at the Port Vila-Eratap sites were difficult to record during the assessments owing to the predominance of high tides over the period of sampling. However, the data that was able to be collected at this location showed a diversity of crab hole sizes (Figure 93).

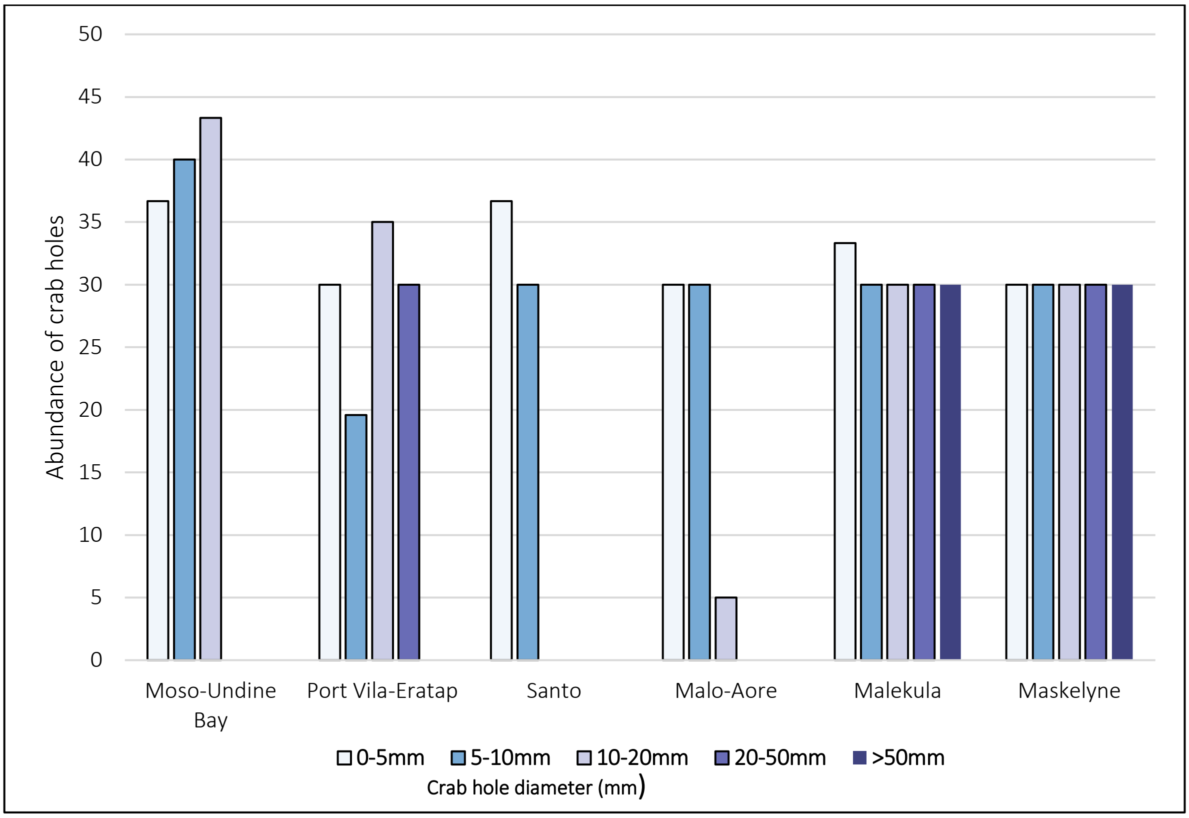


Figure 93. Average abundance of crab holes at each of the four locations sampled in the Solomon Islands, across five crab hole size categories (0-5mm, 5-10mm, 10-20mm, 20-50mm, >50mm). Note that for some sites, predominantly in Moso-Undine Bay and Port Vila-Eratap, there was missing data due to tidal inundation preventing crab hole observations during surveys.

[183] Lee SY (1998) "Ecological role of grapsid crabs in mangrove ecosystems: a review," *Marine and Freshwater Research*, 49(4):335.

6.5 Summary

The seagrass and mangrove ecosystems of Vanuatu provide essential services like biodiversity enhancement, coastal protection, carbon sequestration, food production, as well as sources of firewood and construction materials. The results of this rapid assessment found that, despite varying between sites and locations, many seagrass and mangrove systems across Vanuatu remain resilient and continue to support essential ecosystem functions, likely sustaining high levels services. However, there was indication that ecosystem function and associated services, were measurably reduced at sites and locations exposed to high levels of threats.

Key findings:

Seagrass Ecosystems

- Vanuatu is host to eleven (11) recorded species of seagrass, with the most common species in the region being *Thalassia hemprichii, Cymodocea rotunda, Enhalus acoroides, Halodule univeris* and *Halophila ovalis*. This project recorded seven (7) of those eleven. Seagrass meadows are typically located in sheltered bays and lagoons, often adjacent to mangroves and reefs.
- Current threats to seagrasses include species collection and harvesting, including seagrass fauna, sand mobilisation from cyclones, development, as well as destructive fishing practices. Most sites had relatively high levels of seagrass cover (41-54%), with the highest levels in Port-Vila Eratap. However, Malekula had the least coverage of 29%, which was mostly related to species composition rather than threats.
- Santo resulted with a high threat level at the landscape scale. This location had a multitude of threats which were mostly related to anthropogenic activities.
- The rapid biodiversity assessment found a range of species that inhabit seagrasses, including IUCN-listed species such as Green Sea Turtles (Endangered) and Dugongs (Vulnerable).

Mangrove Ecosystems

- Vanuatu has approximately 2,000 hectares of mangrove forests, with 25 recorded mangrove species. A total of seven (7) of the 25 mangrove species known to inhabit Vanuatu were recorded at the study locations.
- The range in tree Diameter at Breast Height (DBH) reflects varying levels of environmental threats and biodiversity value. Specifically, degraded sites with lower DBH values suggest significant removal of large trees, leading to reduced biodiversity. However, the degraded sites in Vanuatu showed no difference in mangrove DBH when compared to the intact sites. This may be related to species composition rather than other external factors but could also reflect that mangrove forests across all locations sampled in Vanuatu are impacted to some degree. All locations exhibited a similar average DBH, ranging from 13 to 22 cm. The smaller DBHs observed in Vanuatu indicate that these forests face higher levels of environmental threats, resulting in lower structural diversity, potentially reduced biodiversity, and decreased ecosystem resilience.
- For Moso-Undine Bay, on Efate, there were relatively lower levels of benthic biodiversity and seedling counts, when compared to the other locations. This indicates that there is likely lower biodiversity and ecosystem resilience in mangrove forests in this region. However, for Malekula, benthic biodiversity and seedling abundances suggest the system remains resilient despite existing pressures.
- The rapid biodiversity assessment recorded a wide range of fauna species, including Pacific Kingfishers, mangrove crabs and Yellow-lipped Sea Krait.

Threat Assessment

- Threats to mangroves include invasive species, species collection and harvesting, land use change, including but not limited to unsealed roads, agriculture, catchment clearing and plantations. Other threats include extreme weather events, increased frequency of high tides and sea-level rise.
- The threat assessments indicated that while some areas are relatively intact, others are significantly impacted by human activities and natural events. Malekula and Maskelyne resulted with the lowest level of threat at both the habitat and landscape scale. Santo and Port Vila-Eratap had the highest level of threat at both the habitat and landscape scale, primarily due to mangrove clearing for development, agriculture, tourism and village housing.

Appendices

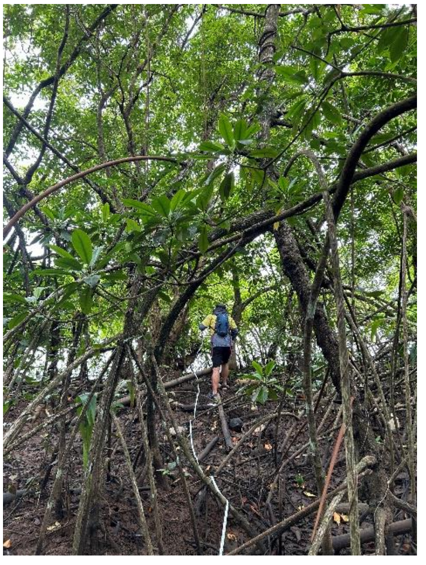
Appendix **A**

Fiji site photos

A.1. Fiji site photos

A.1.1. Fiji seagrass site photos

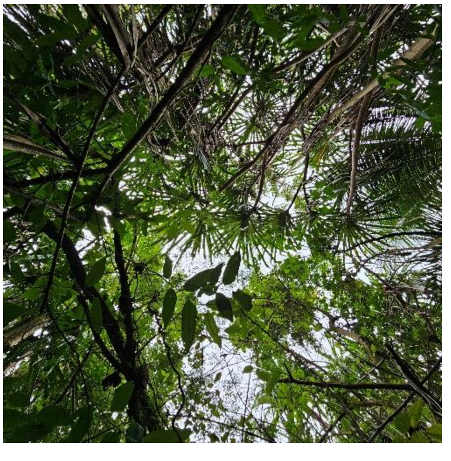
Rewa - Viti Levu

Site	Photograph
Rewa Vuni Vadra (VV)	     

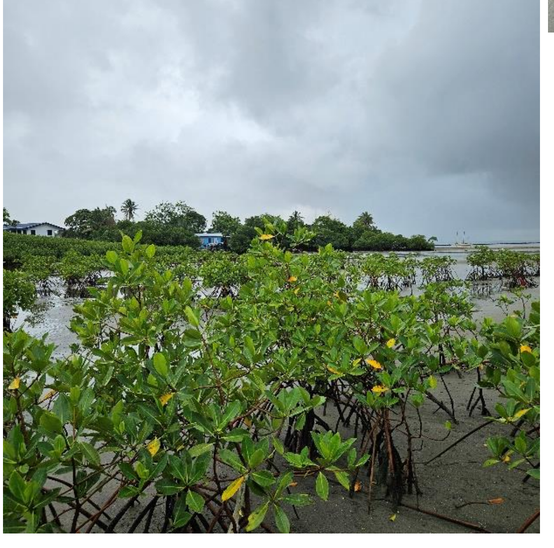
Site	Photograph
Nanuka degraded (ND)	

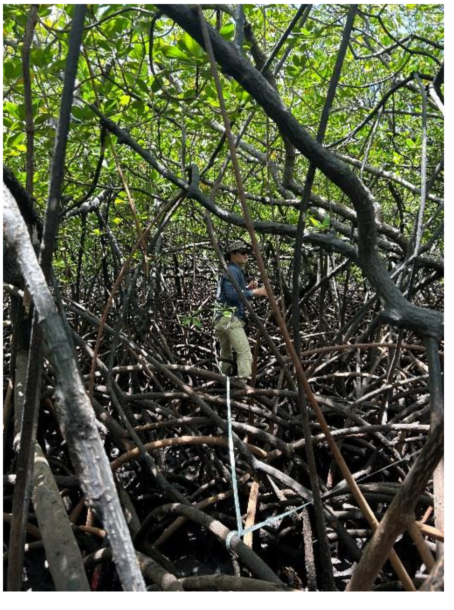


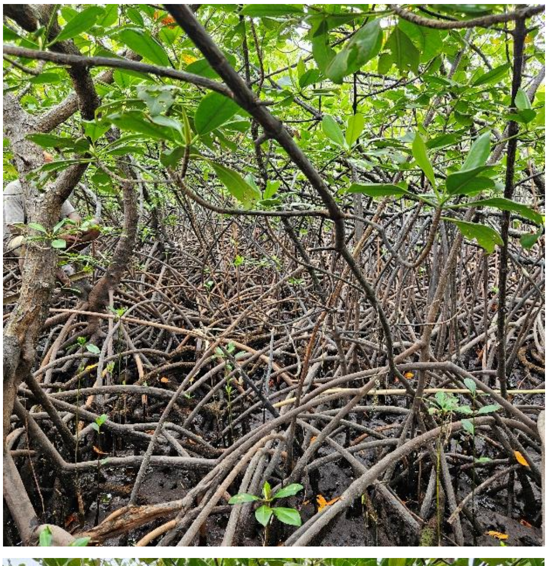


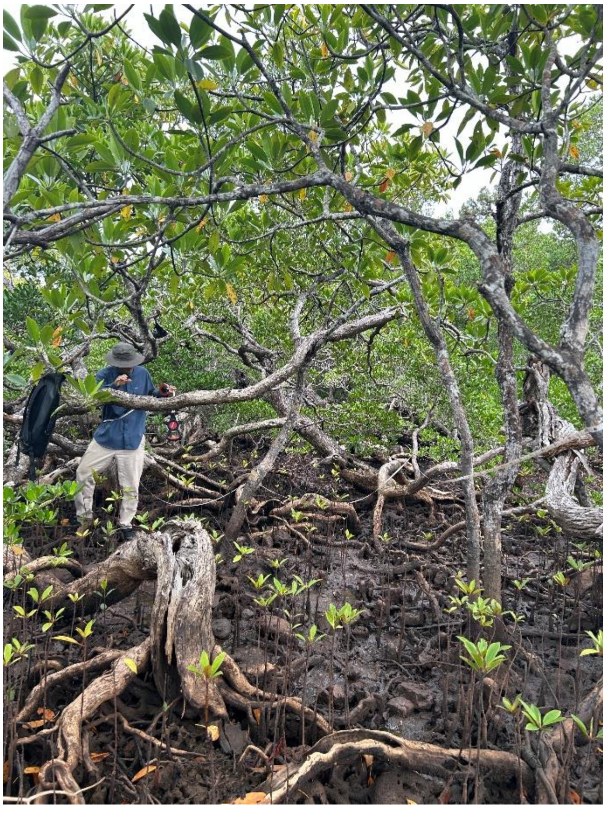
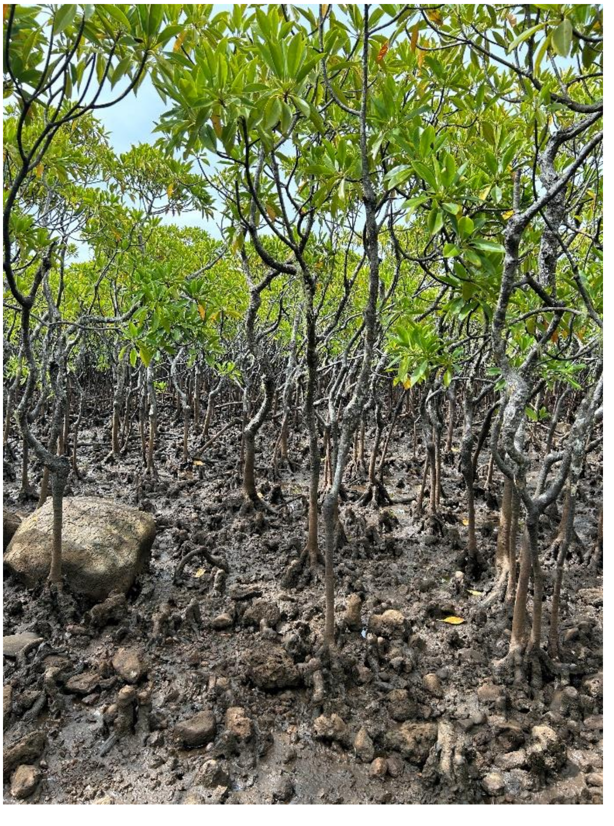


Site	Photograph
Rewa 2 (D2)	  

Site	Photograph
USP campus restoration site (SU)	  

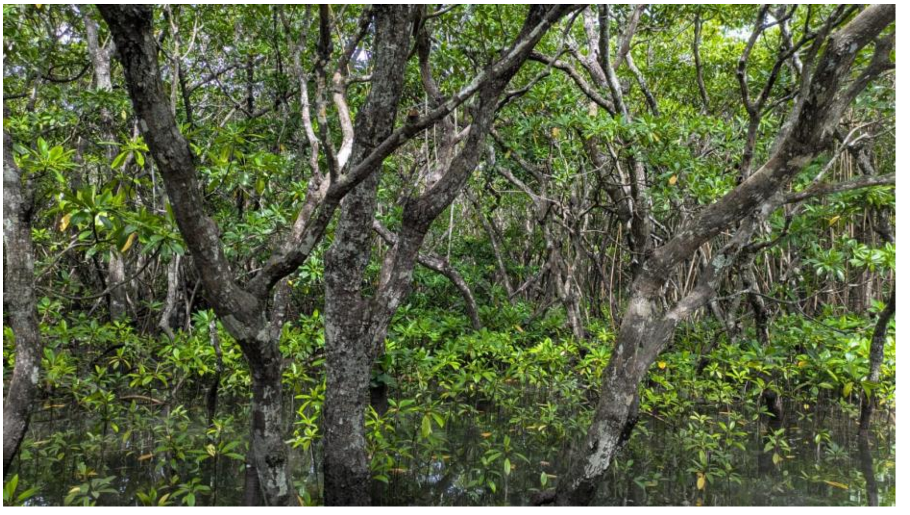
Ovalau – Moturiki	
Site	Photograph
Yanuca (YA)	  

Site	Photograph
Nasauvuki (NA)	  

Site	Photograph
Kuawai (KU)	 

Site	Photograph
Buresale (BU)	

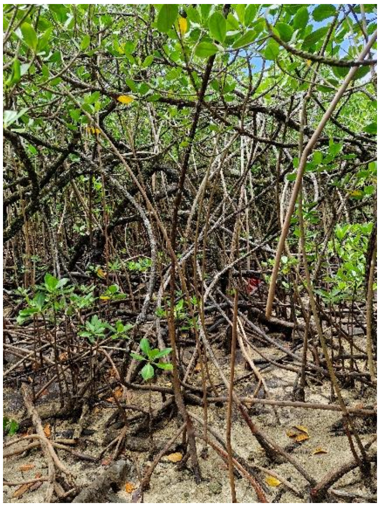
South Vanua Levu	
Site	Photograph
Natuva (NA)	

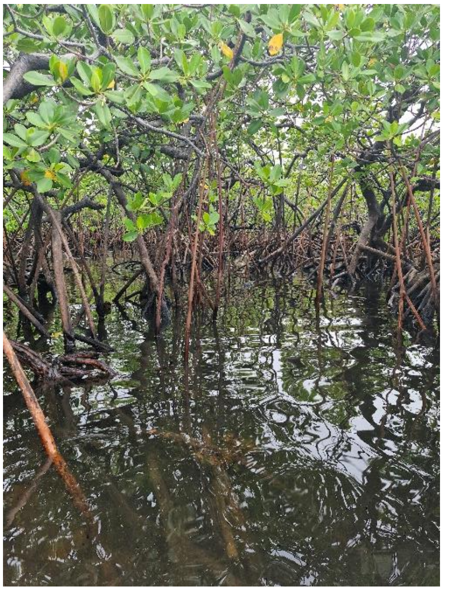
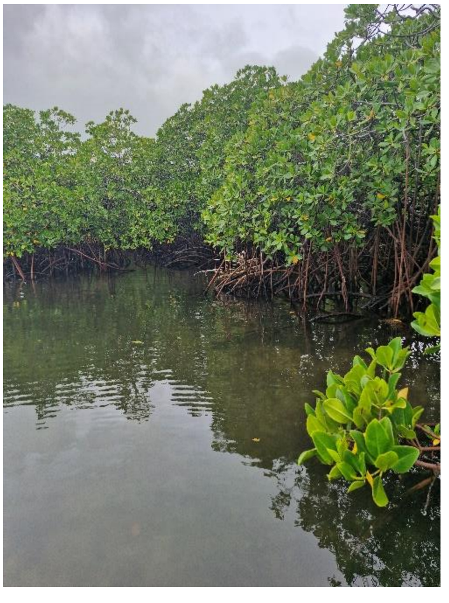
Site	Photograph
Ganilau (GA)	  

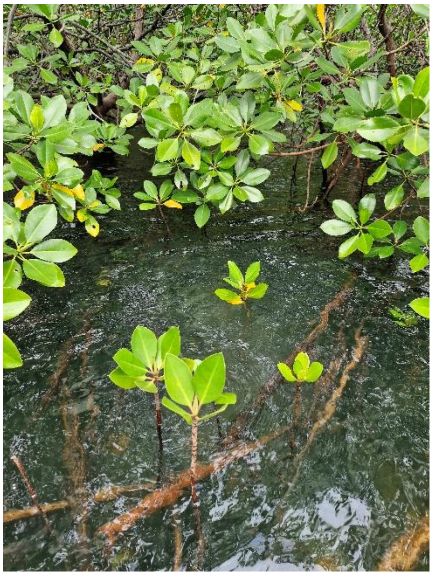
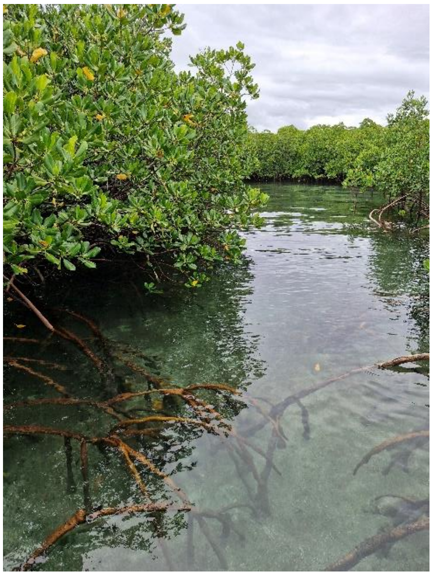
Site	Photograph
Ndrekeniwai (ND)	  

Site	Photograph
Daria (DF)	  

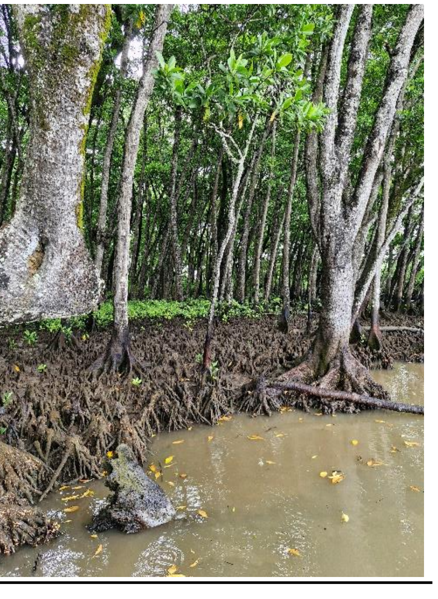
Site	Photograph
Daria (DR)	   

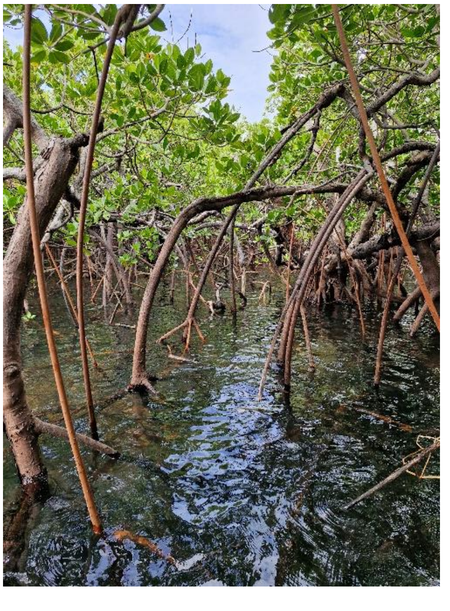
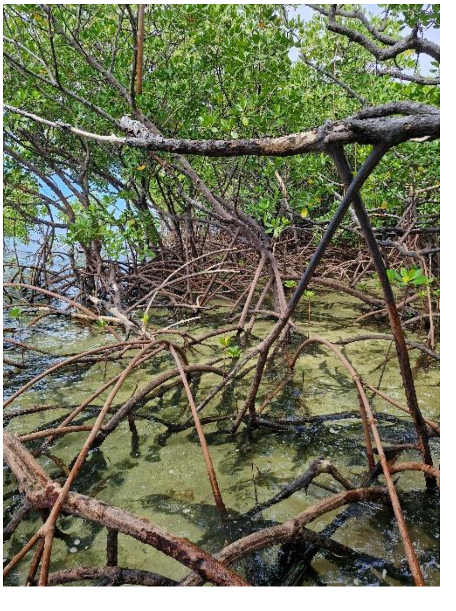
Galoa Bay – Vanua Levu	
Site	Photograph
Nukugase (GB1)	   

Site	Photograph
Tavea Island (GB2)	  

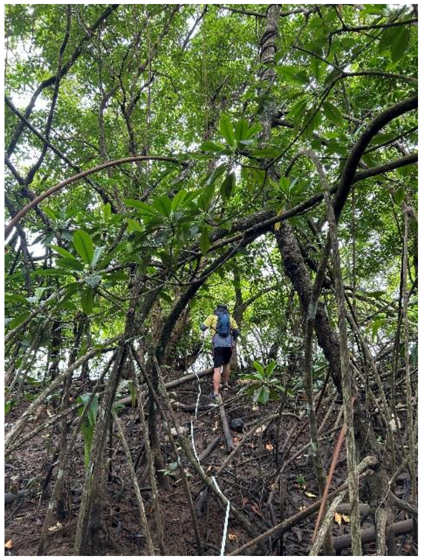
Site	Photograph
Nukuira Island (GB3)	  

Labasa – Vanua Levu	
Site	Photograph
Labasa River (LA1)	    

Site	Photograph
Labasa River (LA2)	    

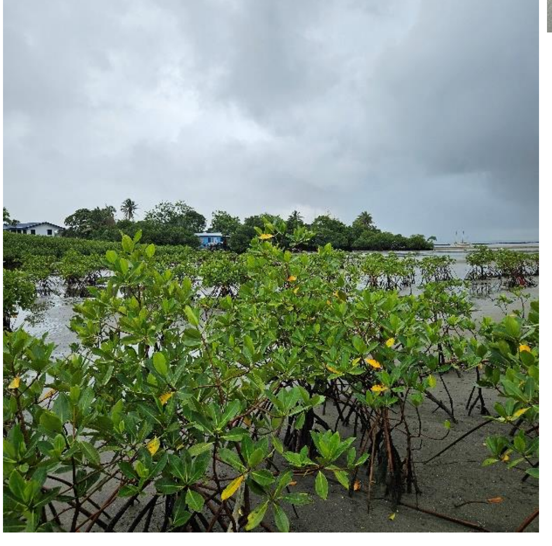
Site	Photograph
Mali Island (LA3)	   

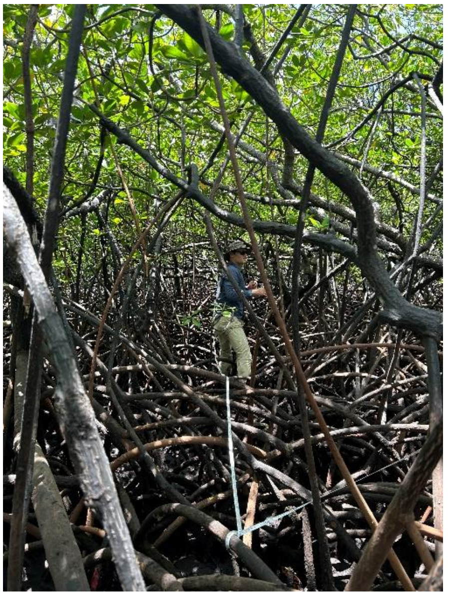
A.1.2. Fiji mangrove site photos

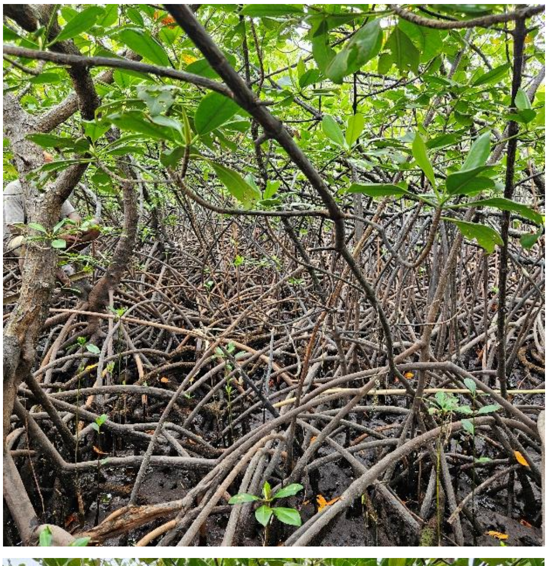
Rewa - Viti Levu	
Site	Photograph
Rewa Vuni Vadra (VV)	     

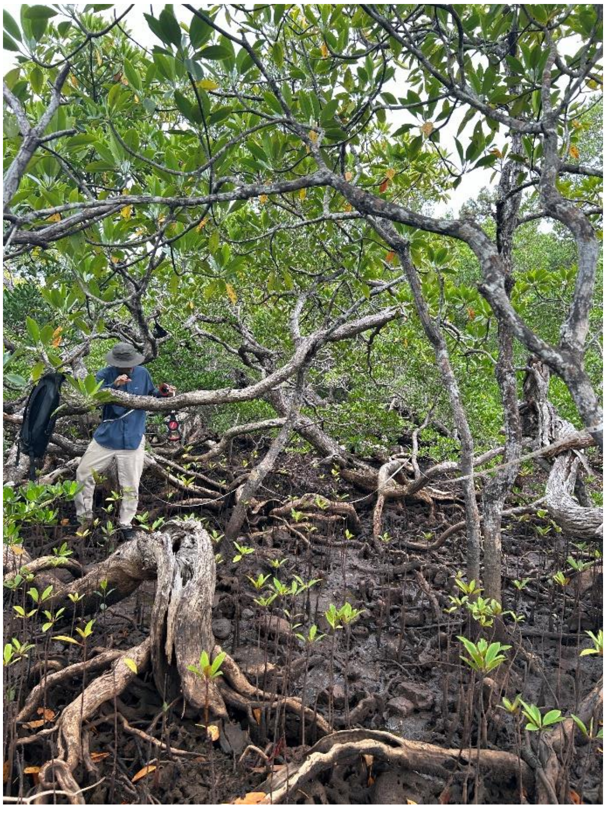
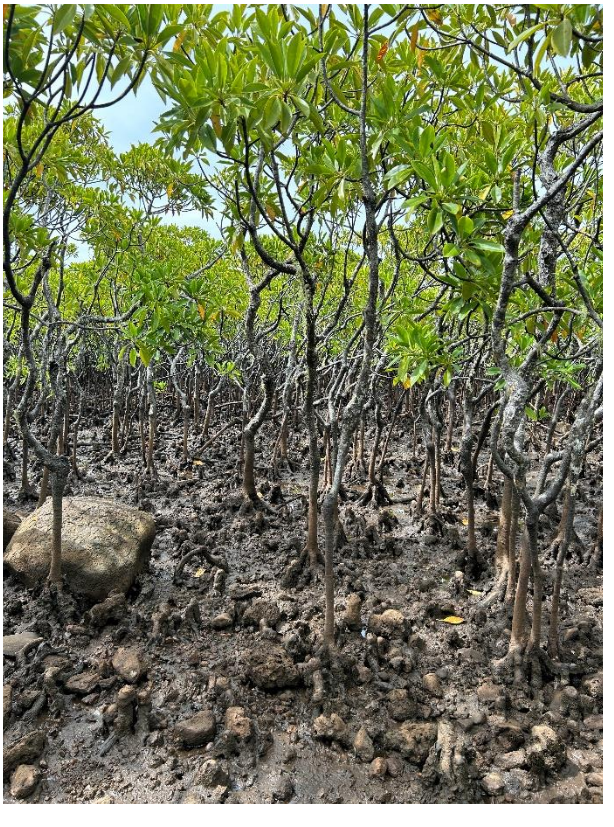
Site	Photograph
Nanuka degraded (ND)	    

Site	Photograph	
Rewa 2 (D2)	 	

Site	Photograph
USP campus restoration site (SU)	  

Ovalau – Moturiki	
Site	Photograph
Yanuca (YA)	  

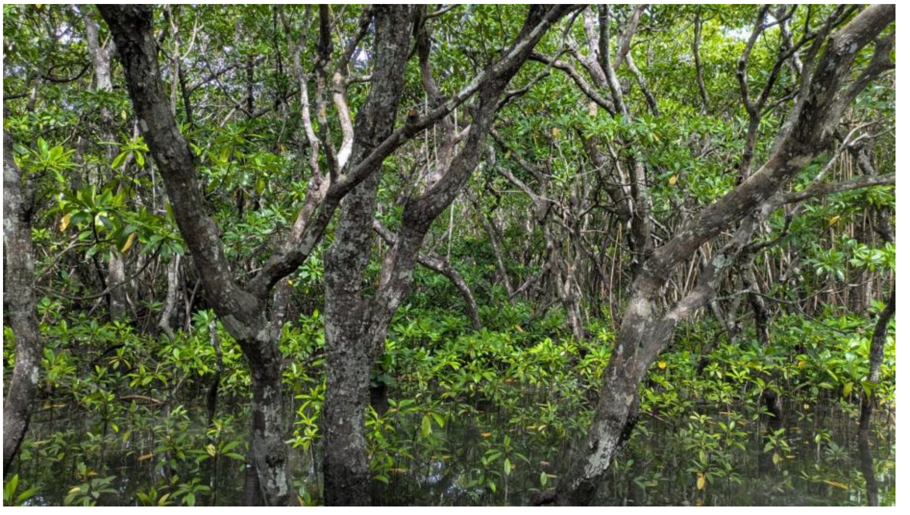
Site	Photograph
Nasauvuki (NA)	  

Site	Photograph
Kuawai (KU)	 

Site	Photograph
Buresale (BU)	

South Vanua Levu

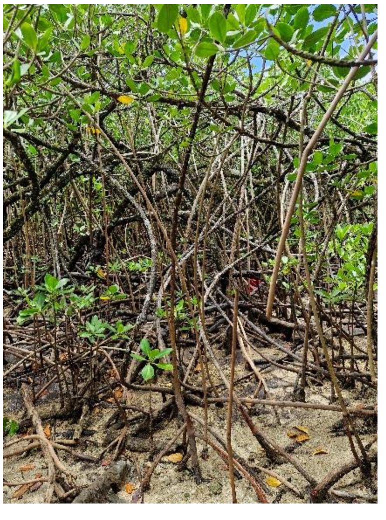
Site	Photograph
Natuva (NA)	   

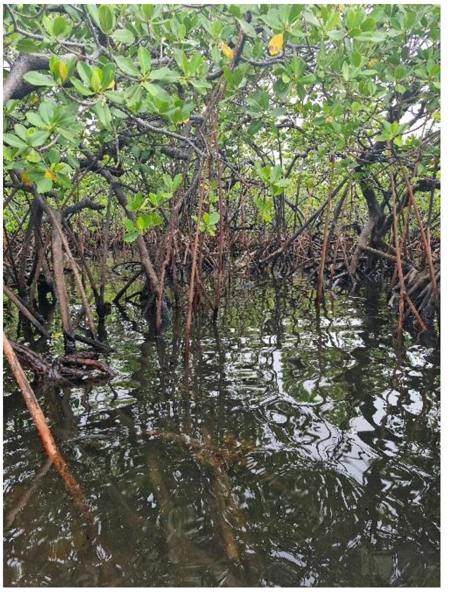
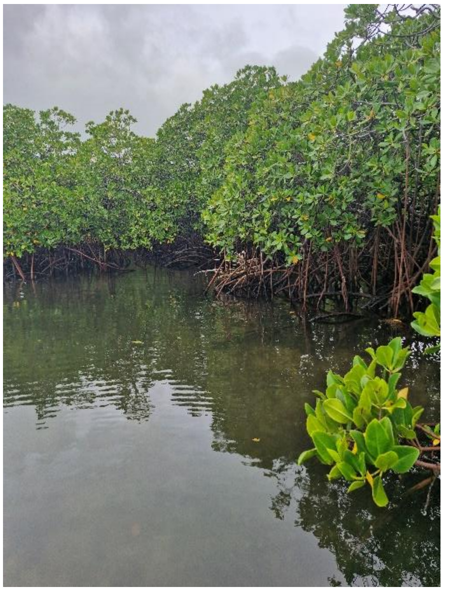
Site	Photograph
Ganilau (GA)	  

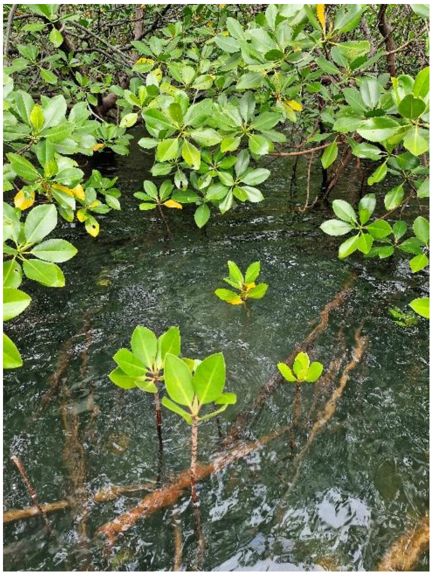
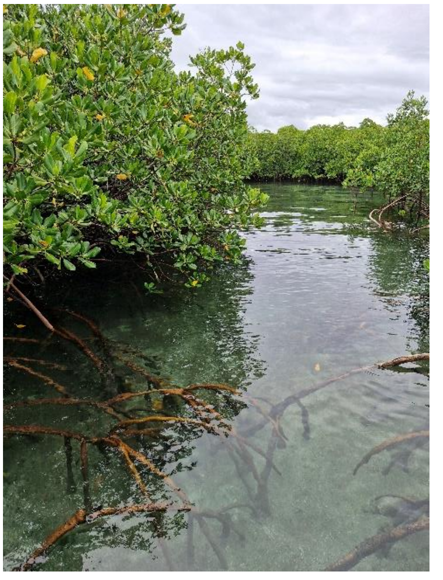
Site	Photograph
Ndrekeniwai (ND)	  

Site	Photograph
Daria (DF)	  

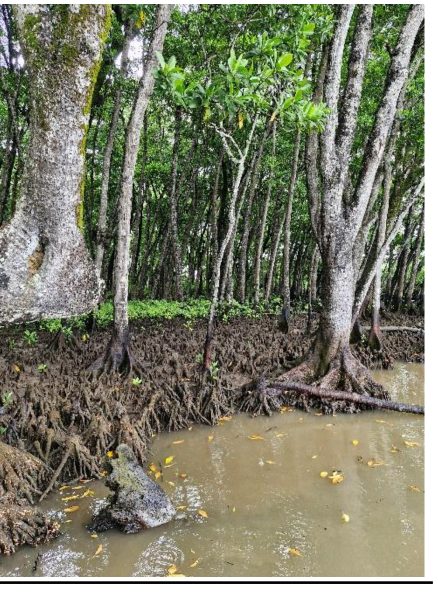
Site	Photograph
Daria (DR)	   

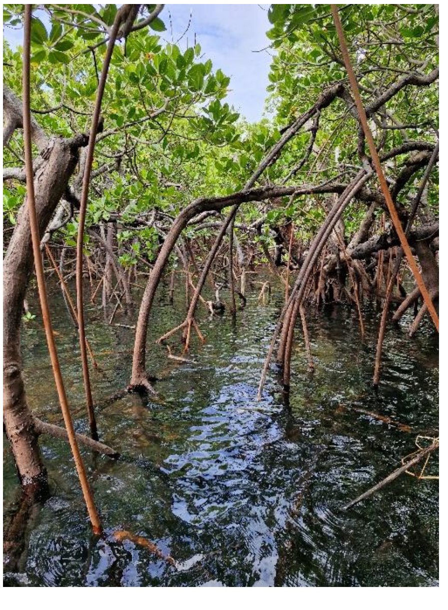
Galoa Bay – Vanua Levu	
Site	Photograph
Nukugase (GB1)	   

Site	Photograph
Tavea Island (GB2)	  

Site	Photograph
Nukuira Island (GB3)	  

Labasa – Vanua Levu	
Site	Photograph
Labasa River (LA1)	    

Site	Photograph
Labasa River (LA2)	    

Site	Photograph
Mali Island (LA3)	   

Appendix **B**

Papua New Guinea site photos

B.1. Papua New Guinea site photos

B.1.1. Papua New Guinea seagrass site photos

CENTRAL	
Site	Photograph
Mirigeda Site 1	

Site	Photograph
Mirigeda Site 2	

Site	Photograph
Bautama Site 4	

Site	Photograph
Bautama Site 5	 

MILNE BAY	
Site	Photograph
Mahabarina Island	

Site	Photograph
Wagatumay au Island	

Site	Photograph
Dohlet Conservation Reserve	

WEST NEW BRITAIN	
Site	Photograph
Liamo Reef Resort	

Site	Photograph
Dauli	

Site	Photograph
Kulungi	 

Site	Photograph
Patanga	   

NEW IRELAND	
Site	Photograph
Tome	

Site	Photograph
Bangatang Island	 

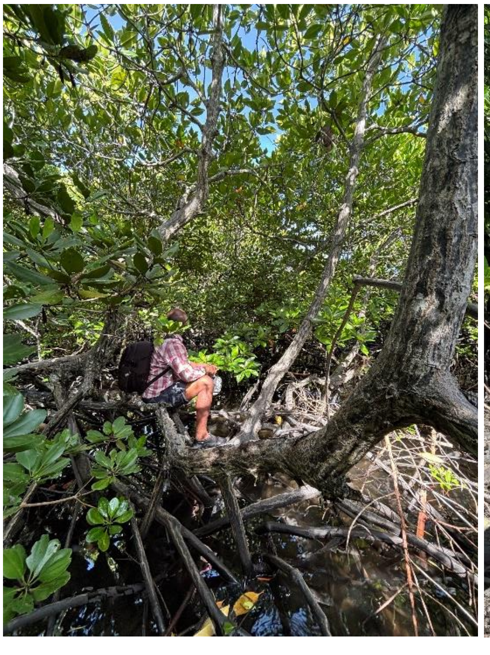
Site	Photograph
Sivasat	

WESTERN	
Site	Photograph
Parama Site 1	

Site	Photograph
Parama Site 2	

B.1.2. Papua New Guinea mangrove site photos

Appendices

CENTRAL	
Site	Photograph
Bautama Site 1	  

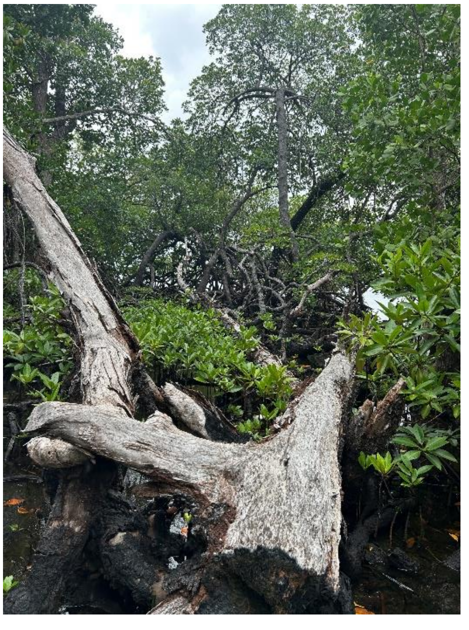
Site	Photograph
Bautama Site 2	 

Site	Photograph
Bautama Site 3	 

Site	Photograph
Mirigeda Site 3	

Site	Photograph
Mirigeda Site 4	

MILNE BAY	
Site	Photograph
Dolhet Conservation Site	 

Site	Photograph
Dolhet Conservation Site B	   

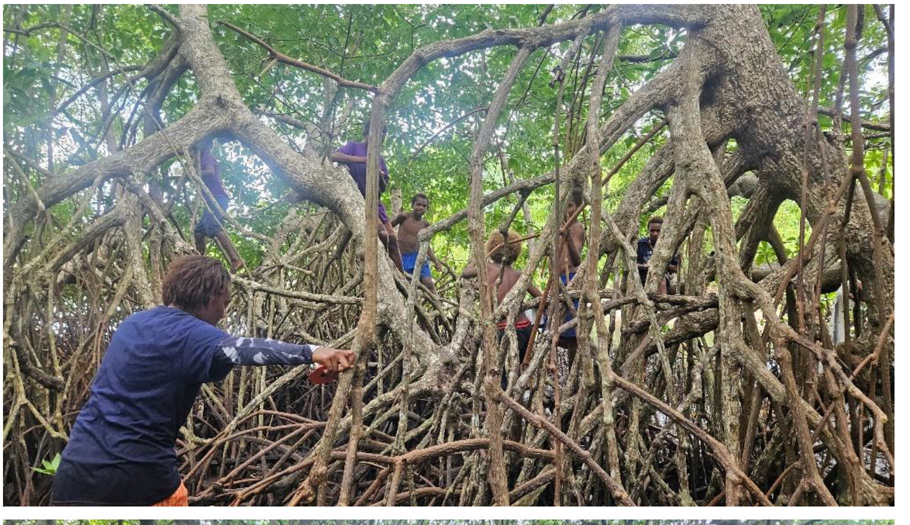
Site	Photograph
Maiwara Mangroves River Site	 

Site	Photograph
Maiwara Mangroves Bay Site	 

WEST NEW BRITAIN	
Site	Photograph
Dargi West River Mouth	 

Site	Photograph
Numundo Site	  

Site	Photograph
Numundo Site	  

Site	Photograph
Patanga	  

NEW IRELAND	
Site	Photograph
Sivasat A	 

Site	Photograph
Sivasat B	 

Site	Photograph
Sivasat C	 

Site	Photograph
Tome	 

Site	Photograph
Lavatbura	 

WESTERN	
Site	Photograph
Paho Site 1	 

Site	Photograph
Paho Site 2	

Site	Photograph
Mabaduan Site 1	

Site	Photograph
Mabaduan Site 2	

Site	Photograph
Old Mawatta	

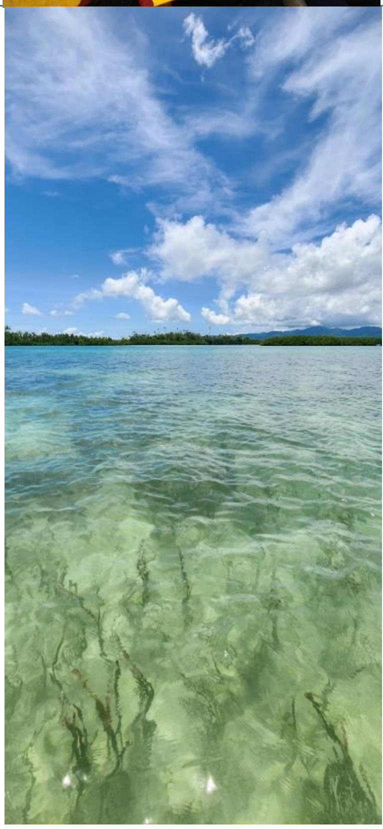
Appendix **C**

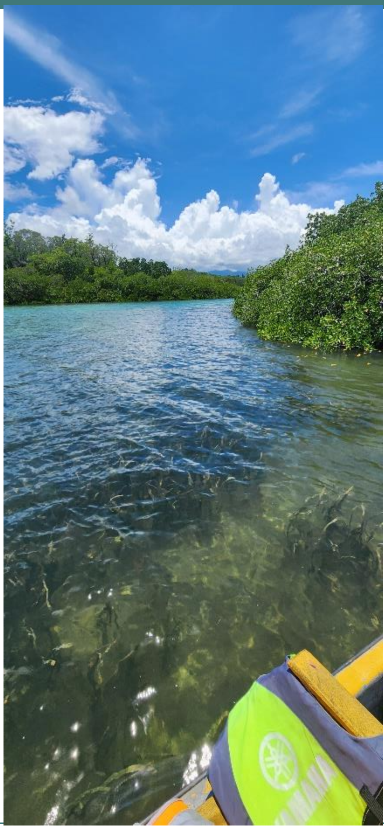
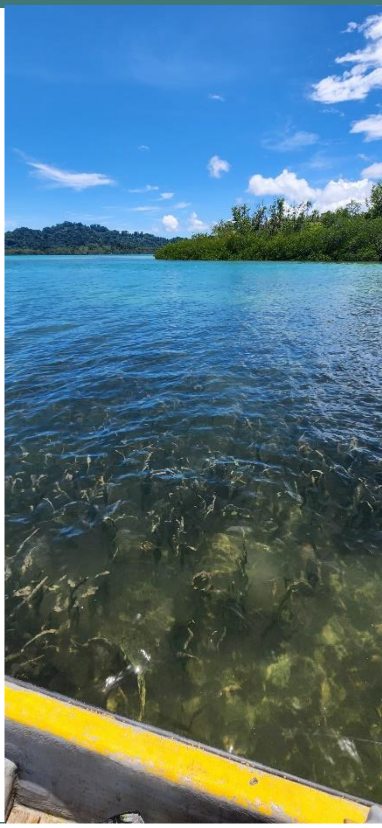
Solomon Islands site photos

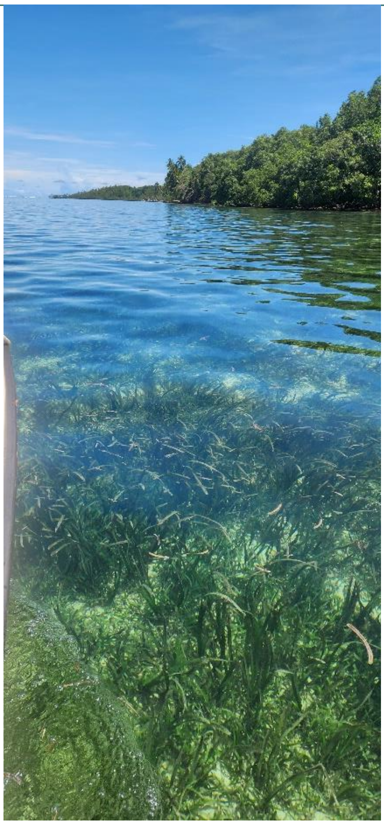
C.1. Solomon Islands site photos

C.1.1. Solomon Islands seagrass site photos

Appendices

Site	Photograph	
Maravo Lagoon (MLB)		
Marovo Lagoon (MHL)		

Site	Photograph
Holole (MH)	 
Papatura Island (IPI)	

Site	Photograph
Banafao (IB)	
Baolo Village (IBV)	 

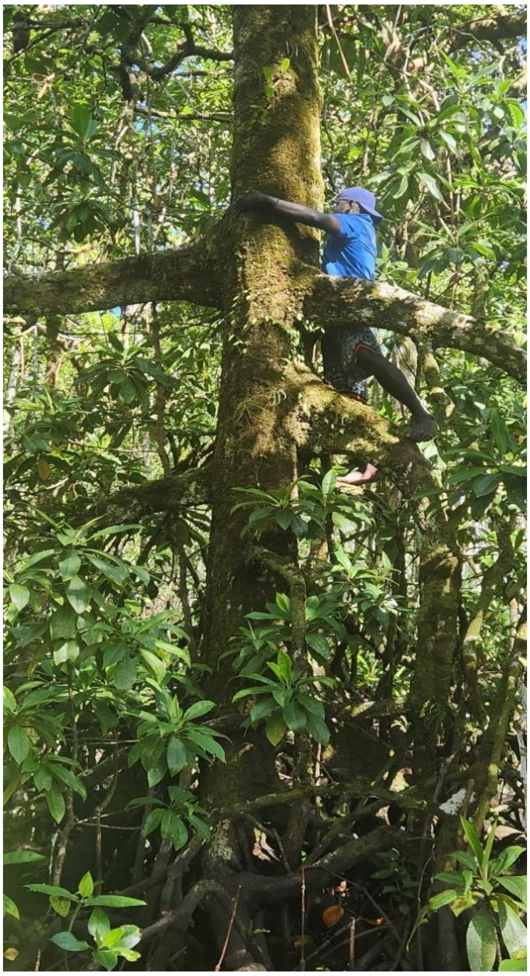
Site	Photograph
Lau Lagoon Site 1	 

Site	Photograph
Lau Lagoon Site 6	
Lau Lagoon Site 9	

Site	Photograph
Lau Lagoon Site 10 & 11	

C.1.2. Solomon Islands mangrove site photos

Site	Photograph
Ketoketo Island (MK)	  

Site	Photograph
Jalire River Mouth (MJ)	  

Site	Photograph
Rurukongga Island (CBR)	 

Site	Photograph
Koreke (CBK)	 

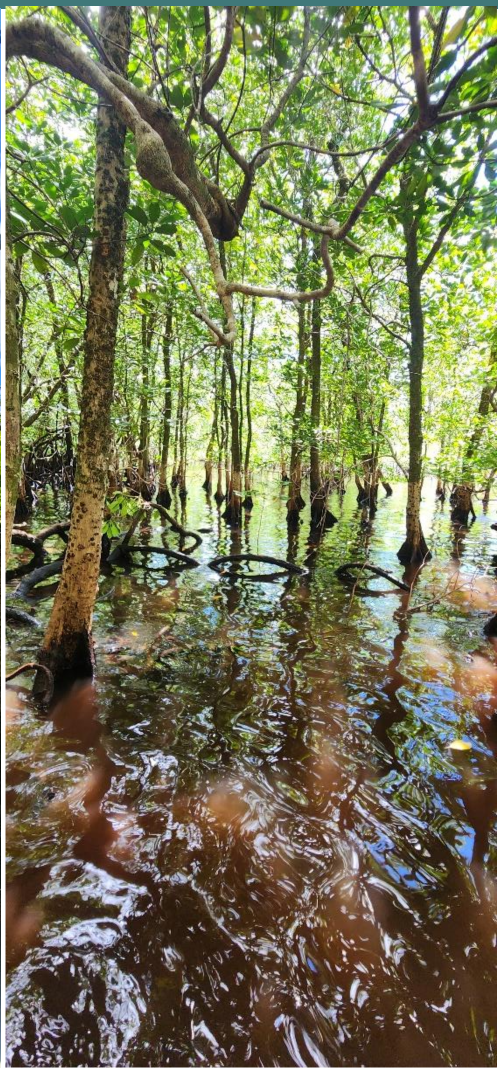
Site	Photograph
Mohe River (CM)	 

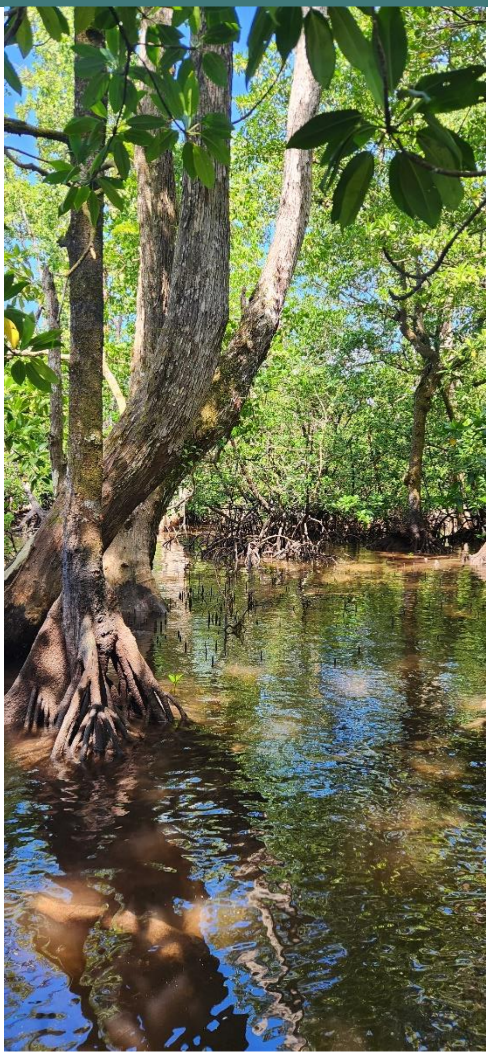
Site	Photograph
Sesehura Fa Island (ISF)	  

Site	Photograph
Papatura Faa Island (IPF)	 

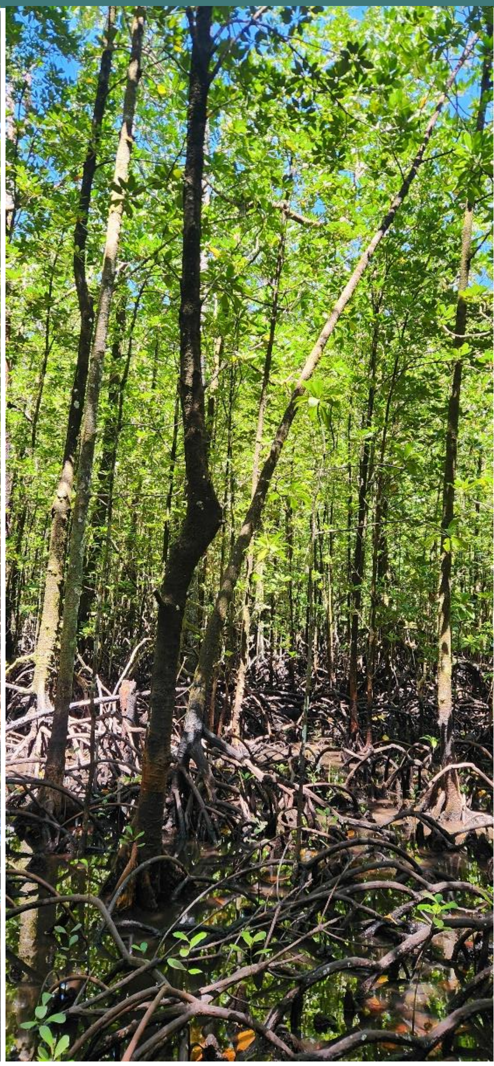
Site	Photograph
Chumbikopi Gaio Passage (CBG)	 

Site	Photograph
Choi Hivata (CH)	 

Site	Photograph	
Papatura Island (IPI)		

Site	Photograph
Banafao (IB)	 

Site	Photograph
Mamazi River (IM)	 

Site	Photograph
Pazeghere (IPZ)	 

Site	Photograph
Lau Lagoon Site 2	
Lau Lagoon Site 3	

Site	Photograph
Lau Lagoon Site 4	
Lau Lagoon Site 5	

Site	Photograph
Lau Lagoon Site 7	 

Site	Photograph
Lau Lagoon Site 8	 

Site	Photograph
Honiara Site 1	 

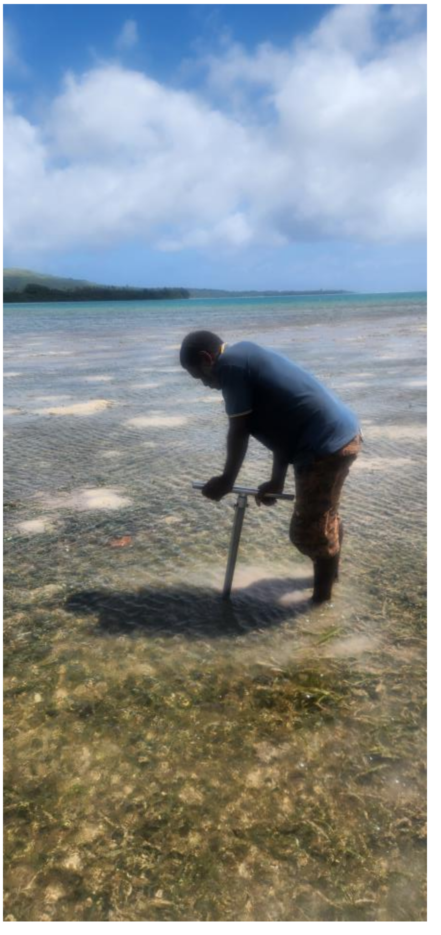
Site	Photograph
Honiara Site 2	 

Appendix **D**

Vanuatu site photos

D.1. Vanuatu site photos

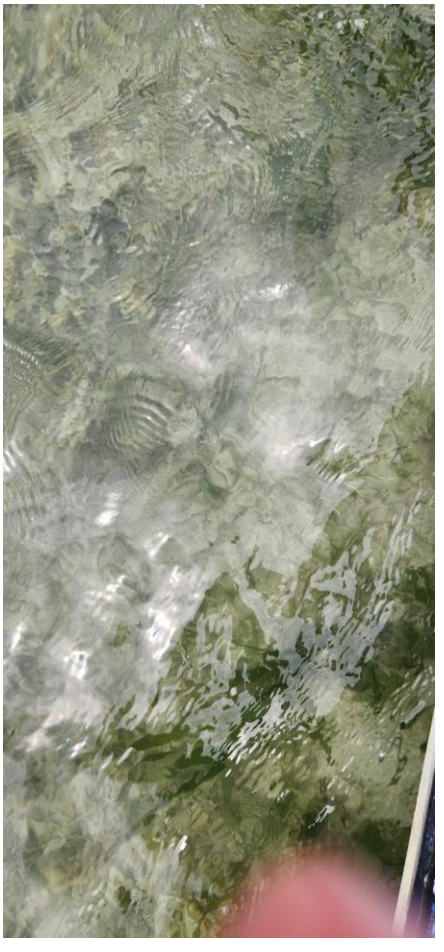
D.1.1. Vanuatu seagrass site photos

MOSO-UNDINE BAY	
Site	Photograph
Lakengola (LG)	  

Site	Photograph
Moso Landing (ML)	No Photographs taken at this location for seagrass

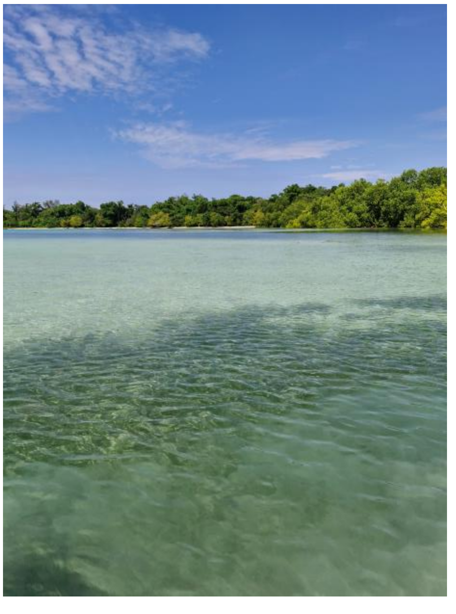
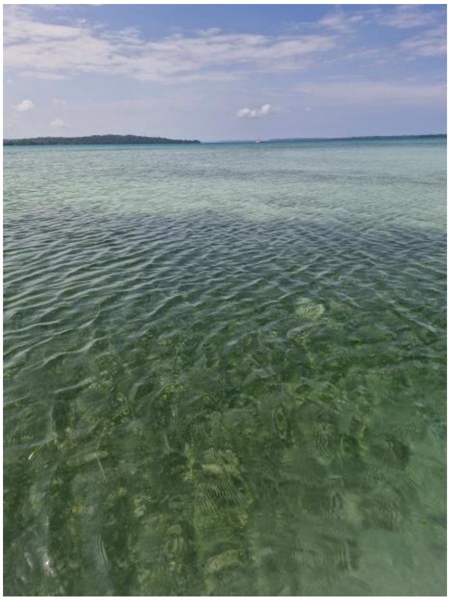
Site	Photograph
Paonangisu (PG)	  

Site	Photograph
Moso Island (MI)	No Photographs were taken at this site

PORT VILA-ERATAP	
Site	Photograph
Eratrap Island (EI)	 

Site	Photograph
Tuuaimatic (TM)	No Photographs were taken at this site

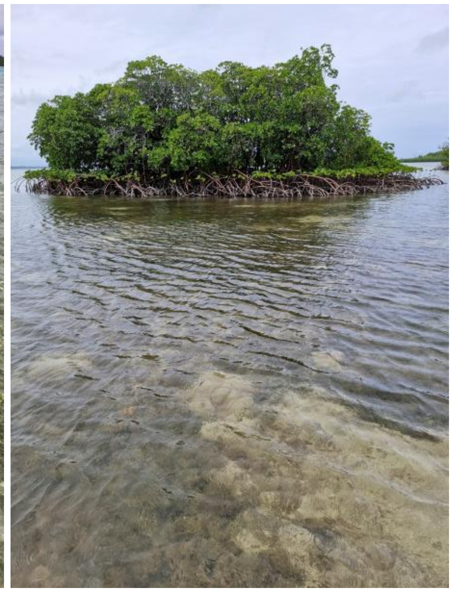
Site	Photograph
Epakor (EP)	 

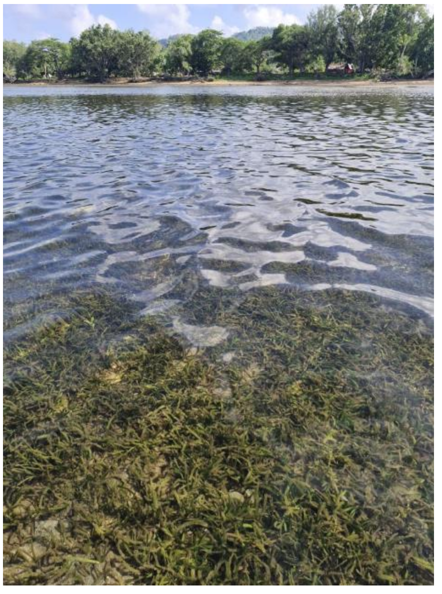
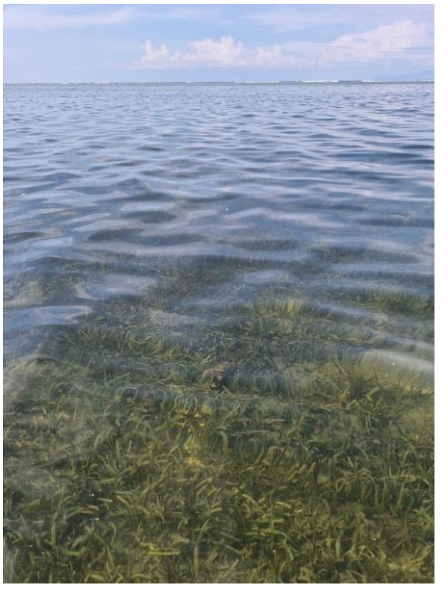
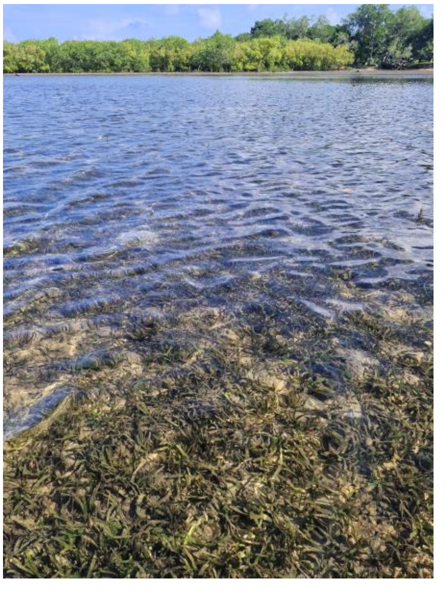
SANTO	
Site	Photograph
Palikulo Bay (PB)	   

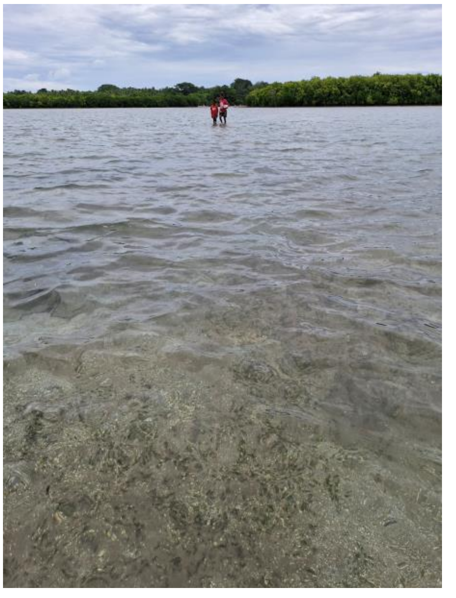
Site	Photograph
Turtle Bay (TB)	 

MALO-AORE

Site	Photograph
Malo North/ Pass (MN)	   

Site	Photograph
Malo Killikilli (MK)	   

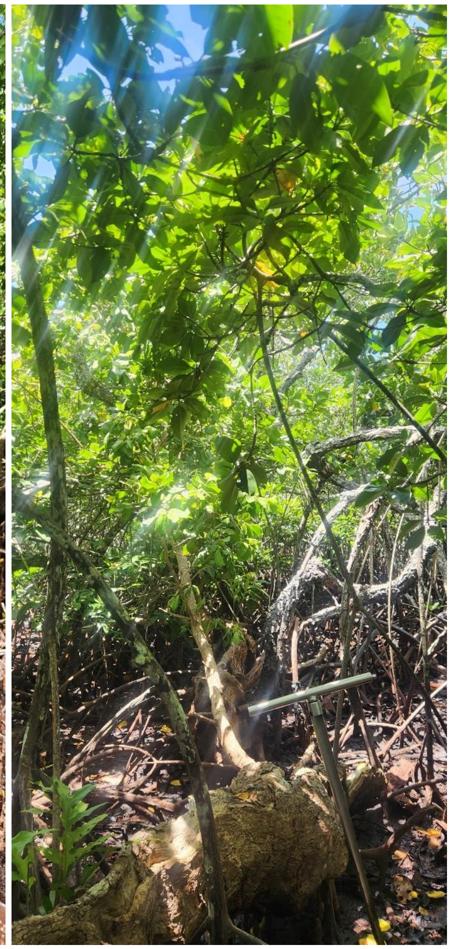
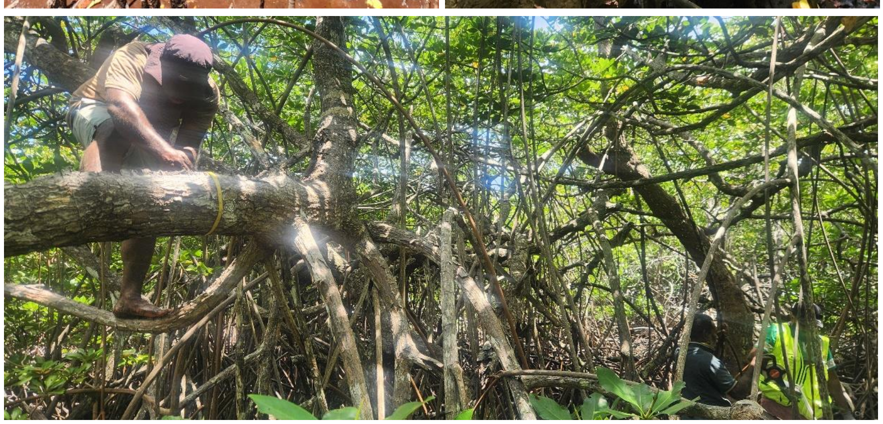
MALEKULA	
Site	Photograph
Malekula Port Sandwich (LAM)	   

Site	Photograph
Malekula Port Stanley (NOR)	 

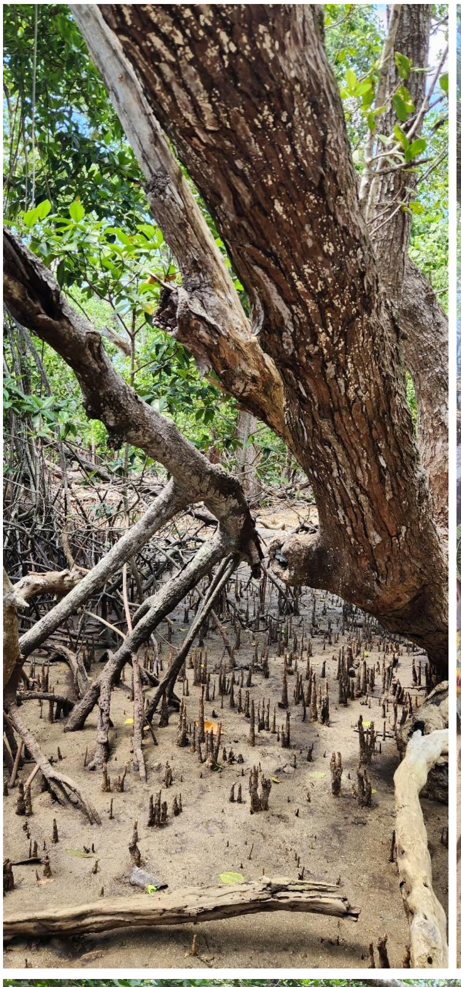
MASKELYN	
Site	Photograph
Maskelyn Islands Peskarus (MAS1)	

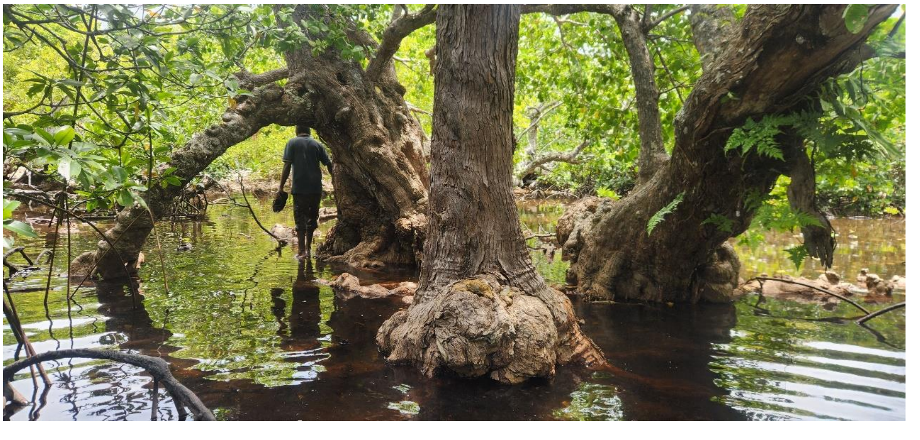
Site	Photograph
Maskelyn Islands Sakao (MAS2)	

D.1.2. Vanuatu mangrove site photos

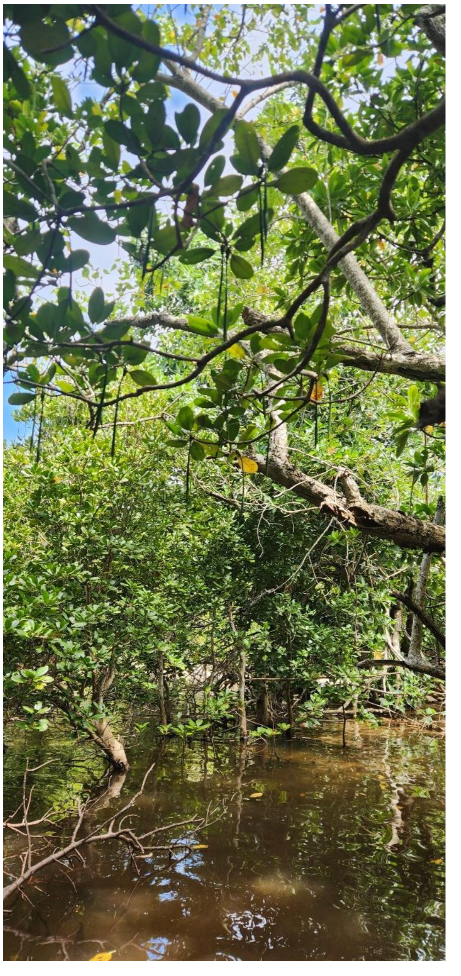
MOSO UNDINE-BAY	
Site	Photograph
Nasinu (NA)	  

Site	Photograph
Kintoa (KT)	  

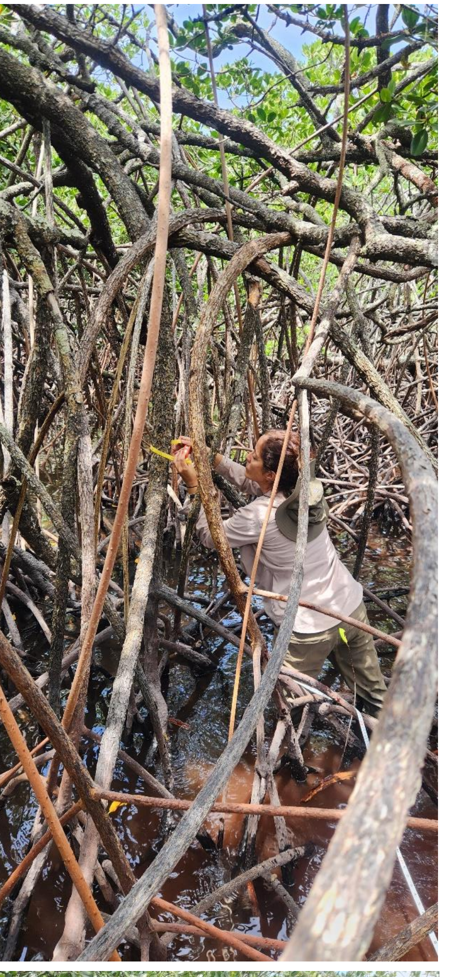
Site	Photograph
Malatia School (MS)	  

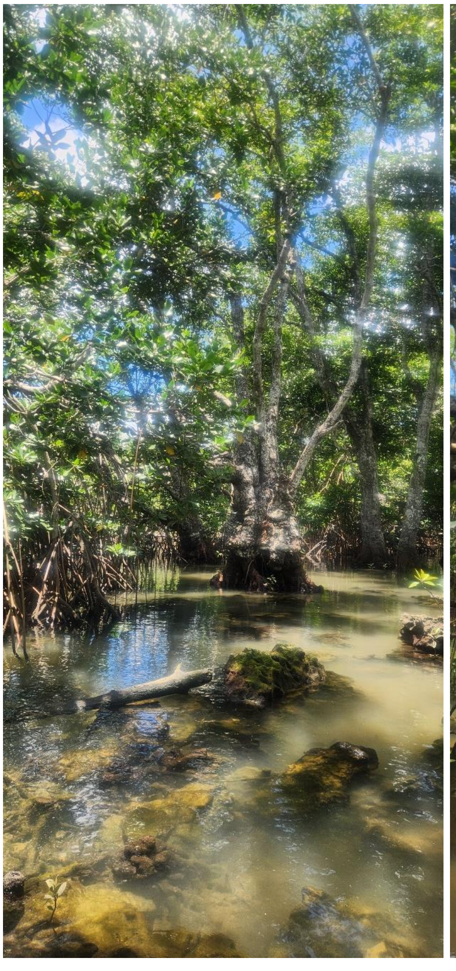
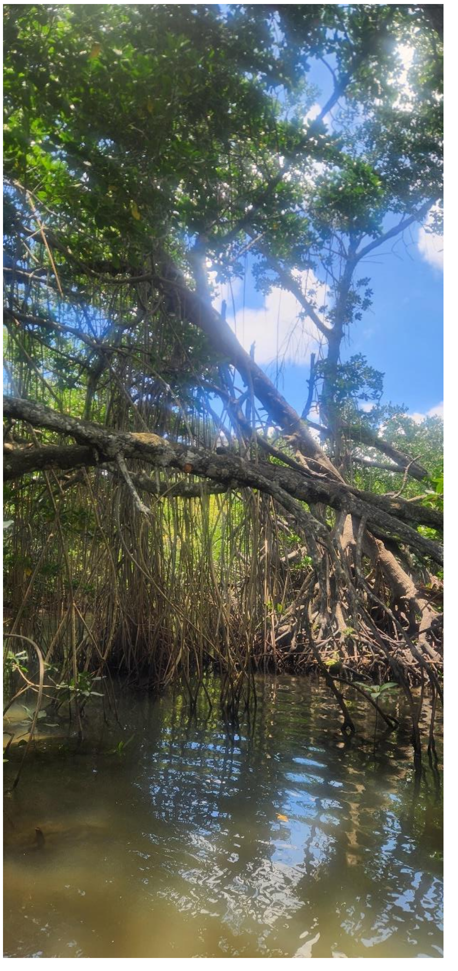
Site	Photograph
LK (LK)	  

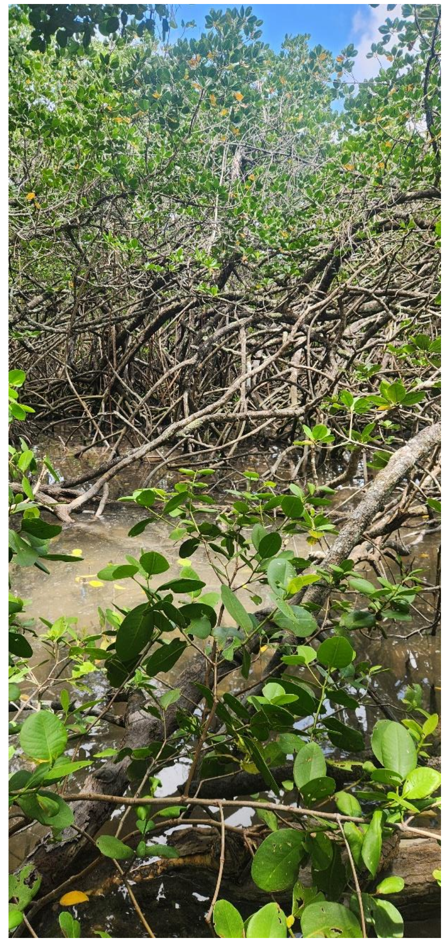
Site	Photograph
Manatawora (MN)	  

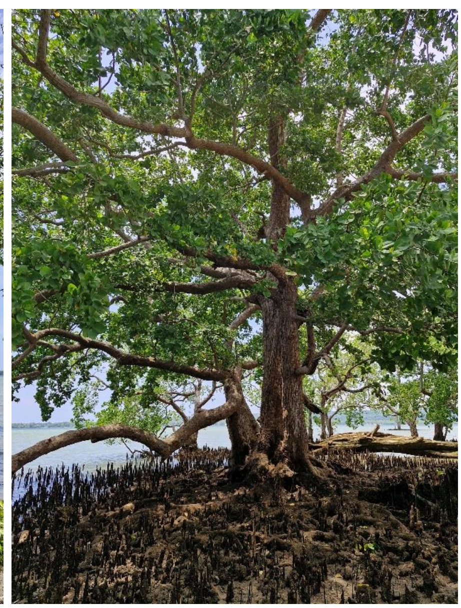
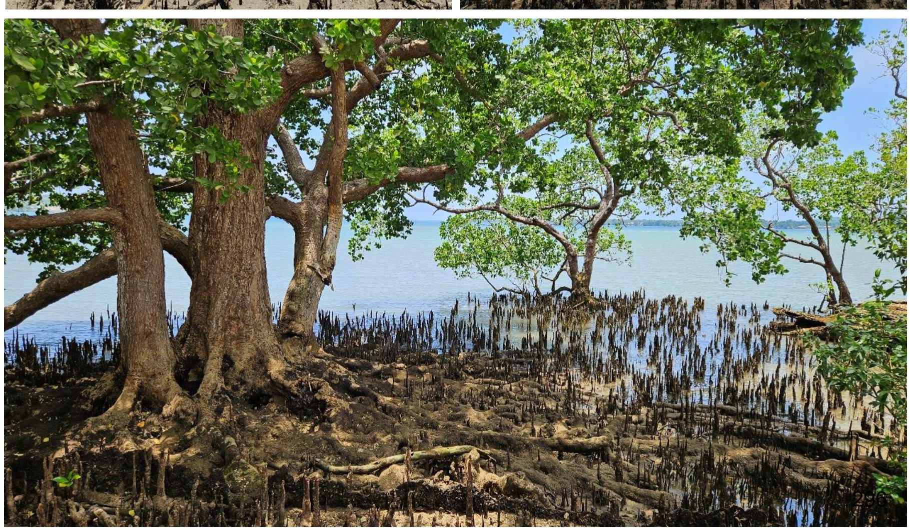
Site	Photograph
Lakengola (LG)	 

Site	Photograph
Moso Landing (MS)	 

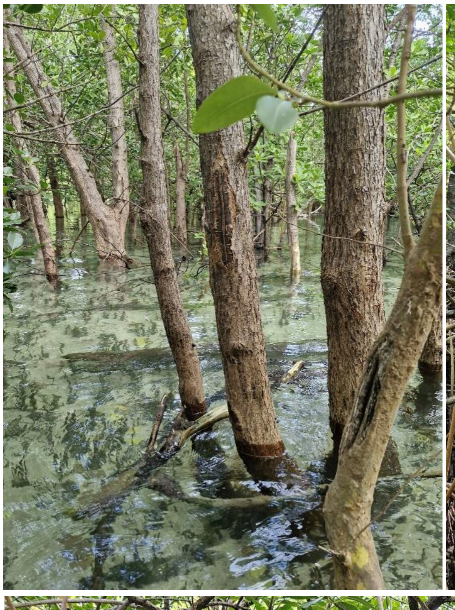
PORT-VILA ERATAP	
Site	Photograph
Eratrap Island (EI)	  

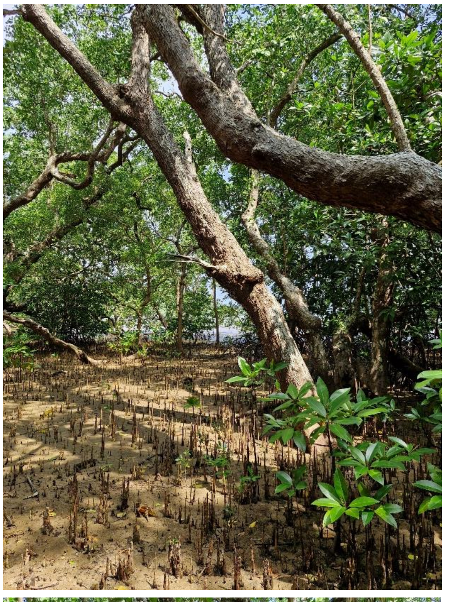
Site	Photograph
Tuuaimatic (TM)	 

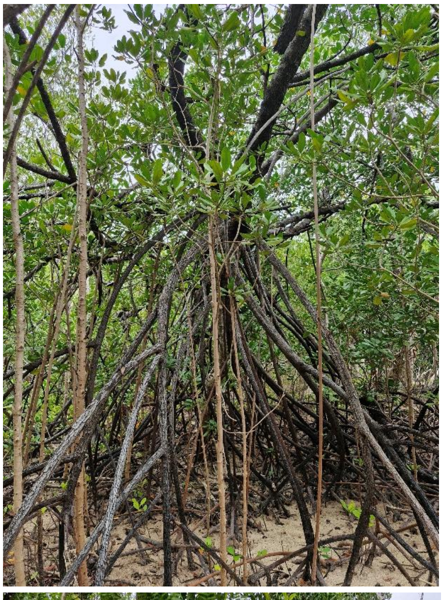
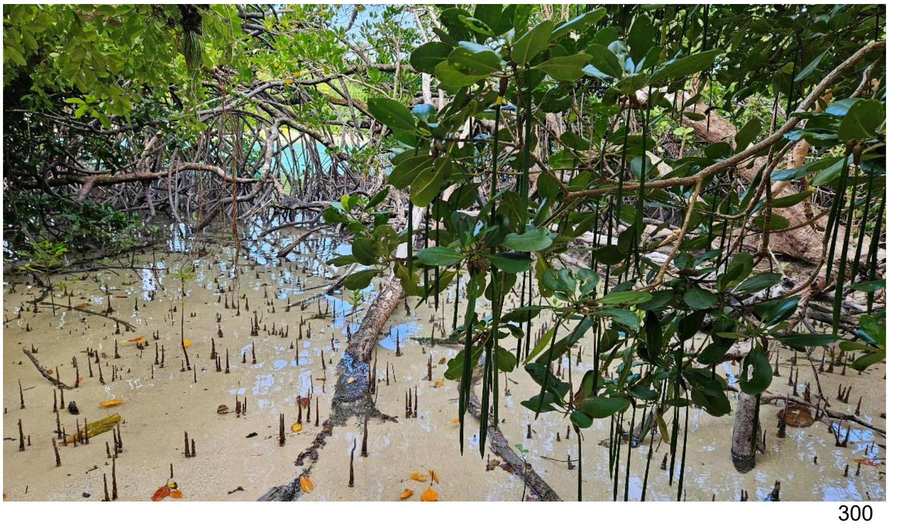
Site	Photograph
Epakor (EP)	  

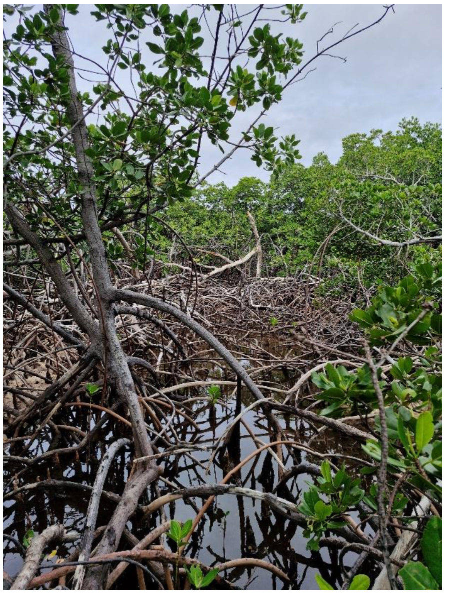
SANTO	
Site	Photograph
Sarakata River Mouth (SR)	    

Site	Photograph
Sarakata River Mouth-Gravel Sites (SR-GRAV)	    

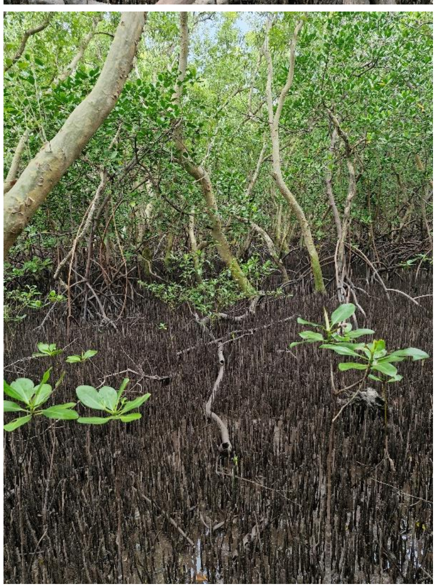
Site	Photograph
Palikulo Bay (PB)	    

Site	Photograph
Turtle Bay (TB)	   

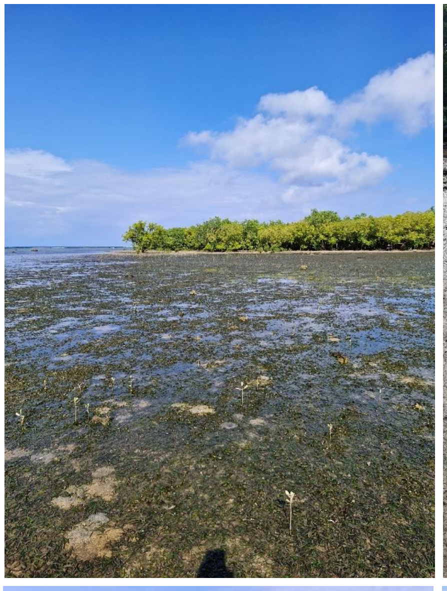
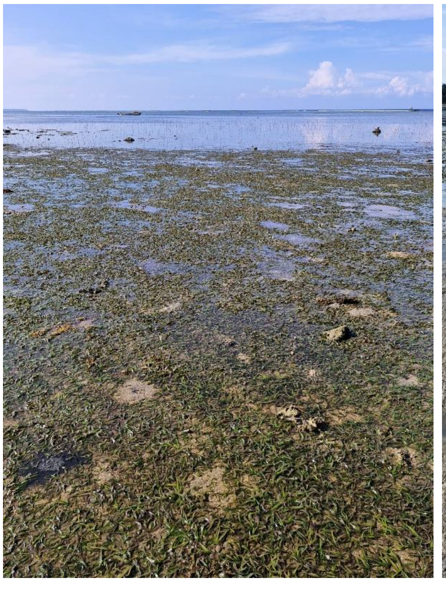
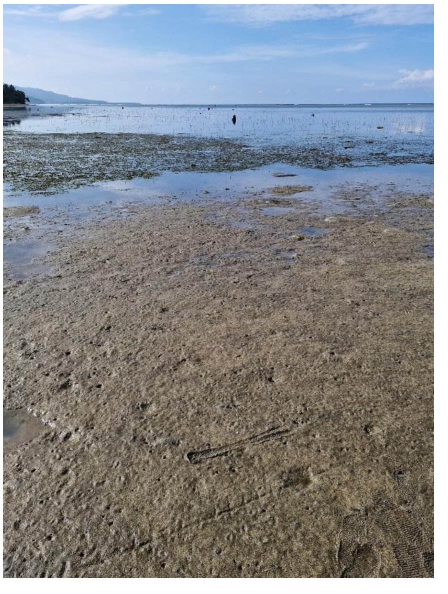
MALO-AORE	
Site	Photograph
Malo North/Pass (MN)	    

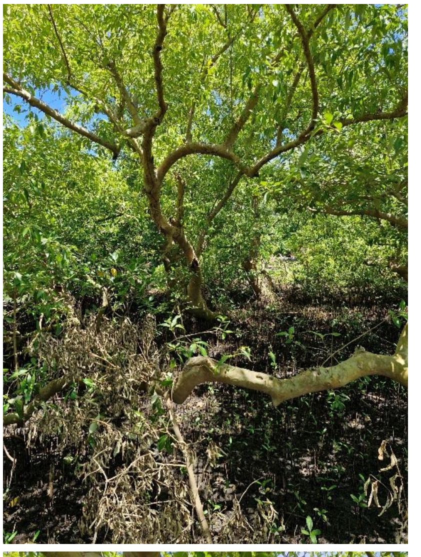
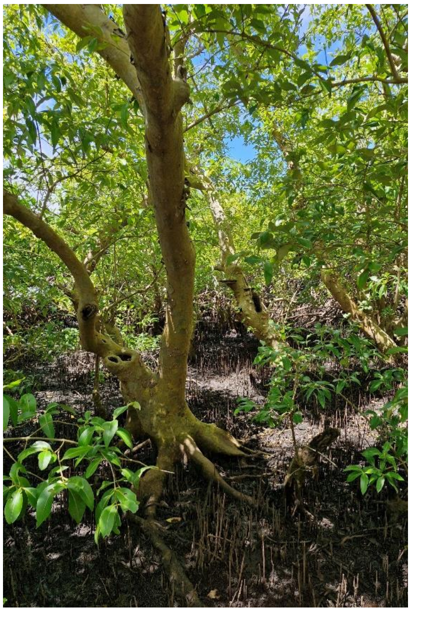
Site	Photograph	
Malo Killikilli (MK)		

MALEKULA	
Site	Photograph
Malekula Norsup Port Stanley Site 1 (NOR1)	

Site	Photograph
Malekula Norsup Port Stanley Site 2 (NOR2)	   

Site	Photograph
Malekula Norsup Port Sandwich Site 1 (LAM1)	   

Site	Photograph
Malekula Norsup Port Sandwich Site 2 (LAM2)	   

MASKELYN	
Site	Photograph
Maskelyn Islands Peskarus (MAS1)	   

Site	Photograph
Maskelyn Islands Sakao (MAS2)