

Blue Carbon Ecosystems of the South Pacific

National Carbon Stock Estimates for Fiji, Papua New
Guinea, Solomon Islands, and Vanuatu

Blue Carbon Assessments for SPREP component of the MACBLUE project

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Disclaimer

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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 für Internationale 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 4 (Carbon Assessment Reports) 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:

- The methods for field carbon assessments, laboratory analysis and carbon stock calculations
- The results of the seagrass and mangrove carbon assessments conducted in-country
- A summary of the findings, conclusions, and limitations of this study.

This document forms the introduction and method section of the report. The results are in separate documents, one for each of the four countries assessed.

Key findings

The standardised methodology enables meaningful comparison of carbon stocks and emissions across countries, supporting regional policy alignment. Presenting national carbon stocks at both 30 cm and 100 cm soil depths allows alignment with international reporting standards and facilitates comparison with future studies.

Most findings in this study aligned with expectations based on previous studies and global trends:

- Tier 2 assessments revealed significantly higher carbon stocks than Tier 1 estimates, particularly in PNG and Solomon Islands.
- Mangroves contributed more to national carbon stocks than seagrass ecosystems, due to larger mapped areas and higher carbon density.
- Carbon stocks varied by geomorphic setting, with riverine mangroves generally storing more carbon than calcareous island or open coast settings.
- Emissions from degradation were highest in sites cleared for development or industry (up to 78% carbon loss), while cyclone-affected sites showed lower emissions (0–10%).

However, one unexpected result was the limited stratification of carbon stocks by geomorphic setting. While riverine sites typically store more carbon, this pattern was not consistently significant across countries. This may reflect limitations in the classification system, high site-level variability, or overlapping influences such as land use, species composition, and disturbance history. Future work should refine geomorphic classification to better capture ecological differences.

Country Highlights

- Fiji: Mangrove carbon stock 11.8–23.5 million Mg C¹; seagrass 2.1–4.6 million Mg C. Riverine mangroves stored the highest TECS.
- PNG: Mangrove carbon stock 124.1–207.8 million Mg C; seagrass 4.1–11.2 million Mg C.
- Solomon Islands: Mangrove carbon stock 40.9–58.1 million Mg C; seagrass 1.6–2.7 million Mg C. Lagoon and riverine sites stored the most carbon.
- Vanuatu: Mangrove carbon stock 0.23–0.34 million Mg C; seagrass 21,105–45,493 Mg C. Riverine mangroves were not mapped due to data gaps.

This study fills a major data gap in Pacific blue carbon assessments. It provides the first empirical national carbon stock estimates for mangrove and seagrass ecosystems in the region, supporting improved climate reporting, conservation planning, and restoration prioritisation. The findings demonstrate the value of field-based Tier 2 assessments and highlight the need for updated mapping and refined site classification to improve future estimates.

¹ Mg C stands for megagrams (metric tonnes) of carbon stored in an ecosystem.

Foreword

Blue carbon ecosystems, specifically, mangroves and seagrasses, play a crucial role in regulating our climate by capturing and storing atmospheric carbon dioxide. These ecosystems are capable of sequestering up to five times more carbon than terrestrial forests. However, when disturbed or removed, they release significant amounts of stored carbon back into the atmosphere. Protecting and restoring them is therefore essential for safeguarding biodiversity and mitigating climate change.

The National Carbon Stock Estimates report represents a significant milestone in advancing blue carbon stock and emission data for seagrass and mangrove ecosystems in the Pacific. For the first time, a coordinated, standardised, and field-based blue carbon stock assessment was conducted across four Pacific Island nations – Fiji, Papua New Guinea, Solomon Islands and Vanuatu. The methods adhered to the Intergovernmental Panel on Climate Change (IPCC) guideline, and the multi-country approach allowed meaningful comparisons between countries and contexts to understand patterns, identify priority areas for protection and inform future management interventions. The produced Tier 2 data support the countries in their national greenhouse gas inventories, their reporting to international agreements such as the Nationally Determined Contributions (NDCs) and the development of appropriate national policies.



The study found that mangrove ecosystems in the Pacific store significant amount of carbon which are comparable, and in some cases exceeding, global averages. Most of these carbon, 70 – 83% are found below ground. The carbon stock levels in seagrass were determined to also align with global averages, specifically in Papua New Guinea and Vanuatu. Emission levels were found to be typically higher at sites where mangroves were cleared for development and relatively less at sites disturbed by natural events such as cyclones.

The study is commissioned under the Management of Blue Carbon Ecosystems in Pacific Island Countries (MACBLUE) project, implemented by the Secretariat of the Pacific Regional Environment Programme (SPREP) in partnership with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the Pacific Community (SPC).

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.

The results stand as both a scientific contribution and a call to action, emphasizing the urgent and collective actions needed to safeguard seagrass and mangrove ecosystems, while highlighting the contribution of blue carbon studies in enhancing knowledge and capacity in this field.

A handwritten signature in black ink, appearing to read 'Sefanaia Nawadra'.

Sefanaia Nawadra

Director General SPREP

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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

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- Mr Asaeli Tamanitokula – Bua Province
- Mr Manasa Vula – Cakaudrove Province
- Ms Vasiti Vosabalavu Naikoyadau – Macuata Province
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- Youth President, Maiwara Village
- Bautama Seventh Day Adventist Church
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- Benjamin Keni – Central Province / Hiri District
- Dianah Gigiba – South Fly District
- Gideon Bogosia – New Ireland Province
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- Village Chief Chachabule Rebi Amoi, Michi Michi; Trustees Jebert Mala and Freeman Hite
- Village Chief, Chumbikopi; Council of elders Chairman Hamley Anderson; community conservation chairman Scofiel Vora; Treasurer Timothy Jama
- Village Nazareth Land trustees (Choe Land Trust Board); Jeremiah Piko Chairman CLTB; Morish Ngira Secretray CLTB; Misach Tivuru Deputy Chairman CLTB and Ronald Lada tribal leader
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- Guadalcanal Province

Vanuatu

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- Chief, Peskarus
- Mayor, Sanma Province
- Town Clerk and Deputy Town Clerk, Luganville
- Malampa Province

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GLOSSARY

AG	Above-ground
AGB	Above-ground biomass
AG TCS	Above-ground tree carbon storage
BD	Bulk Density
BG	Below-ground
BGB	Below-ground biomass
BG TCS	Below-ground tree carbon storage
CC	Carbon concentrations
FPIC	Free, Prior, and Informed Consent
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Corporation for International Cooperation)
Mg C	Megagrams of carbon (which is equal to 1 metric tonne)
Mg C ha⁻¹	Megagrams of carbon per hectare
MACBLUE	Management and Conservation of the Blue Carbon Ecosystems
NGO	Non-Governmental Organisation
PNG	Papua New Guinea
SaM	Seagrass and Mangrove
SE	Standard Error
SOC	Soil organic carbon
SPC	The Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
TCS	Tree carbon storage
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, SaMs contribute to the cultural heritage of Pacific communities, offering resources for traditional practices and medicines.

The protection and restoration of these BCEs, not only protects their carbon stores contributing to climate change mitigation but is essential for the sustainable development and resilience of Pacific Island Nations in general.

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 these 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 and 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 seagrass and mangrove 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 report is part of a series of Seagrass and Mangrove (SaM) Ecosystem Assessment Reports developed for Stage 6: National Carbon Stock Assessments of the project titled *“Consultancy Services to Conduct Blue Carbon Ecosystems Assessments for the SPREP Component of the MACBLUE Project.”*

The purpose of this document is to present national carbon stock estimates derived from field-based assessments conducted in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu. While the preceding report² in this series detailed the results of the field-based carbon stock assessments, this report builds upon those findings by outlining the methodology and presenting results specific to national-level estimates.

Specifically, this report includes:

- A summary of methods used for field-based carbon assessments, laboratory analysis, and carbon stock calculations
- A description of the approach applied to derive national carbon stock and emission estimates
- National carbon stock estimates for seagrass and mangrove ecosystems in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu
- Carbon emissions estimates for mangrove ecosystems exposed to different land-use pressures and land-use changes
- A summary of key findings, conclusions, and limitations of the study.

1.3 About the project

This 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"* (www.macblue-Pacific.info). The Management and Conservation of Blue Carbon Ecosystems (or MACBLUE) is a joint effort between the Deutsche Gesellschaft für Internationale 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 for this project will allow inventories of carbon stocks and 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 blue carbon habitats
- Train and build capacity in each of the countries.

² Alluvium Group, 2025, *Blue Carbon Ecosystems of the South Pacific: Field Based Carbon Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu*, report prepared by Alluvium Group for the MACBLUE Project, Brisbane, Australia.

2 Existing understanding

2.1 Past total ecosystem carbon stock assessments in Pacific Island Nations

Existing knowledge of blue carbon stocks in Pacific Island Nations is limited and fragmented, particularly for mangrove and seagrass ecosystems. Here we have summarised some geographically relevant study findings in Table 1. In Fiji, localised studies—such as those by Cameron, Lovelock, and Adame (2021)—have focused on key river deltas like Ba, Tuva, and Rewa on Viti Levu.³ These studies estimated total ecosystem carbon stocks (TECS) in mangroves at approximately 481.6 Mg C ha⁻¹, which is lower than global averages.^{4,5} However, this figure is likely an underestimate, as most soil carbon in deltaic systems is stored below 1 m depth, and the Fiji study only sampled to 1.5 m. This highlights the importance of deeper soil sampling for accurate carbon accounting, especially in sediment-rich environments.

In contrast, Papua New Guinea (PNG), Solomon Islands, and Vanuatu have seen even fewer studies, with most data derived from small-scale or site-specific assessments. Despite having some of the most extensive mangrove forests in the region, PNG lacks comprehensive carbon stock inventories. Similarly, the Solomon Islands and Vanuatu have limited published data on mangrove or seagrass carbon stocks, making regional comparisons difficult.

Regional studies such as Donato et al. (2011), which sampled soil carbon to depths of up to 3 m across the Indo-Pacific, underscore the significance of deep soil carbon pools in mangrove ecosystems. Our study—which has focused on the top 1 m of soil—likely provides valuable but conservative estimates of carbon stocks. By applying a standardised assessment approach across multiple sites in Fiji, PNG, Solomon Islands, and Vanuatu, this carbon assessment helps characterise variation in carbon stocks across mangrove and seagrass ecosystems and contributes to filling critical regional data gaps.

³ Cameron, M. J., Lovelock, C. E., & Adame, M. F. (2021). Carbon stocks of mangrove forests in Fiji: Implications of soil depth and land use. *Forest Ecology and Management*, 482, 118879. <https://doi.org/10.1016/j.foreco.2020.118879>

⁴ Kauffman, J. B., Bernardino, A. F., Ferreira, T. O., Giovannoni, L. R., & Jesus Garcia, M. (2020). Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. *Ecological Applications*, 30(3), e02089. <https://doi.org/10.1002/eap.2089>

⁵ Alongi, D. M. (2023). *Blue carbon ecosystems and climate change mitigation: A global perspective*. Springer.

Table 1. Summary of previous studies of seagrass ecosystem carbon stock assessments in Pacific nations and other surrounding nations.

Country	Above-ground Biomass (Mg C ha ⁻¹)	Below-ground Biomass (Mg C ha ⁻¹)	Live Seagrass Biomass (Mg C ha ⁻¹)	Soil Organic Carbon Content (%)	Soil depth profile (cm)	Total Soil Carbon (Mg C ha ⁻¹)	Total ecosystem carbon (Mg C ha ⁻¹)	Notes and citation
Indonesia	0.01 – 1.85	0.05 – 1.84			≤ 100	0.32 – 65.8		Based on a review of available literature for 13 countries in Southeast Asia. ⁶
Palau & Yap	0.39	-	0.12	16.7	14	48.0	48.12	Carbon stock of Micronesian mangroves and adjacent seagrass communities. ⁷
Fiji	-	0.32 – 0.95	0.21	0.5 – 0.95%	10	31 – 47	78.21	Carbon storage in seagrass meadows near Rewa River and Sigatoka River in Viti Levu, Fiji. ⁸
Singapore	0.09	0.07	0.16	1.1	100	138	138	Carbon stock assessment of intertidal ecosystems in Chek Jawa, Singapore. ⁹
Australia	-	-	-	1.26	240	365.09	365.09	Sedimentary carbon stock assessment in Coffs Harbour, Australia. ¹⁰

⁶ Stankovic, M., Mishra, A. K., Rahayu, Y. P., Lefcheck, J., Murdiyarso, D., Friess, D. A., ... & Pratsep, A. (2023). Blue carbon assessments of seagrass and mangrove ecosystems in South and Southeast Asia: Current progress and knowledge gaps. *Science of the Total Environment*, 904, 166618.

⁷ Kauffman, J. B., Heider, C., Cole, T. G., Dwire, K. A., & Donato, D. C. (2011). Ecosystem carbon stocks of Micronesian mangrove forests. *Wetlands*, 31(2), 343–352. <https://doi.org/10.1007/s13157-011-0148-9>

⁸ Singh, S., Lal, M. M., Southgate, P. C., Wairiu, M., & Singh, A. (2022). Blue carbon storage in Fijian seagrass meadows: First insights into carbon, nitrogen and phosphorus content from a tropical southwest Pacific Island. *Marine Pollution Bulletin*, 183, Article 113432. <https://doi.org/10.1016/j.marpolbul.2022.113432>

⁹ Phang, V. X. H., Chou, L. M., & Friess, D. A. (2015). Ecosystem carbon stocks across a tropical intertidal habitat mosaic of mangrove forest, seagrass meadow, mudflat and sandbar. *Earth Surface Processes and Landforms*, 40(11), 1387–1400. <https://doi.org/10.1002/esp.3745>

¹⁰ Brown, D. R., Conrad, S., Akkerman, K., Fairfax, S., Fredericks, J., Hanrio, E., Sanders, L. M., Scott, E., Skillington, A., Tucker, J., van Santen, M. L., & Sanders, C. J. (2016). Seagrass, mangrove and saltmarsh sedimentary carbon stocks in an urban estuary; Coffs Harbour, Australia. *Regional Studies in Marine Science*, 8, 1–6. <https://doi.org/10.1016/j.rsma.2016.08.005>

Table 2. Summary of previous studies of mangrove ecosystem carbon stock assessments in Pacific nations and other surrounding nations

Country	Above-ground Biomass (Mg C ha ⁻¹)	Below-ground Biomass (Mg C ha ⁻¹)	Live tree Biomass (Mg C ha ⁻¹)	Soil Organic Carbon Content (%)	Soil profile depth (cm)	Total Soil Carbon (Mg C ha ⁻¹)	Total ecosystem carbon (Mg C ha ⁻¹)	Notes and citation
Papua New Guinea	242.4 – 432.5	-	-	-	NA	-	-	Global study based on remotely sensed measurements of tree cover and canopy heights, no localised field data ¹¹
Fiji			4.5 – 231.7	1.76 – 10.83	150	83.9 – 490.3	132.8 – 772.8	<i>Viti Levu: Ba, Rewa, Nadroga-Navosa</i> ¹²
Vanuatu	536.9 – 1,318.4	486.6	155 – 747	-	-	-	-	Biomass surveys of Amal/Crab Bay and Eratap in Vanuatu dominated by <i>Bruguiera gymnorrhiza</i> , <i>Rhizophora sp.</i> , <i>Xylocarpus granatum</i> , <i>Ceripos tagal</i> , and <i>Avicennia marina</i> . ¹³
Palau & Yap	588	483	657	~18.3	160	1058.3	1,715.3	Mangrove carbon stocks in Palau & Yap. ¹⁴
Australia	297	1842			3500	1530	2139	Queensland, <i>Rhizophora stylosa</i> dominated, Base on published and unpublished data by authors ¹⁵
Indonesia	19	684			62		703	<i>Rhizophora stylosa</i> dominated; based on published and unpublished data by authors ¹⁶

¹¹ Simard, M., Fatoyinbo, L., Smetanka, C., Rivera-Monroy, V.H., Castañeda-Moya, E., Thomas, N., Van der Stocken, T., 2019. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nat. Geosci.* 12 (1), 40–45.

¹² 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

¹³ 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. (2025). *Mangrove EcoSystems for Climate Change Adaptation and Livelihoods (MESCAL) Biodiversity Assessments Technical Report*. Viliame Pita Waqalevu (Ed.). Vanuatu: MESCAL Project.

¹⁴ Kauffman, J. B., Heider, C., Cole, T. G., Dwire, K. A., & Donato, D. C. (2011). Ecosystem carbon stocks of Micronesian mangrove forests. *Wetlands*, 31(2), 343–352. <https://doi.org/10.1007/s13157-011-0148-9>

¹⁵ Daniel M Alongi (2012) Carbon sequestration in mangrove forests, *Carbon Management*, 3:3, 313-322, DOI: 10.4155/cmt.12.20

¹⁶ Daniel M Alongi (2012) Carbon sequestration in mangrove forests, *Carbon Management*, 3:3, 313-322, DOI: 10.4155/cmt.12.20

Country	Above-ground Biomass (Mg C ha ⁻¹)	Below-ground Biomass (Mg C ha ⁻¹)	Live tree Biomass (Mg C ha ⁻¹)	Soil Organic Carbon Content (%)	Soil profile depth (cm)	Total Soil Carbon (Mg C ha ⁻¹)	Total ecosystem carbon (Mg C ha ⁻¹)	Notes and citation
Indonesia	0.03 – 742.6	0.16 – 211.2			≤100	2 – 575		Based on review of available literature for 13 countries in Southeast Asia ¹⁷
Singapore	138	52	190	4.5	100	307	497	Carbon stock assessment in Chek Jawa mangrove dominated by <i>Avicennia</i> sp., <i>Bruguiera cylindrica</i> , <i>Ceriops tagal</i> , <i>Excoecaria agallocha</i> , <i>Rhizophora</i> sp., <i>Sonneratia caseolaris</i> , and <i>Xylocarpus moluccensis</i> . ¹⁸
Australia	-	-	-	4.17	300	1069.81	1069.81	Sedimentary carbon stock assessment in Coffs Harbour, Australia. ¹⁹

¹⁷ Stankovic, M., Mishra, A. K., Rahayu, Y. P., Lefcheck, J., Murdiyarso, D., Friess, D. A., ... & Prathep, A. (2023). Blue carbon assessments of seagrass and mangrove ecosystems in South and Southeast Asia: Current progress and knowledge gaps. *Science of the Total Environment*, 904, 166618.

¹⁸ Phang, V. X. H., Chou, L. M., & Friess, D. A. (2015). Ecosystem carbon stocks across a tropical intertidal habitat mosaic of mangrove forest, seagrass meadow, mudflat and sandbar. *Earth Surface Processes and Landforms*, 40(11), 1387–1400. <https://doi.org/10.1002/esp.3745>

¹⁹ Brown, D. R., Conrad, S., Akkerman, K., Fairfax, S., Fredericks, J., Hanrio, E., Sanders, L. M., Scott, E., Skillington, A., Tucker, J., van Santen, M. L., & Sanders, C. J. (2016). Seagrass, mangrove and saltmarsh sedimentary carbon stocks in an urban estuary; Coffs Harbour, Australia. *Regional Studies in Marine Science*, 8, 1–6. <https://doi.org/10.1016/j.rsma.2016.08.005>

2.2 Past estimates of total national carbon stocks in Pacific Island Nations

To date, no Pacific Island nation has published national-level carbon stock estimates for mangrove or seagrass ecosystems based on field-based carbon assessments. Existing figures have relied exclusively on Tier 1 default values provided by the IPCC, which offer generalized estimates rather than country-specific data. For example, PNG's Second National REDD+ Forest Reference Level²⁰ reports a total forest carbon stock of approximately 4,022 million Mg C, derived from above- and below-ground biomass across 29.1 million hectares of terrestrial forest. This estimate includes montane forests, which are among the most carbon-rich globally due to favourable climatic conditions and large tree biomass. However, mangrove ecosystems are not separately reported in this national inventory, and similar gaps exist for Fiji, Vanuatu, and Solomon Islands.

Recent global studies highlight the importance of soil depth in carbon stock assessments. Kauffman et al. (2020)²¹ demonstrated that limiting soil measurements to 1 meter depth results in global mangrove carbon stock estimates of less than 5,000 million Mg C, whereas including deeper profiles (up to 3 meters) increases estimates to over 11,200 million Mg C. These findings underscore the importance of presenting results across multiple soil depths to reflect the full carbon storage potential of coastal ecosystems.

Table 3 summarises some existing literature estimates, showing significant variation depending on methodology and assumptions. Table 4 presents new national-level estimates for national carbon stock estimate based on IPCC Tier 1 default values for mangroves (511 Mg C ha⁻¹). These estimates range from 0.44 million Mg C in Vanuatu to over 162.9 million Mg C in PNG which provide a baseline for comparison with field-based assessments presented later in this report.

²⁰ Government of Papua New Guinea (2023). *Second National REDD+ Forest Reference Level Modified Submission for the UNFCCC Technical Assessment in 2023*. Accessed 19 Aug 25, available at: [png_2nd_frl_modified_version_fv_0717.pdf](#)

²¹ Kauffman, J. B., Adame, M. F., Arifanti, V. B., Schile-Beers, L. M., Bernardino, A. F., Bhomia, R. K., ... & Hernández Trejo, H. (2020). Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological monographs*, 90(2), e01405.

Table 3. Examples of carbon stock estimates reported in existing literature.

Sources	Region/system	Mangrove area (ha)	Total carbon stock estimate (Mg C)	Notes
Kauffman et al. (2020) ²²	Global mangroves	14,700,000	11,700,000,000	Values include above-ground biomass, below-ground biomass, and soil organic carbon to depths of up to 3 meters.
World Bank CWON Report (2024) ²³	Global mangroves	14,735,900	8,500,000,000	Conservative estimates compared to Kaufmann (2020), likely due to methodological differences including shallower soil depth assumptions.
Second National REDD+ Forest Reference Level ²⁴	Papua New Guinea terrestrial forest	29,100,000	4,022,235,206	Based on forest type, mangroves not included.

Table 4. Estimated national mangrove carbon stocks for Pacific Island nations based on IPCC Tier 1 default values for mangrove (511 Mg C ha⁻¹).²⁵ Values represent total carbon stocks (Mg C) for soil organic carbon (0–100 cm). These estimates provide a preliminary baseline for each country and are intended for comparison with field-based assessments presented later in this report.

Country	Mangrove area (ha) ²⁶	National carbon stock estimate based on IPCC Tier 1 default values for mangroves (511 Mg C ha ⁻¹)
Fiji	51,983	26,563,068
Papua New Guinea	318,778	162,895,328
Solomon Island	56,105	28,669,783
Vanuatu	864	441,499

²² Kauffman, J. B., Adame, M. F., Arifanti, V. B., Schile-Beers, L. M., Bernardino, A. F., Bhomia, R. K., ... & Hernández Trejo, H. (2020). Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological monographs*, 90(2), e01405.

²³ World Bank. (2024). The changing wealth of nations 2024: Revisiting the measurement of comprehensive wealth. World Bank Group. <https://www.worldbank.org/en/publication/the-changing-wealth-of-nations>

²⁴ Government of Papua New Guinea (2023). *Second National REDD+ Forest Reference Level Modified Submission for the UNFCCC Technical Assessment in 2023*. Accessed 19 Aug 25, available at: [png_2nd_frrl_modified_version_fv_0717.pdf](https://www.png2ndfrrlmodifiedversionfv0717.pdf)

²⁵ Kauffman, J. B., Adame, M. F., Arifanti, V. B., Schile-Beers, L. M., Bernardino, A. F., Bhomia, R. K., ... & Hernández Trejo, H. (2020). Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological monographs*, 90(2), e01405.

²⁶ Refer to section 3.2

3 Method

3.1 Summary

This assessment applied a standardised approach to estimate carbon stocks in mangrove and seagrass ecosystems across Fiji, PNG, Solomon Islands, and Vanuatu. The methodology followed internationally recognised guidelines, including the Coastal Blue Carbon Manual²⁷ and IPCC Wetlands Supplement²⁸. By incorporating field-based measurements of biomass and soil carbon, and developing regionally relevant emission factors, the approach satisfies the criteria for a Tier 2 estimate under the IPCC framework.

Here we present a summary of the field and laboratory methods, however these are described in full in other key reports in this series, specifically: *Blue Carbon Ecosystems of the South Pacific: Field-Based Carbon Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu*²⁹ and *Blue Carbon Ecosystems Assessment for Carbon Stock, Biodiversity and Threats: MACBLUE Blue Carbon Training and Field Manual*.³⁰

3.1.1 Site Selection

Sites were chosen to represent the diversity of habitat types (mangrove and seagrass), geomorphic settings (e.g., river deltas, lagoons, islands), and land-use conditions (intact, degraded, converted).^{31,32} Mangrove soil carbon varies significantly across geomorphic settings due to differences in tidal influence, river discharge, and other environmental processes (Figure 1).^{33, 34} To capture this variability, site selection aimed to include all major geomorphic categories where possible. However, selection also considered accessibility, safety, and community consent, ensuring coverage of priority areas identified by national stakeholders.

While sites were chosen to capture variability across different settings, they were not randomly selected and therefore do not constitute a statistically representative sample. This limitation should be considered when interpreting results, particularly when extrapolating findings to broader regional or national scales.

²⁷ Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., Telszewski, M. (eds.) (2019 update). Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.

²⁸ IPCC. (2014). 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., & Troxler, T.G. (Eds.). Intergovernmental Panel on Climate Change. Retrieved from <https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/>

²⁹ Alluvium Group, 2025, *Blue Carbon Ecosystems of the South Pacific: Field-Based Carbon Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu*, report prepared by Alluvium Group for the MACBLUE Project, Brisbane, Australia.

³⁰ Alluvium Group, 2025, *Blue Carbon Ecosystems Assessment for Carbon Stock, Biodiversity and Threats: MACBLUE Blue Carbon Training and Field Manual*, report prepared by Alluvium Group for the MACBLUE Project, Brisbane, Australia.

³¹ Adame, M. F., Connolly, R. M., Turschwell, M. P., Lovelock, C. E., Fatoyinbo, T., Lagomasino, D., ... & Brown, C. J. (2021). Future carbon emissions from global mangrove forest loss. *Global change biology*, 27(12), 2856-2866.

³² Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global Change Biology*, 26(10), 5844–5855. <https://doi.org/10.1111/gcb.15275>

³³ Rovai, A. S., Twilley, R. R., Castañeda-Moya, E., Riul, P., Cifuentes-Jara, M., Manrow-Villalobos, M., ... & Pagliosa, P. R. (2018). Global controls on carbon storage in mangrove soils. *Nature Climate Change*, 8(6), 534-538.

³⁴ Dürr, H. H., Laruelle, G. G., van Kempen, C. M., Slomp, C. P., Meybeck, M., & Middelkoop, H. (2011). Worldwide typology of nearshore coastal systems: defining the estuarine filter of river inputs to the oceans. *Estuaries and coasts*, 34, 441-458.

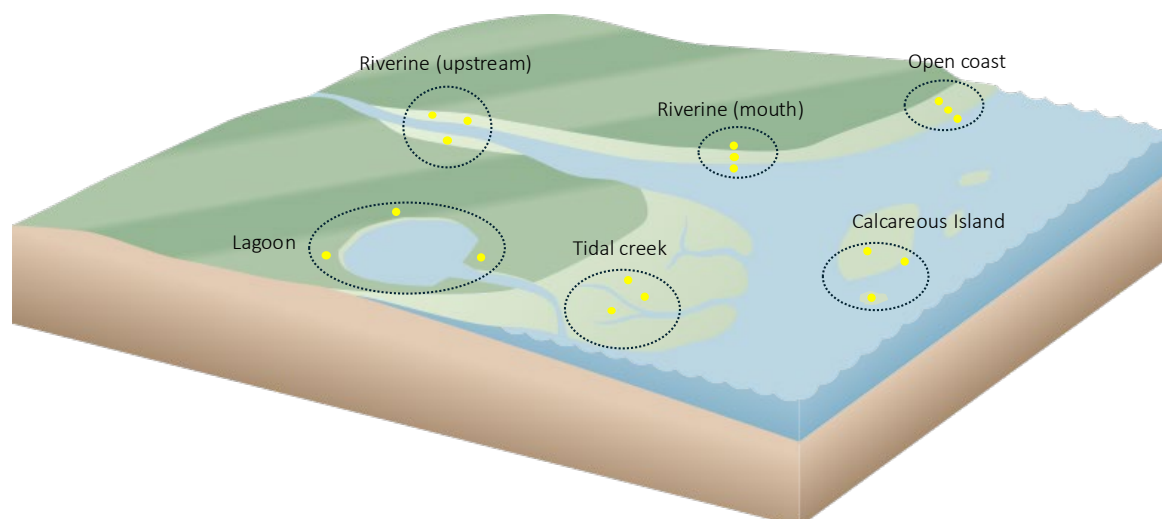


Figure 1. Conceptual diagram demonstrating the different geomorphic settings that should be represented when considering site selection. Black circles represent site options, and yellow circles represent plots within a site. These geomorphic setting categories align with those used in Adame et al (2021) and Durr et al (2011), as they are known to significantly vary in soil carbon.^{35,36, 37}

3.1.2 Field Sampling

At each site, three replicate plots were established. For mangroves, all trees within plots were identified and measured for diameter at breast height (DBH) to estimate above- and below-ground biomass using species-specific or general allometric equations. For seagrass, above- and below-ground biomass was not assessed due to its minor contribution to total carbon stocks; the focus was on sediment carbon.

Soil cores were collected from the centre of each plot to a maximum depth of 1 m (or to refusal), segmented by depth intervals (0-15cm, 15-30cm, 30-50cm, >50cm), and sub-sampled for bulk density and carbon content. Where conditions limited coring (e.g., safety risks, shallow bedrock or remnant reef, high sand content), alternative methods such as grab sampling were used.

3.1.3 Laboratory Analysis and Calculations

Soil samples were dried, weighed, and analysed for organic carbon using elemental analysis following acid fumigation to remove inorganic carbon. Carbon stocks (Mg C ha^{-1}) were calculated by combining carbon concentration, bulk density, and depth for each segment, then summed to 1 m depth. Mangrove biomass carbon was estimated using allometric equations, applying conservative species-specific models where possible.

³⁵ Adame, M. F., Connolly, R. M., Turschwell, M. P., Lovelock, C. E., Fatoyinbo, T., Lagomasino, D., ... & Brown, C. J. (2021). Future carbon emissions from global mangrove forest loss. *Global change biology*, 27(12), 2856-2866.

³⁶ Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global Change Biology*, 26(10), 5844–5855. <https://doi.org/10.1111/gcb.15275>

³⁷ Dürr, H. H., Laruelle, G. G., van Kempen, C. M., Slomp, C. P., Meybeck, M., & Middelkoop, H. (2011). Worldwide typology of nearshore coastal systems: defining the estuarine filter of river inputs to the oceans. *Estuaries and coasts*, 34, 441-458.

3.1.4 Allometric equations for above and below-ground carbon stock estimates

Above-ground (AG) and below-ground (BG) biomass carbon was not assessed for seagrass meadows in this study due to its relatively minor contribution to the total carbon pool, with over 95% of seagrass carbon typically stored in the sediment. Additionally, standardised allometric equations for estimating biomass carbon are limited or not well-developed for many seagrass species, particularly in Pacific Island contexts, making consistent and accurate estimation challenging. As a result, the focus was placed on sediment carbon, which represents the dominant carbon stock in seagrass ecosystems.

Tree Carbon Storage (TCS) refers to the amount of carbon stored within trees (Figure 2), which can be stored in above-ground biomass (in their trunks, stems, foliage, aerial roots and prop roots) and below-ground biomass (in their roots). Total TCS refers to the sum of the carbon stored in trees both above-ground (AG) and below-ground (BG).

Allometric equations were used to estimate the AG biomass of all trees measured in the field. Species-specific equations were used whenever available to ensure accurate biomass calculations (refer to Table 6 in preceding report). In cases where species-specific equations were not available, general allometric equations were applied (the table of allometric equations is presented in the Carbon Assessment report).³⁸ The carbon content of biomass was calculated by multiplying by a factor of 0.48 for AG biomass and 0.39 for BG biomass.

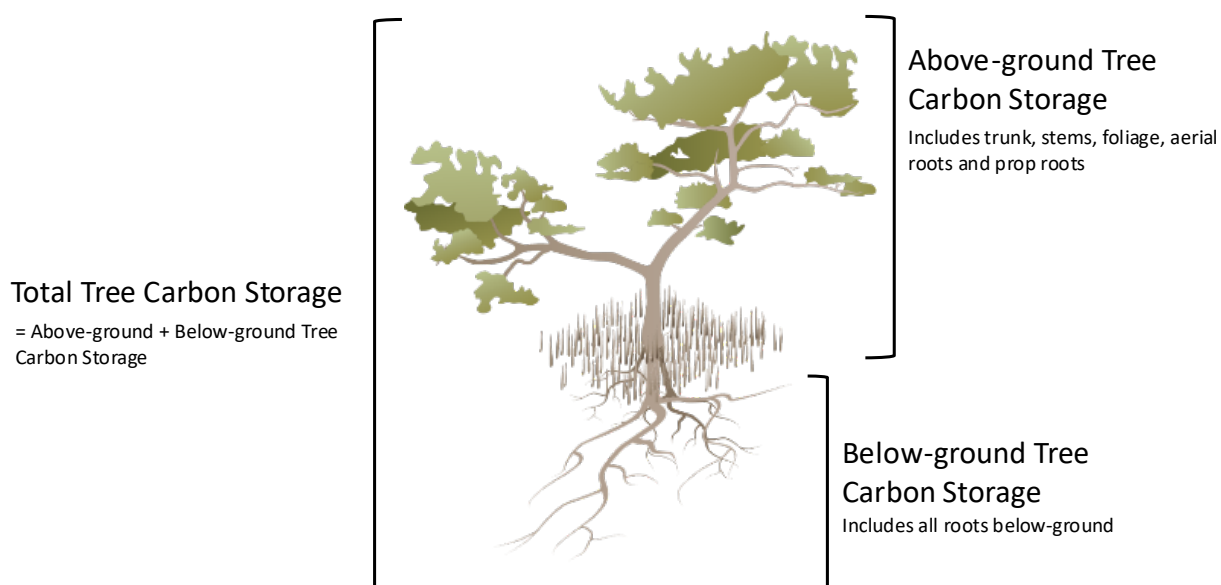


Figure 2. Illustration of Total Tree Carbon Storage stored in trees both above and below-ground.

3.1.5 Soil organic carbon calculations

Total SOC stock (Mg C ha^{-1}) was calculated using the formula:

$$\text{SOC (Mg C ha}^{-1}\text{)} = \text{Carbon Concentration (\%)} \times \text{Bulk Density (g cm}^{-3}\text{)} \times \text{Soil Depth (cm)}$$

This integrates carbon concentration with soil physical properties to estimate carbon per unit area. For each site, SOC was calculated for each depth interval and summed to represent the total SOC to the maximum sampled depth (≤ 1 m). The mean SOC per depth was derived by averaging values from up to three replicate plots per site. Not all sites had three replicates for every depth due to field constraints (e.g., sandy sediments, inundation, shallow bedrock, crocodile risk).

³⁸ Alluvium Group, 2025, *Blue Carbon Ecosystems of the South Pacific: Field Based Carbon Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu*, report prepared by Alluvium Group for the MACBLUE Project, Brisbane, Australia.

Although sampling was limited to 1 m, this depth is widely accepted in blue carbon assessments because most SOC in mangrove and seagrass ecosystems is concentrated within the upper meter. Studies show that >90% of SOC is typically within this depth, with 30–50% often in the top 20 cm, especially in younger or dynamic systems. Therefore, where sampling did not reach 1 m, estimates may be conservative—except in sand-dominated sediments, where SOC is inherently low.

A subset of soil samples from 190 sites across all countries was laboratory analysed for carbon concentration (CC%). The laboratory data were then used to develop a predictive relationship between CC% and bulk density (BD):

$$CC\% = 3.0418 \times BD^{-1.293} (R^2=0.77)$$

The high coefficient of determination ($R^2 = 0.77$) indicates a strong relationship between CC% and BD, making this equation a robust and widely accepted surrogate for estimating carbon concentrations where direct laboratory analysis is not feasible for every soil sample. This approach represents the majority of sites in this study.

3.1.6 Reference for Full Methods

For detailed protocols, including sampling design, equipment specifications, and carbon calculation procedures, refer to:

- Blue Carbon Ecosystems of the South Pacific: Field-based Carbon Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu³⁹
- Blue Carbon Ecosystems Assessment for Carbon Stock, Biodiversity and Threats: MACBLUE Blue Carbon Training and Field Manual⁴⁰

³⁹ Alluvium Group, 2025, *Blue Carbon Ecosystems of the South Pacific: Field Based Carbon Assessments in Fiji, Papua New Guinea, Solomon Islands, and Vanuatu*, report prepared by Alluvium Group for the MACBLUE Project, Brisbane, Australia.

⁴⁰ Alluvium Group, 2025, *Blue Carbon Ecosystems Assessment for Carbon Stock, Biodiversity and Threats: MACBLUE Blue Carbon Training and Field Manual*, report prepared by Alluvium Group for the MACBLUE Project, Brisbane, Australia.

3.2 Mangrove and seagrass extent

3.2.1 Mangrove mapping

Mangrove area coverage was assessed to calculate national carbon stocks by classifying existing spatial data on mangrove distributions according to geomorphic typologies. To align with site geomorphic setting categories (Figure 1), mangrove areas were calculated based on their geomorphic context. This involved using global datasets for river hydrology and coastal reefs to manually assign mangrove areas to specific typologies, following the criteria and methods outlined in Table 5 and Table 6. The process is illustrated in Figure 3 and Figure 4.

Table 5. Mangrove remote-mapping typology applied to mangrove extent spatial data

Remote-mapping typology	Criteria
Large River	Major river systems with high discharge and sediment load, typically forming extensive deltas.
Medium River	Rivers with moderate discharge and sediment transport, often forming more developed estuarine systems.
Small River	Rivers with modest discharge and sediment input, potentially forming small deltas or tidal systems.
Very Small River	Minor river systems with limited discharge and sediment load, often forming small tidal creeks or estuarine inlets.
Calcareous Island	Small reef-fringed islands composed primarily of carbonate rock, often with minimal freshwater input and limited sedimentation.
Open Coast	Coastal areas that are directly exposed to oceanic conditions, with little to no estuarine or riverine influence.

Table 6. Spatial mapping processes for assigning mangrove typologies classifications in QGIS to existing mangrove ecosystem distribution data.

Remote-mapping typology	Spatial dataset(s) *	Mapping criteria and methods	Mapping prioritisation
Large River	Mangrove ecosystem distribution data (SPC) GloRiC (HydroSHEDS)	Large River features GloRiC buffered by 500 m on each side on each side of the waterline. Mangrove polygons intersecting with the buffered river are assigned to Large River typology.	1A – Large rivers are considered the most influential geomorphological feature in the landscape. If a mangrove polygon overlaps with a Large River and any other typologies, 'Large River' is given priority during assignment.
Medium River	Mangrove ecosystem distribution data (SPC) GloRiC (HydroSHEDS)	Medium River features GloRiC buffered by 500 m on each side of the waterline. Mangrove polygons intersecting with the buffered river are assigned to Medium River typology.	1B – Medium rivers are highly influential geomorphological features within the landscape. If a mangrove polygon overlaps with a Medium River and any other typologies, 'Medium River' is given priority during assignment. However, if the polygon also overlaps with a Large River, the 'Large River' typology takes precedence.
Small River	Mangrove ecosystem distribution data (SPC) GloRiC (HydroSHEDS)	Small River features GloRiC buffered by 300 m on each side of the waterline. Mangrove polygons intersecting with the buffered river are assigned to Small River typology.	1C – Small rivers are influential geomorphological features but are given priority only over typologies other than rivers of a larger size. If a mangrove polygon overlaps with a Small River and any typology except Large or Medium Rivers, the 'Small River' typology is given priority during assignment.
Very Small River	Mangrove ecosystem distribution data (SPC) GloRiC (HydroSHEDS)	Very Small River features GloRiC buffered by 300 m on each side of the waterline. Mangrove polygons intersecting with the buffered river are assigned to Very Small River typology.	1D – Very small rivers are assigned the lowest riverine priority. If a mangrove polygon overlaps with a Very Small River and any other typologies except rivers of a larger size. If there is overlap with any higher-tier river type, the higher-tier typology (Large, Medium, or Small River) prevails.
Calcareous Island	Mangrove ecosystem distribution data (SPC) Geomorphic map (Allen Coral Atlas) National Administrative Boundary (Source) – Small islands only	Manually removed polygons of large islands from National Administrative Boundary, leaving the small islands remaining. Mangrove polygons intersecting with the Geomorphic Map and National Administrative Boundary are assigned to Calcareous Island typology.	2 – Calcareous islands are small, reef-fringed islands composed primarily of carbonate rock and minimal freshwater input. They have highly distinct geomorphologies. If a mangrove polygon overlaps with any river typologies, the river typology is given precedence.
Open Coast	Mangrove ecosystem distribution data (SPC) Administrative boundary – Mainland	Any remaining mangrove polygons were assigned to Open Coast typology.	3 – Open coast is the least influential geomorphological feature and is given the lowest priority. If a mangrove polygon overlaps with any other typology, the other typology is given precedence.

* Additional information regarding spatial datasets can be found in Appendices

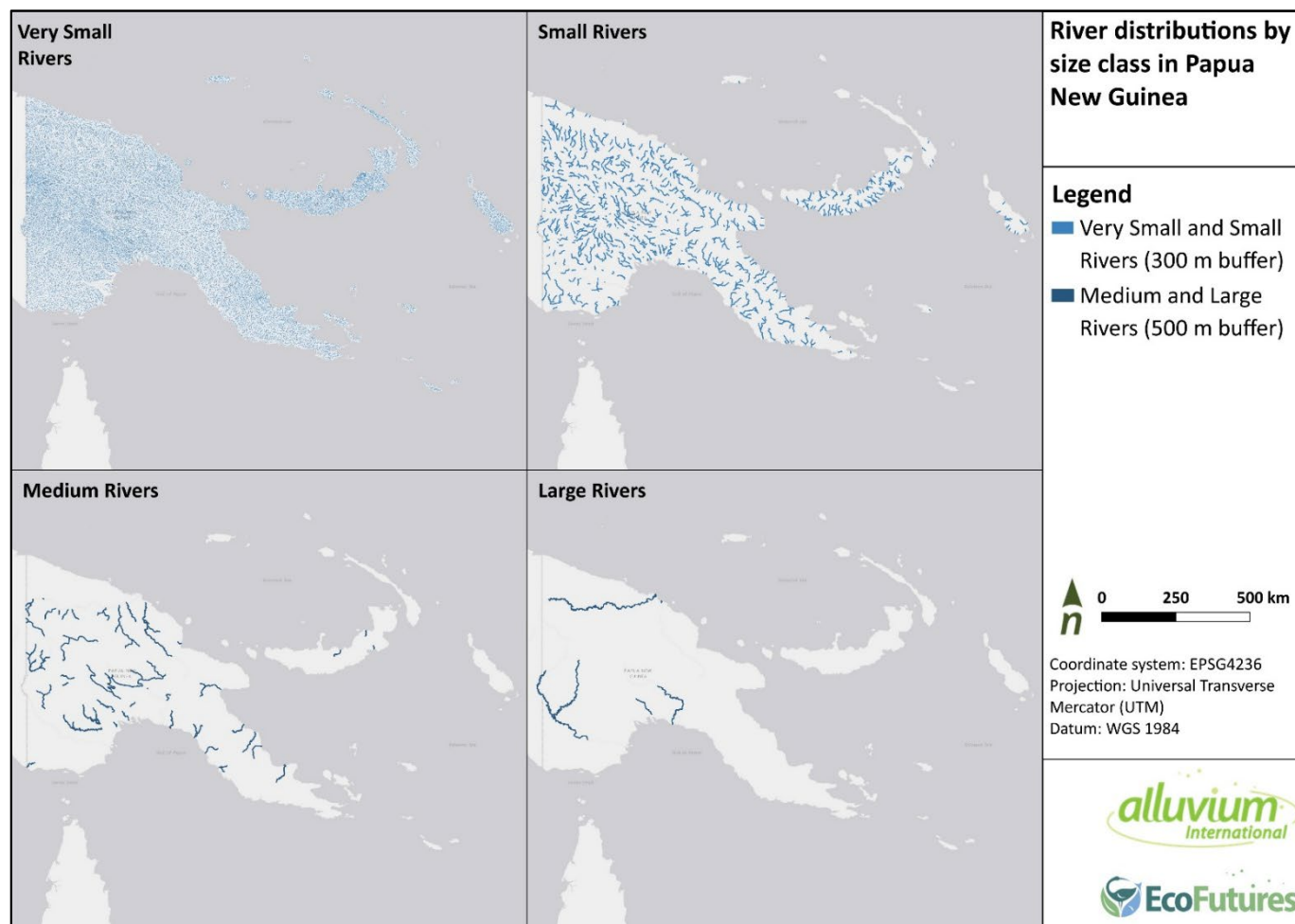


Figure 3. Example of river buffering process as shown in Papua New Guinea buffered according to size class (GloRIC by HydroSHED). Very Small and Small Rivers buffered by 300 m and Medium and Large Rivers buffered by 500 m. This highlights the first step in assigning mangrove remote-mapping typology. *

*Papua New Guinea was used as the example to demonstrate the mapping processes employed in this section as it contained the greatest variation in mangrove typologies and was the only country to have all river size classes present.

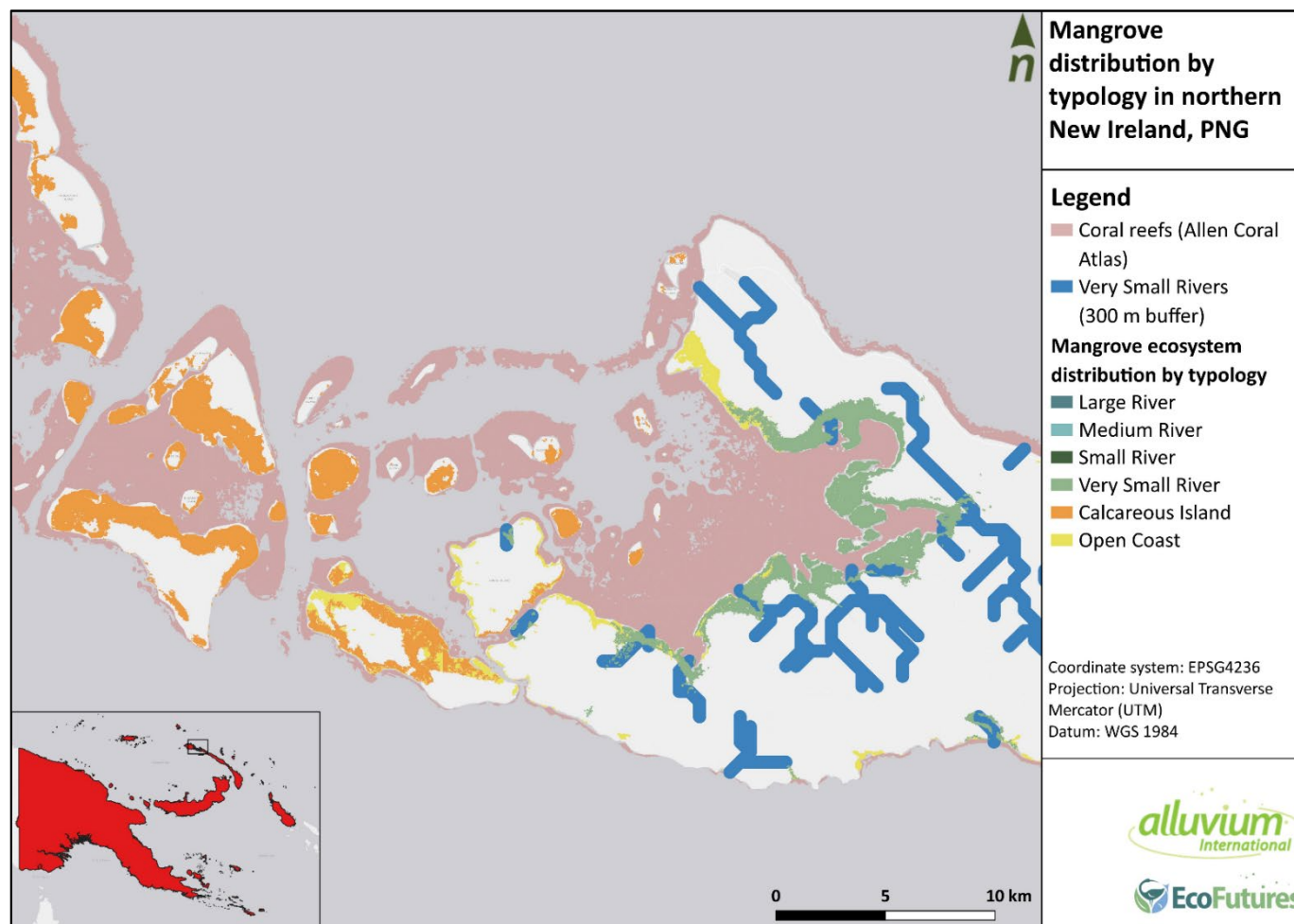


Figure 4. Example of mangrove classification by remote-mapping typology in northern New Ireland, Papua New Guinea using existing distributions of coral reefs (Allen Coral Atlas), rivers (HydroSHED) and mangroves (SPC). Very Small River mangroves (light green) are those overlapping in with Very Small River distribution (blue). Calcareous Island mangroves are those on islands overlapping with coral reefs (light red). Open Coast mangroves (yellow) are those that do not overlap with rivers or coral reefs. This demonstrates the second step in the assigning mangrove remote-mapping typology.

After classifying the mangrove typologies, using the spatial analysis methods in Table 6 and demonstrated in Figure 3 and Figure 4, mangrove polygons were spatially joined using the Dissolve geoprocessing tool in QGIS based on their assigned mangrove typology. This produced one large feature per mangrove typology for each country, and the area was calculated to determine its size in hectares, as shown in Table 7. However, it is important to note that not all mangrove typologies were present in each country according to the mapping criteria established in Table 6. For example, according to the GloRIC river size classes, only Papua New Guinea had Large Rivers present.

Table 7. The area of mangroves by different typologies found in each country and ordered from smallest to largest approximate area size in hectares.

Country	Remote-mapping typology	Area (ha)
Fiji	Medium River	2,001.57
	Calcareous Island	5,104.17
	Small River	6,027.06
	Open Coast	7,813.22
	Very Small River	31,036.50
Papua New Guinea	Calcareous Island	13,531.64
	Medium River	26,355.13
	Large River	41,396.65
	Open Coast	52,096.04
	Small River	58,697.23
	Very Small River	126,700.86
Solomon Islands	Small River	42.66
	Calcareous Island	8,949.70
	Open Coast	13,112.37
	Very Small River	34,000.52
Vanuatu	Very Small River	140.46
	Calcareous Island	160.19
	Open Coast	563.34

Once mangrove extents were estimated for each mapping typology, they were assigned to geomorphic settings that aligned with field-based carbon assessment site data (Table 8). This classification was based on a simplified typology using available mapping classes: Calcareous Island settings were matched directly, Riverine settings were derived from Small River to Large River classes, and Tidal Creek and Open Coast environments were associated with Very Small River and Open Coast classes. Lagoonal settings could not be mapped due to the absence of corresponding spatial data. This approach allowed for a consistent, regionally relevant application of geomorphic context to the mapped mangrove areas (Table 8).

Table 8. Re-assignment of mangrove areas from remote-mapping typology to geomorphic setting. Soil carbon is known to vary between geomorphic settings and therefore was used in this study to provide more accurate representation of mangrove areas in the national carbon stock calculations. ^{41,42, 43}

Geomorphic setting classification	Remote-mapping typology	Country	Area (ha)
Calcareous Island	Calcareous Island	Fiji	5,104
		Papua New Guinea	13,532
		Solomon Islands	8,950
		Vanuatu	160
Tidal Creek/Open Coast	Very Small River + Open Coast	Fiji	38,850
		Papua New Guinea	178,797
		Solomon Islands	47,113
		Vanuatu	704
Riverine	Small River + Medium River + Large River	Fiji	8,029
		Papua New Guinea	126,449
		Solomon Islands	43
		Vanuatu	-
Lagoon	NA	-	-

Caveat: The accuracy of mangrove extent estimates in this assessment is constrained by the quality and resolution of available spatial data. At the time of analysis, updated mangrove maps being developed under the MACBLUE project were not yet available, and existing datasets were limited by coarse resolution and inconsistent mapping across countries. These maps often generalised mangrove areas into large polygons, overlooking smaller or fragmented patches, particularly in cloud-prone or remote island regions. Additionally, the classification of mangrove settings relied on global environmental datasets—such as river hydrology layers—that lack the spatial detail needed to accurately reflect local geomorphic conditions. While a manual clean was undertaken to improve classification accuracy, the assessment remains limited by the foundational mapping data, which introduces uncertainty into estimates of mangrove extent and typology.

⁴¹ Adame, M. F., Connolly, R. M., Turschwell, M. P., Lovelock, C. E., Fatoyinbo, T., Lagomasino, D., ... & Brown, C. J. (2021). Future carbon emissions from global mangrove forest loss. *Global change biology*, 27(12), 2856-2866.

⁴² Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global Change Biology*, 26(10), 5844–5855. <https://doi.org/10.1111/gcb.15275>

⁴³ Dürr, H. H., Laruelle, G. G., van Kempen, C. M., Slomp, C. P., Meybeck, M., & Middelkoop, H. (2011). Worldwide typology of nearshore coastal systems: defining the estuarine filter of river inputs to the oceans. *Estuaries and coasts*, 34, 441-458.

3.2.2 Seagrass mapping

To determine the area size of seagrass meadows in each country, the area was calculated based on benthic seagrass mapping conducted by Allen Coral Atlas (Table 9).

Table 9. Approximate seagrass area coverage in each country based on Allen Coral Atlas benthic seagrass mapping.

Country	Area (ha)
Fiji	49,285.08
Papua New Guinea	91,305.36
Solomon Islands	35,126.23
Vanuatu	469.16

3.3 National carbon stock estimation

National carbon stocks for mangrove and seagrass ecosystems were estimated using an area-weighted upscaling approach, consistent with IPCC guidelines for wetlands and best-practice blue carbon methodologies.^{44,45,46,47} For each geomorphic setting class, mean carbon stock values (Mg C ha⁻¹) were multiplied by the corresponding mapped area (ha), and summed to produce national totals:

$$\text{National Carbon Stock} = \sum (\bar{C}_i \times A_i)$$

Where:

$\bar{C}_i$ = mean carbon stock (Mg C ha⁻¹) for geomorphic setting class i

A_i = total area (ha) of geomorphic setting class i

n = number of geomorphic classes or ecosystem types

For each sampling site, carbon stocks were calculated for two depth scenarios: 0–30 cm and 0–100 cm. Where full-depth sampling was not possible due to inundation, safety constraints, or unstable sediments, but deeper sampling was feasible under normal conditions, values were extrapolated by applying the carbon density from the deepest sampled interval to the remaining depth.⁴⁸ Extrapolation was not applied where bedrock or remnant reef prevented deeper sampling. This approach follows accepted practice for fixed-depth carbon accounting in coastal ecosystems.

Mangrove sites were classified based on their geomorphic setting —tidal creek/open coast, riverine, calcareous island, or lagoon—using field observations and validated by remote sensing (Figure 1). These classes are similar to those defined by Murray et al. (2003)⁴⁹ and Adame et al. (2013)⁵⁰, and also used in Kauffmann (2020)⁵¹. Mean carbon stock values (Mg C ha⁻¹) were calculated for mangroves in each geomorphic setting and depth scenario. These means were multiplied by the estimated national area of mangroves within each geomorphic setting, derived from spatial mapping, and summed to produce national totals.

This stratified approach reflects evidence that geomorphology influences mangrove carbon storage;⁵² however, our results showed minimal variation among typologies, with the exception of riverine sites generally storing more carbon and calcareous island sites storing less.

For seagrass ecosystems, national carbon stocks were estimated by multiplying the mean site-level carbon stock (for 30 cm and 100 cm) by the total mapped seagrass area, without typology stratification.

⁴⁴ Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., Telszewski, M. (eds.) (2019 update). Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.

⁴⁵ IPCC (2014). 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). Published: IPCC, Switzerland. Available from: <https://www.ipcc-nggip.iges.or.jp/public/wetlands/>

⁴⁶ Blue Carbon Initiative (2023). Guidelines for Blue Carbon and Nationally Determined Contributions: Second Edition.

⁴⁷ Green, C., Lovelock, C. E., Sasmito, S., Hagger, V., & Crooks, S. (2021). Coastal Wetlands in National Greenhouse Gas Inventories. Advice on reporting emissions and removal from management of Blue Carbon ecosystems. International Partnership for Blue Carbon. 2021; Commonwealth of Australia.

⁴⁸ Dahl, M., Lavery, P. S., Mazarrasa, I., Samper-Villarreal, J., Adame, M. F., Crooks, S., ... & Serrano, O. (2025). Recommendations for strengthening blue carbon science. *One Earth*, 8(3).

⁴⁹ Murray, M. R., Zisman, S. A., Furley, P. A., Munro, D. M., Gibson, J., Ratter, J., ... & Place, C. J. (2003). The mangroves of Belize: Part 1. distribution, composition and classification. *Forest Ecology and Management*, 174(1-3), 265-279.

⁵⁰ Adame, M. F., Kauffman, J. B., Medina, I., Gamboa, J. N., Torres, O., Caamal, J. P., ... & Herrera-Silveira, J. A. (2013). Carbon stocks of tropical coastal wetlands within the karstic landscape of the Mexican Caribbean. *PloS one*, 8(2), e56569.

⁵¹ Kauffman, J. B., Adame, M. F., Arifanti, V. B., Schile-Beers, L. M., Bernardino, A. F., Bhomia, R. K., ... & Hernández Trejo, H. (2020). Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological monographs*, 90(2), e01405.

⁵² Rovai, A. S., Twilley, R. R., Castañeda-Moya, E., Riul, P., Cifuentes-Jara, M., Manrow-Villalobos, M., ... & Pagliosa, P. R. (2018). Global controls on carbon storage in mangrove soils. *Nature Climate Change*, 8(6), 534-538.

3.4 Emissions calculations

To estimate emissions from mangrove degradation, field sites were classified as either intact or degraded. Degradation was typically attributed to cyclone damage, wood harvesting, or land clearing for development. Emissions were calculated by comparing carbon stocks at degraded sites with the average carbon stocks of intact sites within the same geomorphic setting. This comparison was conducted for both 30 cm and 1 m soil depths to capture a range of potential emissions.

For each degraded site, the difference in carbon stock relative to the corresponding intact average was calculated, and the percentage reduction was determined. This carbon loss was then converted to an equivalent CO₂ emission value using the molecular weight conversion factor of 3.67, which reflects the ratio of carbon to carbon dioxide. The general equation used was:

$$\text{Emissions (CO}_2\text{)} = (C_{\text{intact}} - C_{\text{degraded}}) \times 3.67$$

Where:

C_{intact} = average carbon stock in intact sites (Mg C ha⁻¹)

C_{degraded} = carbon stock in degraded site (Mg C ha⁻¹)

3.67 = molecular weight ratio to convert carbon to CO₂

Where multiple degraded sites with the same disturbance type were sampled within a country, average values are presented; otherwise, individual site estimates are reported. Emissions estimates were calculated following methodologies outlined in the Coastal Blue Carbon Manual⁵³ and IPCC Wetlands Supplement⁵⁴.

⁵³ Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., Telszewski, M. (eds.) (2019 update). Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. Arlington, Virginia, USA.

⁵⁴ IPCC. (2014). 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., & Troxler, T.G. (Eds.). Intergovernmental Panel on Climate Change. Retrieved from <https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/>

4 National carbon stock results

This section presents national-scale estimates of mangrove carbon stocks across Fiji, Vanuatu, Papua New Guinea, and the Solomon Islands. Using field-based measurements and mapped mangrove extents stratified by geomorphic setting, we provide the first regionally consistent estimates of total ecosystem carbon stocks (TECS) for these countries. These results offer a critical baseline for understanding the carbon storage potential of Pacific mangrove ecosystems and for informing future blue carbon accounting and climate mitigation strategies. Importantly, the results presented in this report satisfy the requirements for a Tier 2 estimate under the IPCC framework, as they are based on empirical field data and regionally stratified spatial information rather than global default values

4.1.1 Fiji mangrove carbon stocks

In Fiji, ecosystem carbon storage varied across different geomorphologies and carbon pools (Figure 5 and Figure 6). Calcareous Island sites were found to store less SOC carbon (193 Mg C ha^{-1}) compared to both the Tidal Creek/Open Coast (360 Mg C ha^{-1}) and Riverine settings (349 Mg C ha^{-1}) (Figure 5).

Above-ground (AG) and below-ground (BG) tree carbon storage (TCS) was highly variable within geomorphic settings (Figure 5). Riverine settings typically supported higher (125 Mg C ha^{-1}) and more variable AG TCS compared with Calcareous Islands (39 Mg C ha^{-1}). Below-ground TCS represented the smallest carbon pool across all geomorphologies. (Figure 5).

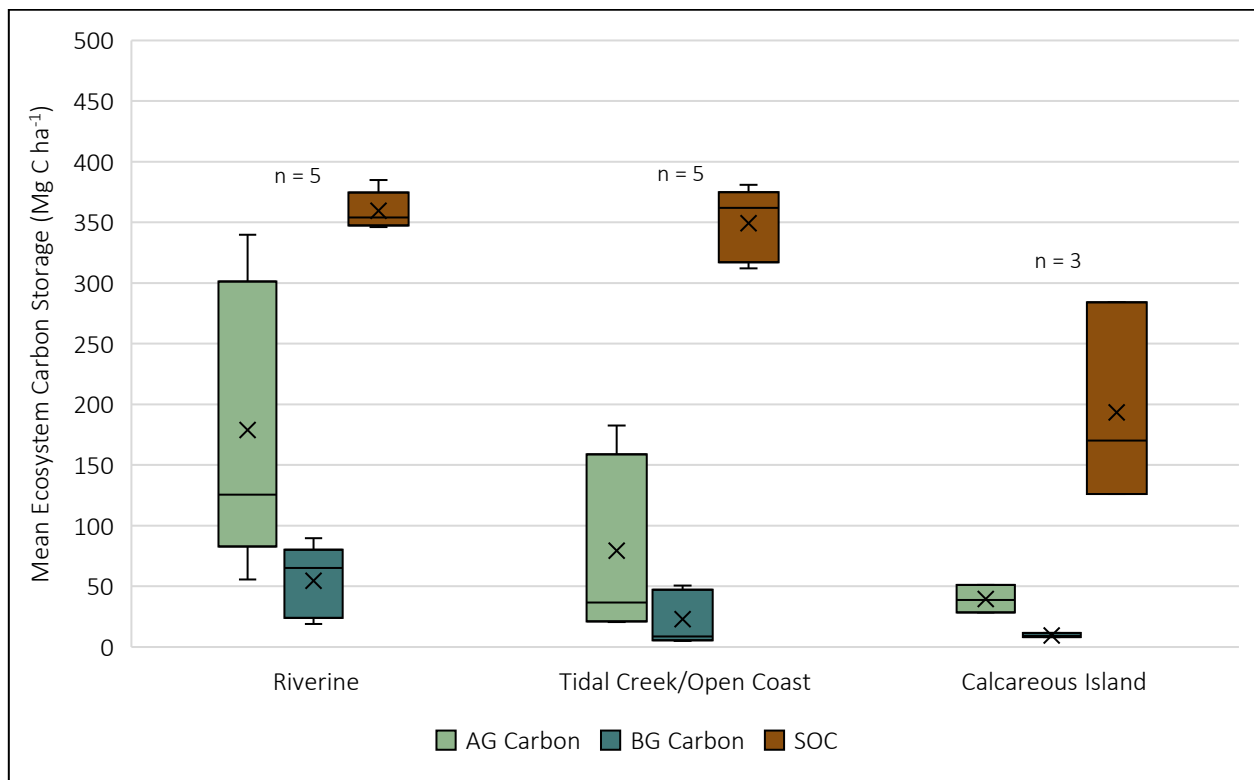


Figure 5. Mangrove mean ecosystem carbon storage in Fiji in different geomorphic settings: riverine, tidal creek/open coast, and calcareous island, presented as different carbon pools: above-ground (AG), below-ground (BG) tree carbon

storage and soil organic carbon (SOC), where SOC includes soil sampling depths up to 100 cm. Riverine settings had notably higher carbon storage in all pools compared with calcareous islands.

Across the three geomorphic settings, Calcareous Islands had the lowest mean TECS (242 Mg C ha^{-1}), compared to Tidal Creek/Open Coast (451 Mg C ha^{-1}) and Riverine settings (593 Mg C ha^{-1}) (Figure 6). Typically, Calcareous Islands have a lower TECS due to their soils being dominated by coarse, carbonate-rich sediments with low organic matter retention, leading to reduced soil organic carbon storage. In contrast, Riverine and Tidal Creek/Open Coast settings receive higher nutrient and sediment inputs from land, promoting greater vegetation growth and organic matter accumulation in both biomass and soil.

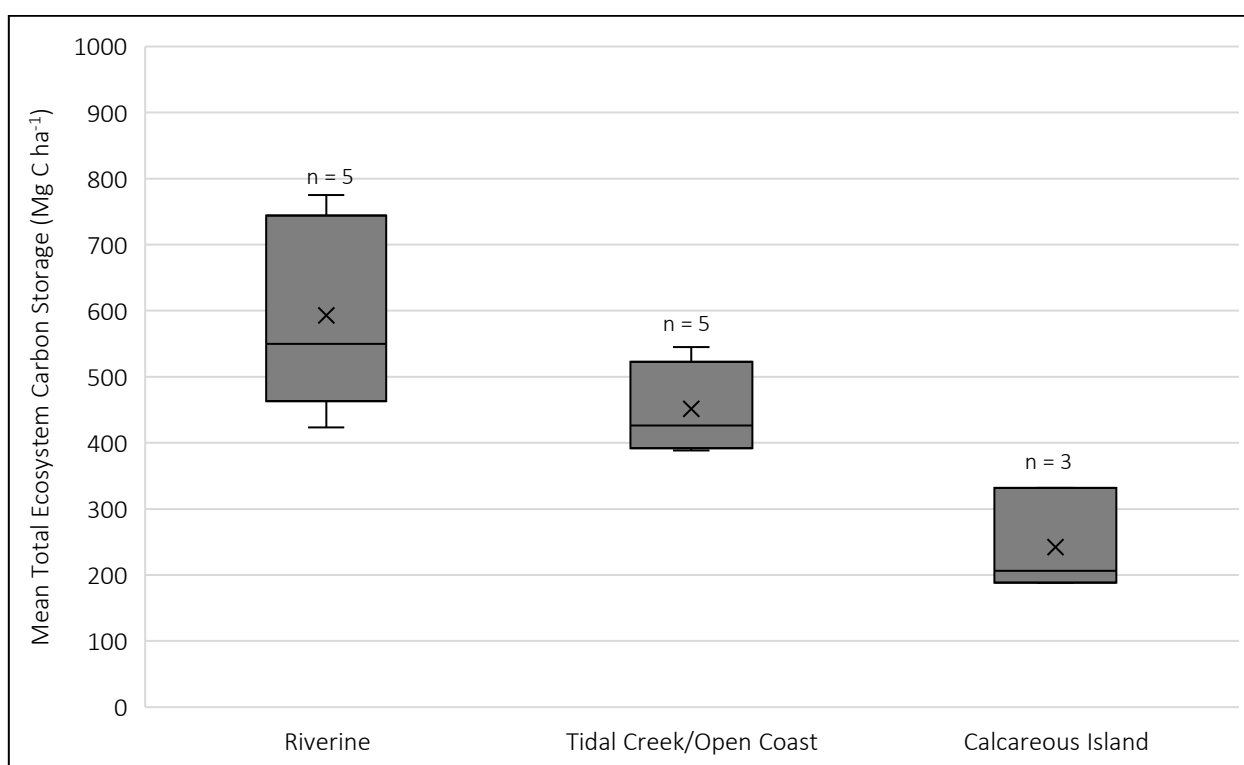


Figure 6. Mangrove mean total ecosystem carbon storage in Fiji in different geomorphic settings: riverine, tidal creek/open coast, and calcareous island. Riverine settings had notably higher carbon storage in all pools compared with calcareous islands.

Intact ecosystems had a mean TECS of 458 Mg C ha⁻¹, while degraded and converted sites had a lower mean at 436 and 234 Mg C ha⁻¹, respectively (Figure 7). Intact sites also displayed a greater variability and wider range of values, with the maximum reaching 775 Mg C ha⁻¹, highlighting the variability between sites.

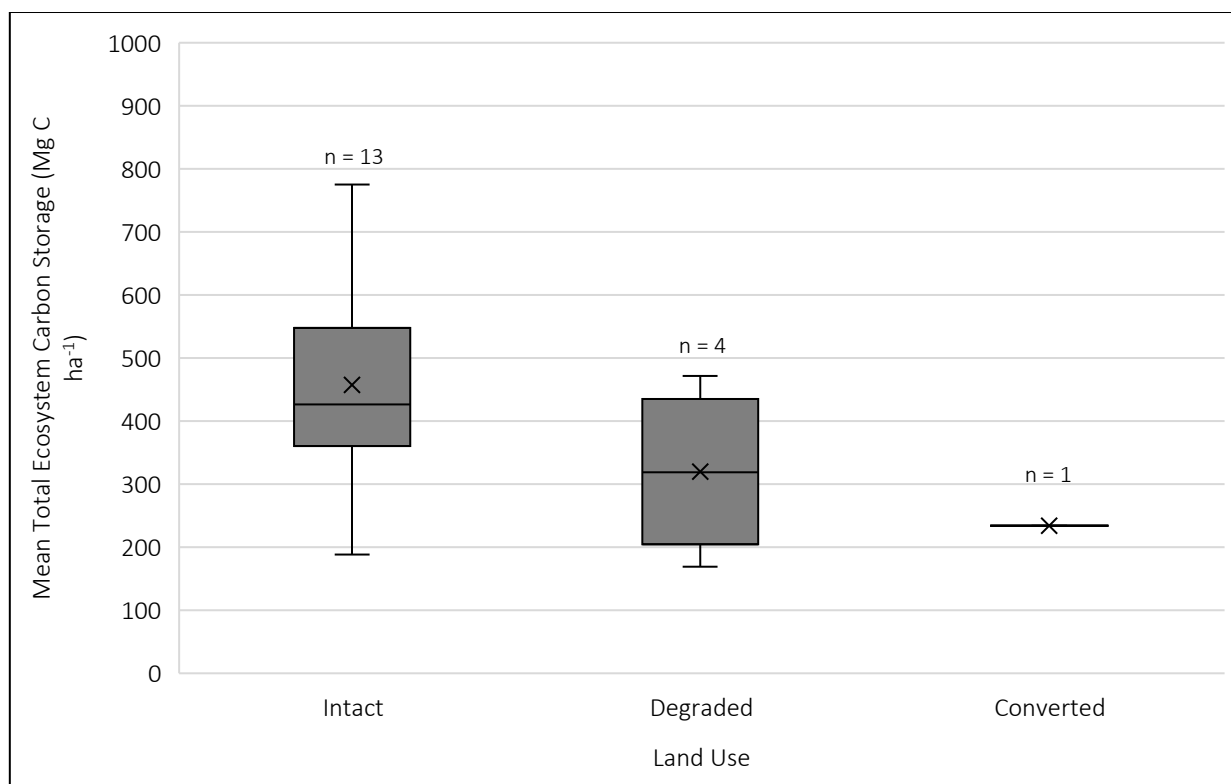


Figure 7. Mean total ecosystem carbon storage in Fiji in different land use types: intact, degraded, and converted. There was no significant difference in mean total ecosystem carbon storage across land use types as most carbon is stored in soil.

Across the different geomorphic settings, Riverine sites exhibited the highest TECS across both depth intervals (Table 10). However, Tidal Creek/Open Coast setting contributed the highest carbon stock at the 0-100 cm depth (17.5 million Mg C), primarily due to its larger mapped area. The national mangrove carbon stock estimate for Fiji, across all geomorphic settings, was 11.8 million Mg C for SOC depths up to 30 cm and 23.5 million Mg C for SOC depths up to 100 cm.

Table 10. Mangrove ecosystem national carbon stock estimates for Fiji, based on areas derived from remote-mapping of geomorphic settings. Carbon stocks are presented as different carbon pools, including above-ground (AG) and below-ground (BG) tree carbon storage, soil organic carbon (SOC), and total ecosystem carbon stocks (TECS). National carbon stocks are calculated based on two SOC depths to provide an upper (0-100 cm) and lower (0-30 cm) estimate.

Geomorphic setting	Remote-mapping area (ha)	No. of sites	AG tree carbon (Mg C ha ⁻¹)	BG tree carbon (Mg C ha ⁻¹)	SOC depth (cm)	SOC (Mg C ha ⁻¹)	TECS (Mg C ha ⁻¹)	Carbon stock (Mg C)
Calcareous Island	5,104	3	39 ± 7	10 ± 1	0-100	193 ± 47	242 ± 45	1,235,209
					0-30	104 ± 12	153 ± 18	780,938
Tidal Creek/Open Coast	38,850	5	79 ± 33	23 ± 10	0-100	349 ± 14	451 ± 31	17,521,225
					0-30	110 ± 3	212 ± 42	8,236,141
Riverine	8,029	5	179 ± 53	55 ± 13	0-100	360 ± 7	593 ± 66	4,760,977
					0-30	114 ± 5	348 ± 66	2,793,963
Fiji Total (0-100 cm)								23,517,411
Fiji Total (0-30 cm)								11,811,042

4.1.2 Fiji seagrass carbon stocks

In Fiji, the highest mean carbon stock was found at 0-100 cm depth (182 Mg C ha⁻¹), exceeding that of 0-30 cm (93 Mg C ha⁻¹) and 0-15 cm (43 Mg C ha⁻¹) depths (Figure 8). Across all seagrass sites, the 0-100cm had the highest variability, ranging from of 38 to 172 Mg C ha⁻¹. Carbon storage in the uppermost layer (0-15 cm) was consistently low and exhibited minimal variability across all sites (Figure 8).

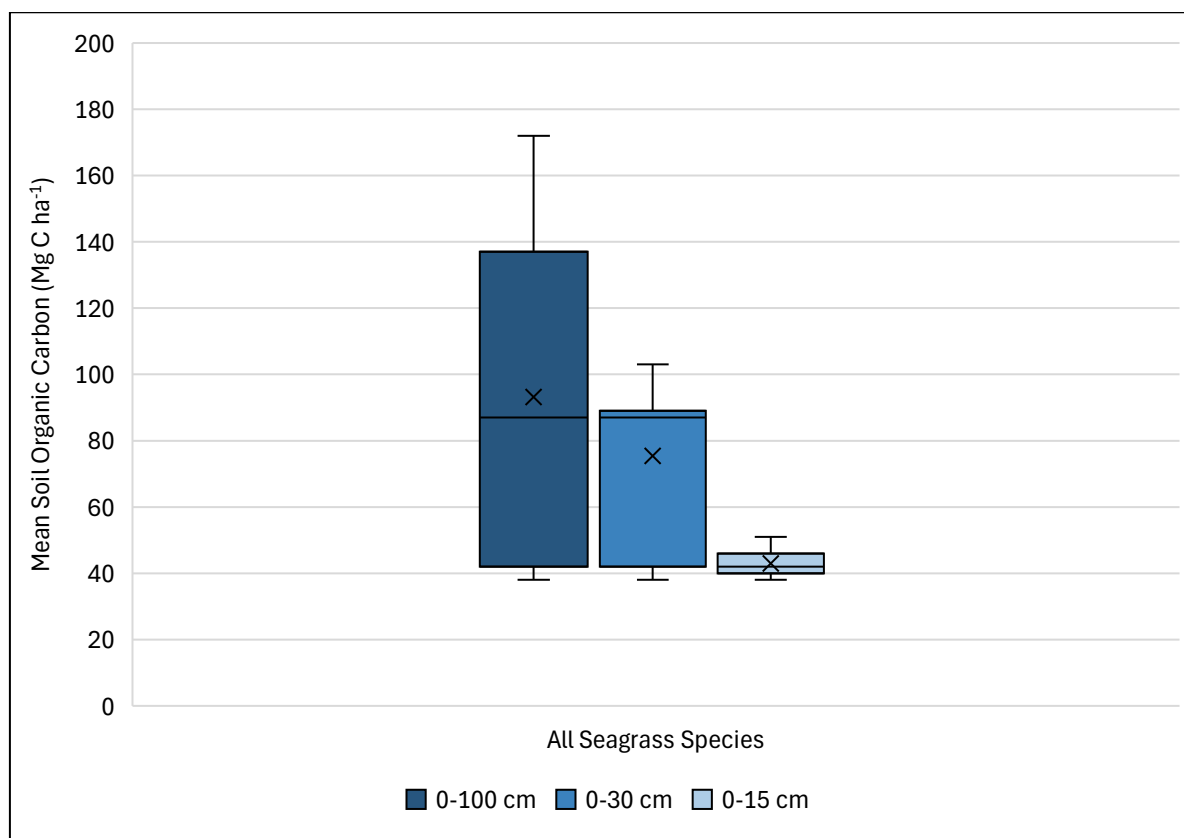


Figure 8. Seagrass mean soil organic carbon storage in Fiji, presented in different depth intervals: 0-100 cm, 0-30 cm, 0-15 cm.

The estimated national carbon stock for seagrass ecosystems in Fiji ranged from 2.1 to 4.6 million Mg C depending on the sampling depth (Table 11). This range highlights the carbon storage capacity of seagrass ecosystems in the region, with deeper cores generally capturing larger carbon pools.

Table 11. Seagrass ecosystem national carbon stock estimates for Fiji, based on areas derived from remote-mapping of seagrass ecosystems. National carbon stocks are calculated based on three soil organic carbon (SOC) depths to provide an upper and lower estimates.

Remote-mapping area (ha)	No. of sites	SOC depth (cm)	SOC (Mg C ha ⁻¹)	Carbon stock (Mg C)
49,285	7	0-100	93 ± 35	4,583,512
		0-30	75 ± 29	3,696,381
		0-15	43 ± 16	2,119,258

4.2 Papua New Guinea

4.2.1 Papua New Guinea mangrove carbon stocks

In Papua New Guinea (PNG), ecosystem carbon storage varied greatly within geomorphic settings and between carbon pools, with less significant variation between geomorphic settings (Figure 9 and Figure 10). Soil organic carbon (SOC) was the largest carbon pool in both the Tidal Creek/Open Coast and Riverine geomorphic settings, with a mean of 387 and 381 Mg C ha^{-1} , respectively (Figure 9). In contrast, above-ground (AG) tree carbon storage (TCS) dominated in Calcareous sites, with a mean of 360 Mg C ha^{-1} (Figure 9).

Below-ground (BG) TCS was consistently the smallest carbon pool across all geomorphic settings. Overall, AG TCS showed the greatest variability across the carbon pools, particularly in Tidal Creek/Open Coast and Riverine systems, while Calcareous Islands had more consistent values across all pools (Figure 9).

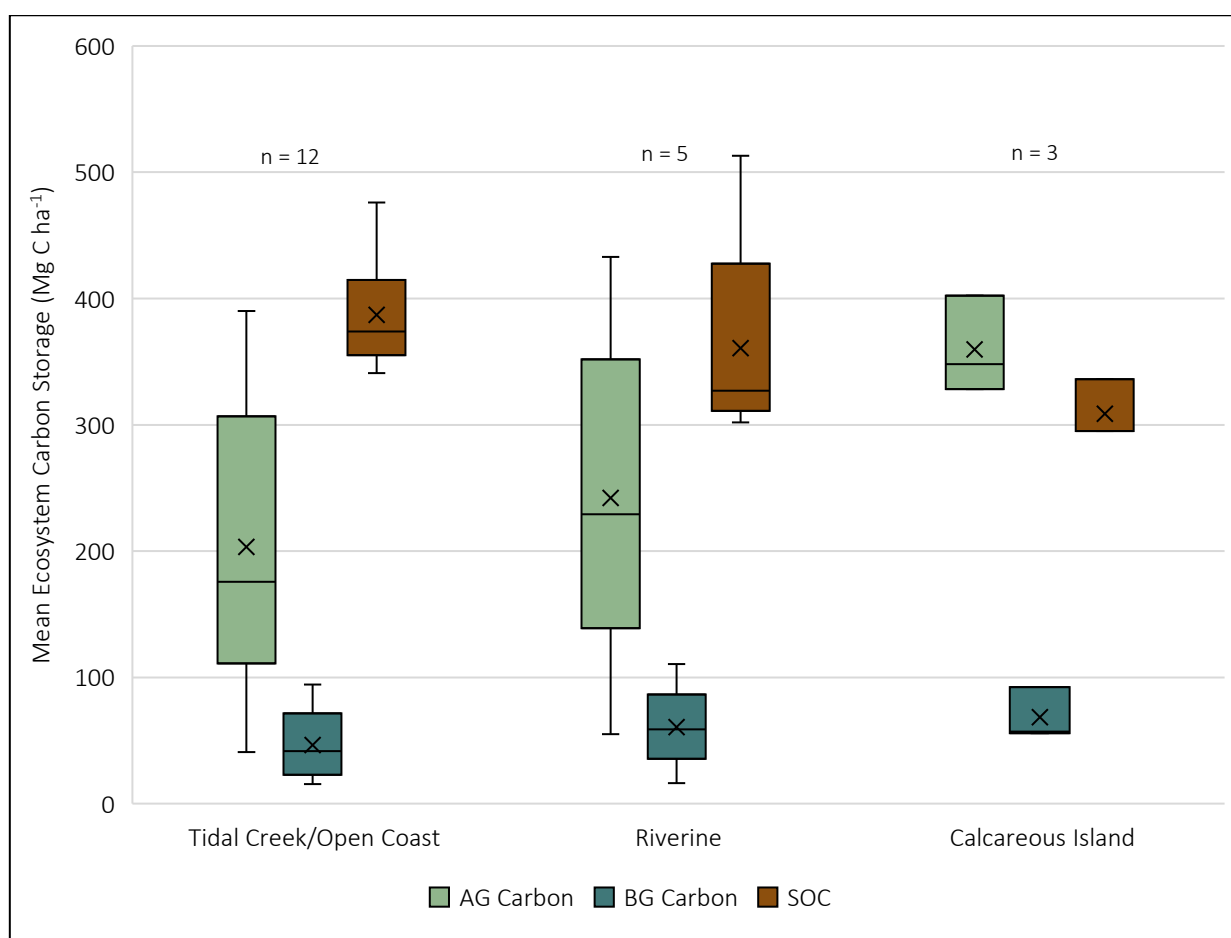


Figure 9. Mangrove mean ecosystem carbon storage in PNG in different geomorphic settings: riverine, tidal creek/open coast, and calcareous island, presented as different carbon pools: above-ground (AG) and below-ground (BG) tree carbon storage and soil organic carbon (SOC), where SOC includes soil sampling depths up to 100 cm.

Across the three geomorphic settings, Calcareous Islands had the highest mean TECS (737 Mg C ha⁻¹), compared to Tidal Creeks/Open Coasts (637 Mg C ha⁻¹) and Riverine settings (664 Mg C ha⁻¹), however the difference was not significant (Figure 10).

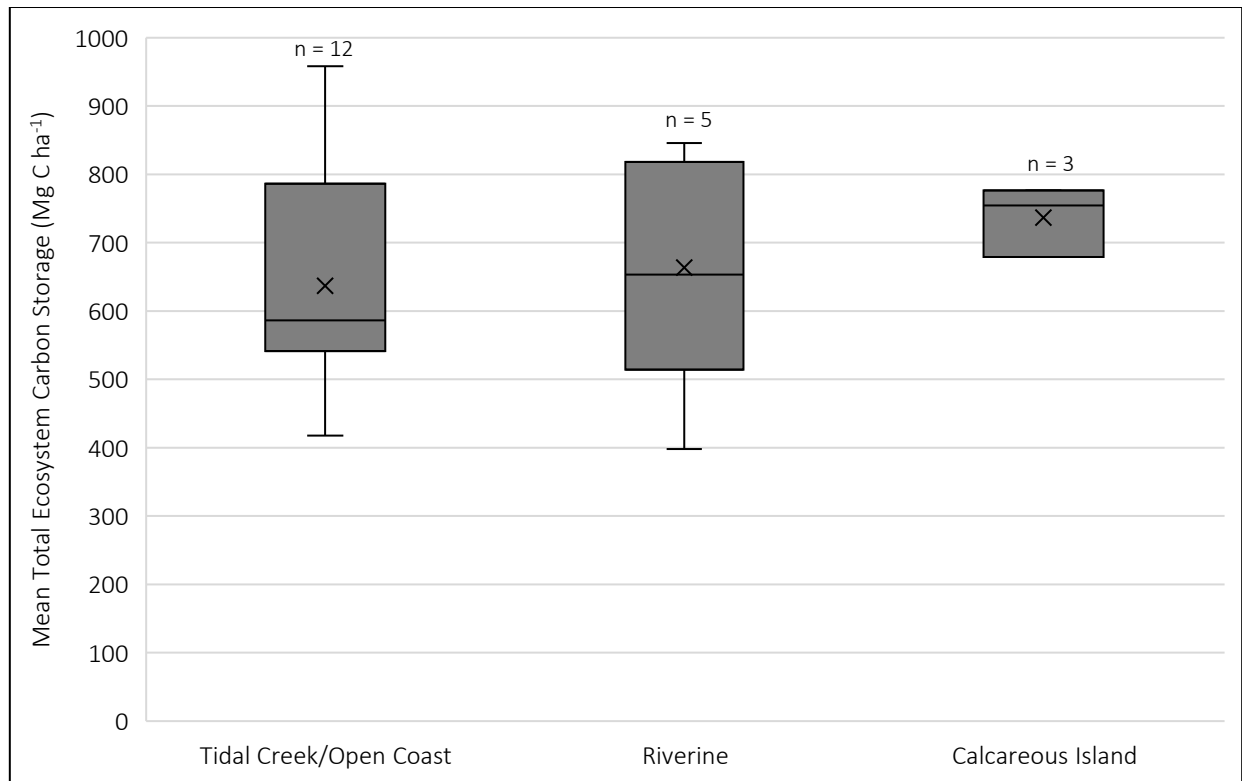


Figure 10. Mangrove mean total ecosystem carbon storage in PNG in different geomorphic settings: riverine, tidal creek/open coast, and calcareous island.

Intact ecosystems had a mean TECS of 658 Mg C ha⁻¹, while degraded sites had a lower mean at 436 Mg C ha⁻¹ (Figure 11). Intact sites also displayed a greater variability and wider range of values, with the maximum reaching 958 Mg C ha⁻¹, highlighting the variability between sites.

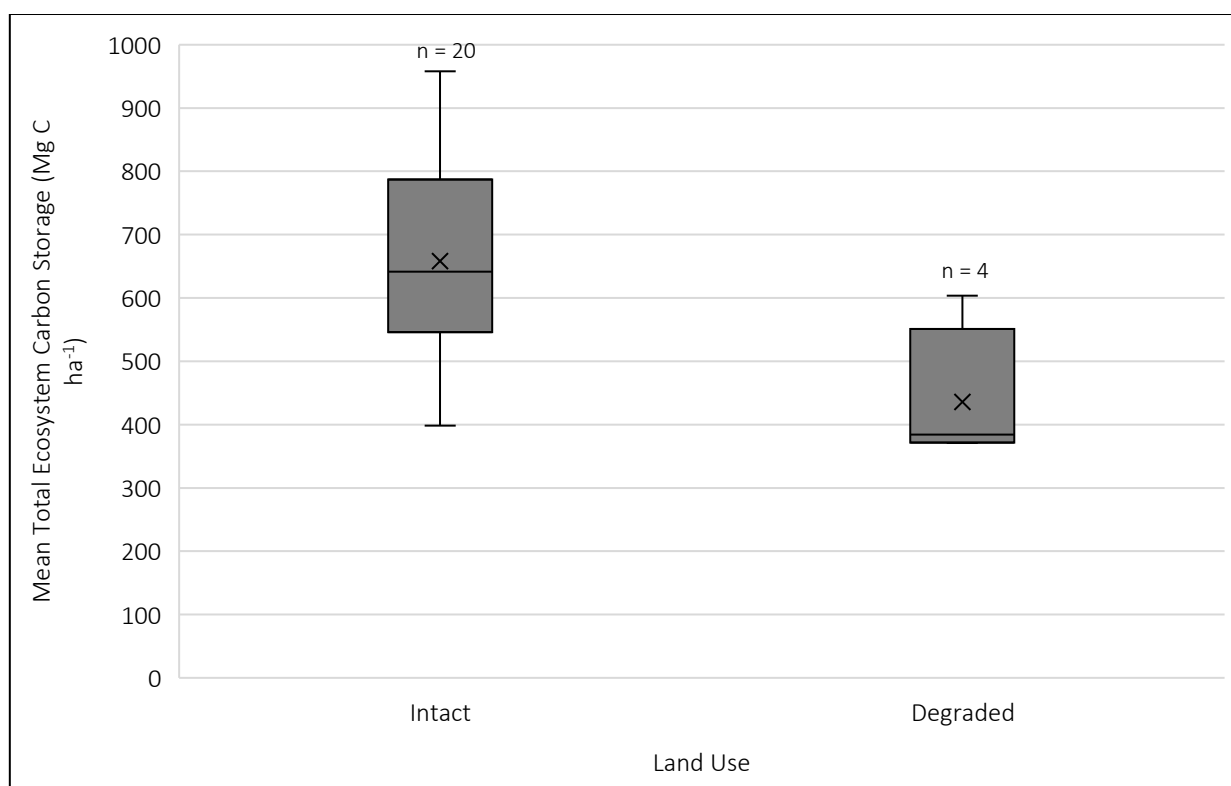


Figure 11. Mean total ecosystem carbon storage in PNG in different land use types: intact and degraded. There was no significant difference in mean total ecosystem carbon storage across land use types.

Across the different geomorphic settings, Calcareous Islands exhibited the highest TECS across both 0-30 cm and 0-100 cm depth intervals (Table 12). However, Tidal Creek/Open Coast setting contributed the most overall to the national carbon stock estimates, primarily due to its larger mapped area, with 65.3 million Mg C including SOC from 0-30 cm depths and 113.9 million Mg C including SOC from 0-100 cm depths. The national mangrove carbon stock estimate for PNG, across all geomorphic settings, was 124.1 million Mg C for SOC depths up to 30 cm and 207.8 million Mg C for SOC depths up to 100 cm.

Table 12. Mangrove ecosystem national carbon stock estimates for PNG, based on areas derived from remote-mapping of geomorphic settings. Carbon stocks are presented as different carbon pools, including above-ground (AG) and below-ground (BG) tree carbon storage, soil organic carbon (SOC), and total ecosystem carbon stocks (TECS). National carbon stocks are calculated based on two SOC depths to provide an upper (0-100 cm) and lower (0-30 cm) estimate.

Geomorphic setting	Remote-mapping area (ha)	No. of sites	AG tree carbon (Mg C ha ⁻¹)	BG tree carbon (Mg C ha ⁻¹)	SOC depth (cm)	SOC (Mg C ha ⁻¹)	TECS (Mg C ha ⁻¹)	Carbon stock (Mg C)	
Calcareous Island	13,532	3	360 ± 22	68 ± 12	0-100	309 ± 14	737 ± 29	9,972,819	
					0-30	90 ± 4	518 ± 24	7,009,390	
Tidal Creek/Open Coast	178,797	12	203 ± 32	46 ± 8	0-100	387 ± 12	637 ± 47	113,893,625	
					0-30	116 ± 5	365 ± 42	65,260,869	
Riverine	126,449	5	242 ± 60	61 ± 15	0-100	361 ± 39	664 ± 78	83,962,143	
					0-30	107 ± 12	410 ± 75	51,844,094	
PNG Total (0-100 cm)									207,828,587
PNG Total (0-30 cm)									124,114,353

4.2.2 Papua New Guinea seagrass carbon stocks

Across all seagrass sites in PNG, the mean SOC was 123 Mg C ha⁻¹ for sampling depths up to 100 cm, with a wide range of 42 to 338 Mg C ha⁻¹. Soil organic carbon storage in the surface layer (0-15 cm) was consistently low and exhibited minimal variability across all site types (Figure 12).

Among the seagrass sites in PNG, some were dominated by *Enhalus* seagrass. *Enhalus*-dominated sites presented high mean SOC of 182 Mg C ha⁻¹ at 0-100 cm depths and also displayed the greatest variability, with SOC ranging between 45 to 338 Mg C ha⁻¹. In contrast, mixed-species sites had a lower mean SOC of 84 Mg C ha⁻¹ at 0-100 cm depths and displayed minimal variability. This highlights the deeper, more organic-rich sediments which are characteristic of *Enhalus*-dominated areas.

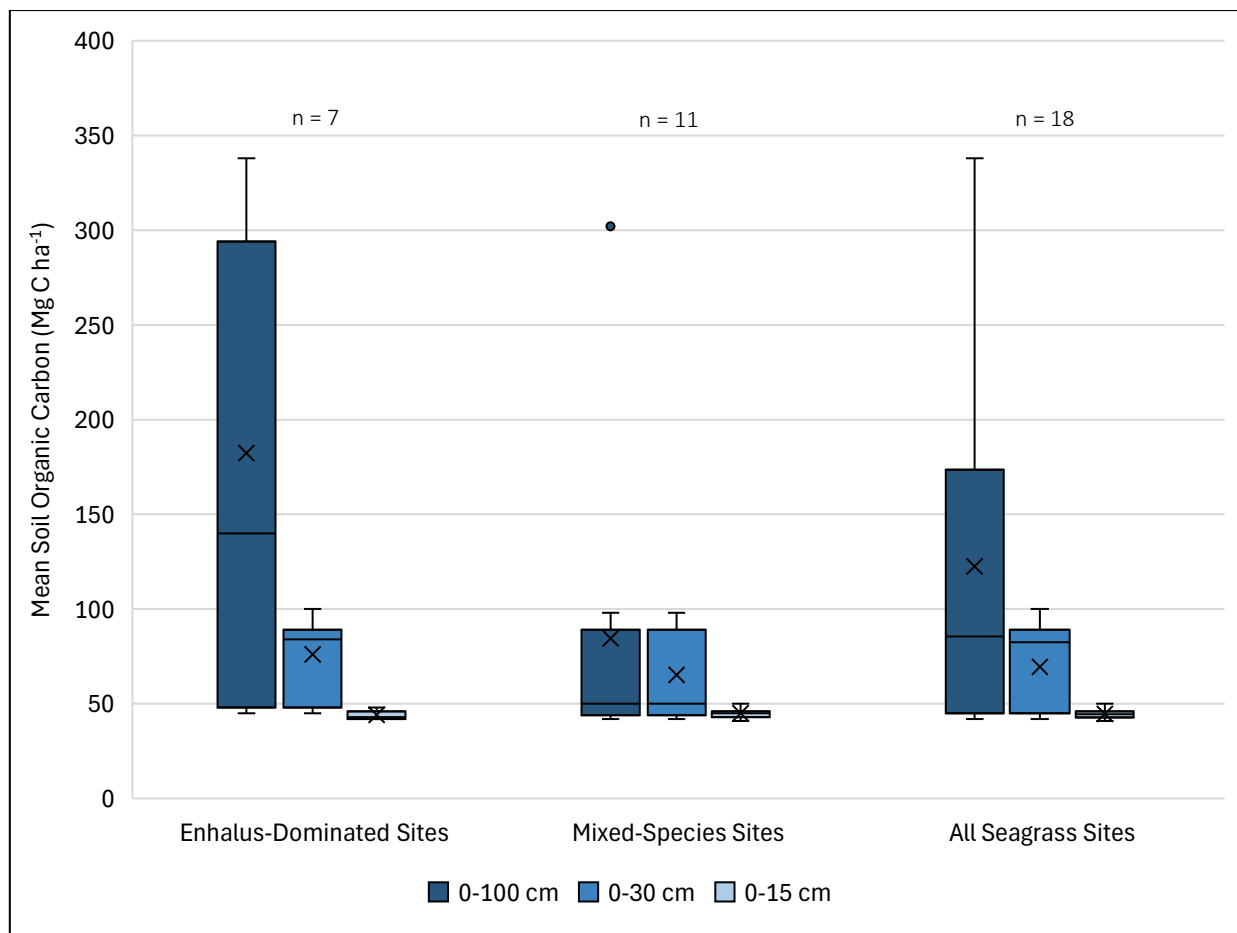


Figure 12. Mean soil organic carbon storage in seagrass meadows of PNG, shown for all sites combined as well as for *Enhalus*-dominated and mixed-species meadows, across depth intervals of 0–100 cm, 0–30 cm, and 0–15 cm.

The estimated national carbon stock for seagrass ecosystems in PNG ranged from 4.1 to 11.2 million Mg C depending on the sampling depth (Table 13). This range highlights the substantial carbon storage capacity of seagrass ecosystems in the region, with deeper cores generally capturing larger carbon pools.

Table 13. Seagrass ecosystem national carbon stock estimates for PNG, based on areas derived from remote-mapping of seagrass ecosystems. National carbon stocks are calculated based on three soil organic carbon (SOC) depths to provide an upper and lower estimates. SOC for *Enhalus*-dominated and mixed-species meadows are also given.

Seagrass site	Remote-mapping area (ha)	No. of sites	SOC depth (cm)	SOC (Mg C ha ⁻¹)	Carbon stock (Mg C)
All seagrass sites	91,305	18	0-100	123 ± 25	11,230,559
			0-30	70 ± 5	6,391,375
			0-15	45 ± 1	4,108,741
<i>Enhalus</i> -dominated sites	-	7	0-100	182	-
			0-30	76	
			0-15	44	
Mixed-species meadows	-	11	0-100	84	-
			0-30	65	
			0-15	45	

4.3 Solomon Islands

4.3.1 Solomon Islands mangrove carbon stocks

In the Solomon Islands the ecosystem carbon storage varied across geomorphic settings and carbon pools (Figure 13 and Figure 14). Calcareous Island sites stored substantially less above-ground (AG) tree carbon storage (TCS) (155 Mg C ha^{-1}) in comparison to the other geomorphic settings: Lagoon (522 Mg C ha^{-1}), Tidal Creek/Open Coast (538 Mg C ha^{-1}) and Riverine (606 Mg C ha^{-1}). In contrast, soil organic carbon (SOC) showed relatively little variation across the different geomorphic settings, although Tidal Creek/Open Coast having slightly higher values (419 Mg C ha^{-1}) (Figure 13). Below-ground TCS represented the smallest carbon pool across all geomorphologies, with Lagoon sites showing the highest mean storage (130 Mg C ha^{-1}). Overall, AG TCS showed the greatest variability across the carbon pools, particularly in the Riverine systems, while Calcareous Islands displayed more consistent values across all pools (Figure 13).

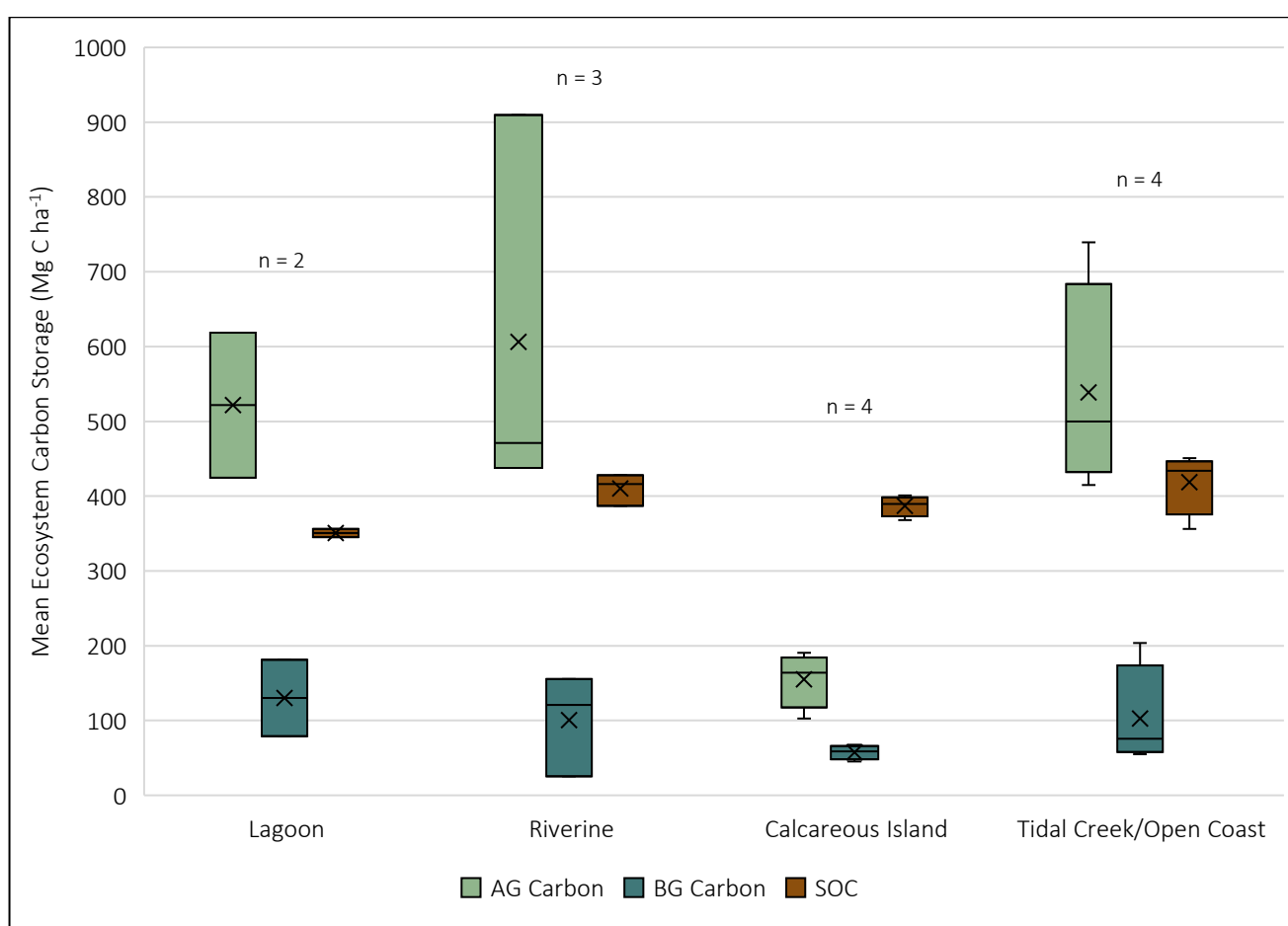


Figure 13. Mangrove mean total ecosystem carbon storage in Solomon Islands in different geomorphic settings: lagoon, riverine, calcareous island, and tidal creek/open coast, presented as different carbon pools: above-ground (AG) and below-ground (BG) tree carbon storage and soil organic carbon (SOC), where SOC includes soil sampling depths up to 100 cm.

Across the four geomorphic settings, Calcareous Islands had the lowest mean total ecosystem carbon stocks (TECS) (600 Mg C ha^{-1}). By comparison, Lagoon, Riverine, and Tidal Creek/Open Coast had notably higher TECS (with means of 1002, 1117, and $1060 \text{ Mg C ha}^{-1}$, respectively).

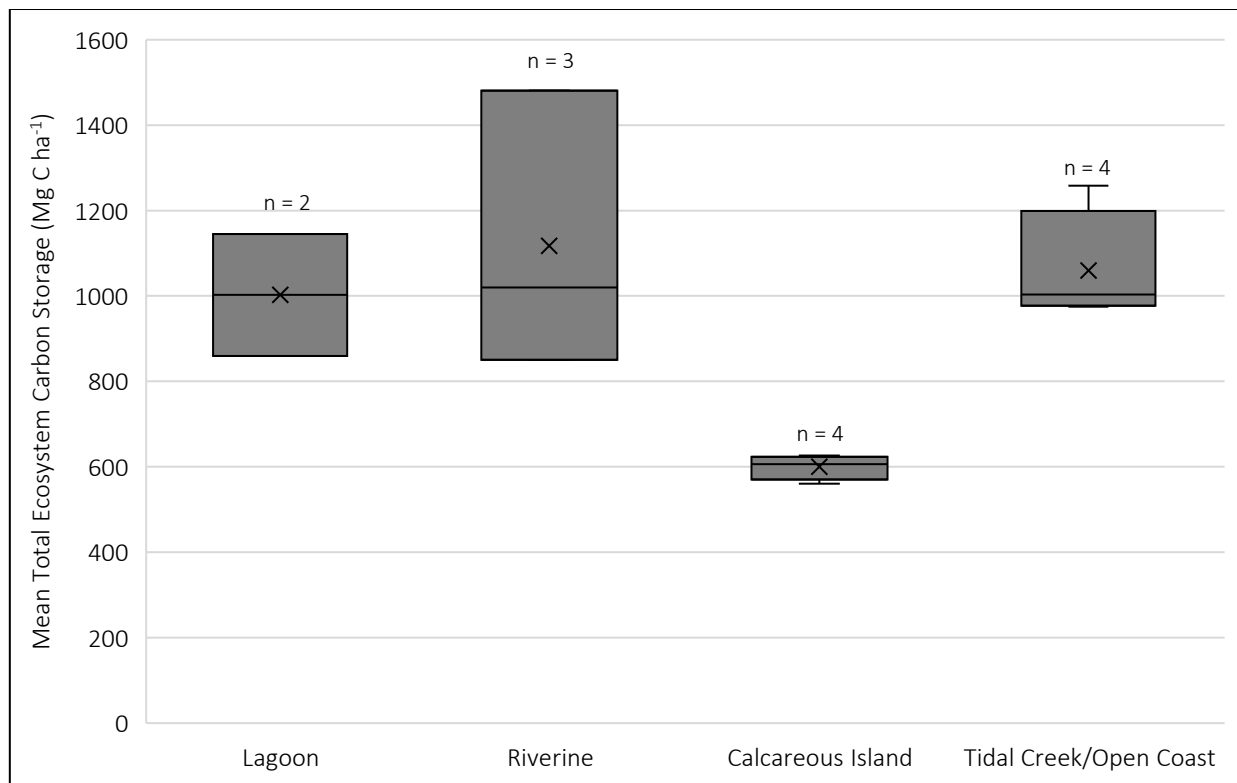


Figure 14. Mangrove mean total ecosystem carbon storage in Solomon Islands in different geomorphic settings: lagoon, riverine, calcareous island, and tidal creek/open coast.

Intact ecosystems had a mean TECS of 658 Mg C ha⁻¹, while degraded sites had a lower mean at 436 Mg C ha⁻¹ (Figure 15). Intact sites also displayed a greater variability and wider range of values, with the maximum reaching 958 Mg C ha⁻¹, highlighting the variability between sites.

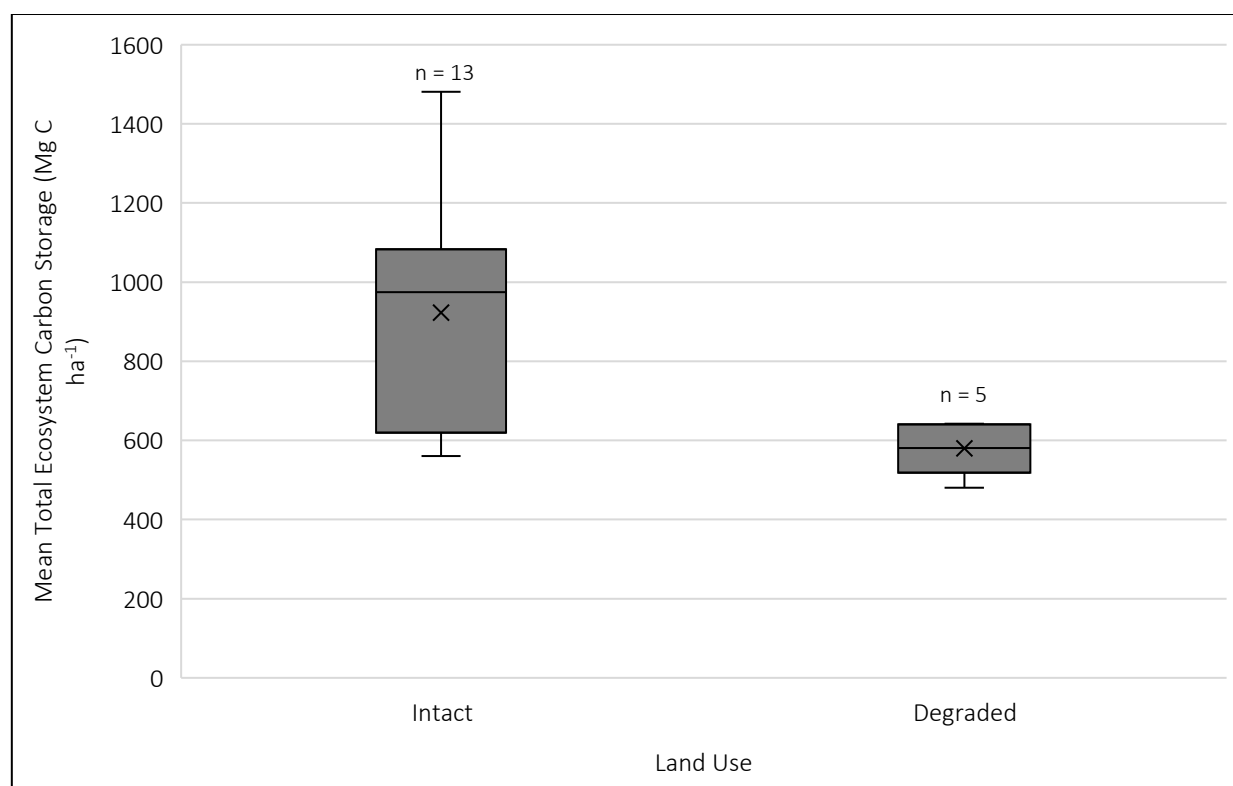


Figure 15. Mean total ecosystem carbon storage in Solomon Islands in different land use types: intact and degraded.
There was no significant difference in mean total ecosystem carbon storage across land use types.

Across the different geomorphic settings, Riverine systems displayed the highest TECS across both 0-30 cm and 0-100 cm depth intervals, with 842 and 1,117 Mg C ha⁻¹, respectively (Table 14). However, this only contributed a small amount to national carbon stocks. Overall, Tidal Creeks/Open Coasts contributed the most to national carbon stocks, due to having substantially more mapped areas, with 36.3 million Mg C including SOC from 0-30 cm depths and 49.9 million Mg C including SOC from 0-100 cm depths. Despite having the lowest TECS, Calcareous Islands contributed the next most to national carbon stocks with 8.1 Mg C including SOC from 0-30 cm depths and 4.5 million Mg C including SOC from 0-100 cm depth. The area of Lagoon geomorphic settings was unable to be derived from remote-mapping, but TECS were calculated and are shown in the table below.

Table 14. Mangrove ecosystem national carbon stock estimates for Solomon Islands, based on areas derived from remote-mapping of geomorphic settings. Carbon stocks are presented as different carbon pools, including above-ground (AG) and below-ground (BG) tree carbon storage, soil organic carbon (SOC), and total ecosystem carbon stocks (TECS). National carbon stocks are calculated based on two SOC depths to provide an upper (0-100cm) and lower (0-30cm) estimate.

Geomorphic setting	Remote-mapping area (ha)	No. of sites	AG tree carbon (Mg C ha ⁻¹)	BG tree carbon (Mg C ha ⁻¹)	SOC depth (cm)	SOC (Mg C ha ⁻¹)	TECS (Mg C ha ⁻¹)	Carbon stock (Mg C)
Calcareous Island	13,531	4	155 ± 19	58 ± 5	0-100	387 ± 7	600 ± 14	8,118,600
					0-30	123± 3	336 ± 18	4,546,416
Tidal Creek/Open Coast	47,113	4	538 ± 70	103 ± 34	0-100	419 ± 21	1060 ± 67	49,939,663
					0-30	129 ± 7	770 ± 62	36,276,925
Riverine	43	3	606 ± 152	101 ± 39	0-100	410 ± 12	1117 ± 188	47,651
					0-30	136 ± 6	842 ± 185	35,920
Lagoon	-	2	522 ± 97	130 ± 51	0-100	351 ± 6	1002 ± 143	-
					0-30	112 ± 3	764 ± 145	
Solomon Islands Total (0-100 cm)								58,105,914
Solomon Islands Total (0-30 cm)								40,859,261

4.3.2 Solomon Islands seagrass carbon stocks

Across all seagrass sites in the Solomon Islands, the mean SOC was 78 Mg C ha⁻¹ for sampling depths up to 100 cm, with a wide range of values from 42 to 182 Mg C ha⁻¹ (Figure 16). Meanwhile, mean SOC in the surface layer (0-15 cm) was lower at 47 Mg C ha⁻¹ and also exhibited a lower range of values.

Among the *Enhalus*-dominated sites, presented a high mean SOC of 88 Mg C ha⁻¹ at 0-100 cm depths and also displayed the widest range of SOC values from 38 to 182 Mg C ha⁻¹. In contrast, mixed-species displayed a much lower SOC mean at 0-100 cm depths (65 Mg C ha⁻¹) and less variability. However, these differences are unlikely to be significant due to the overlaps in the range of values.

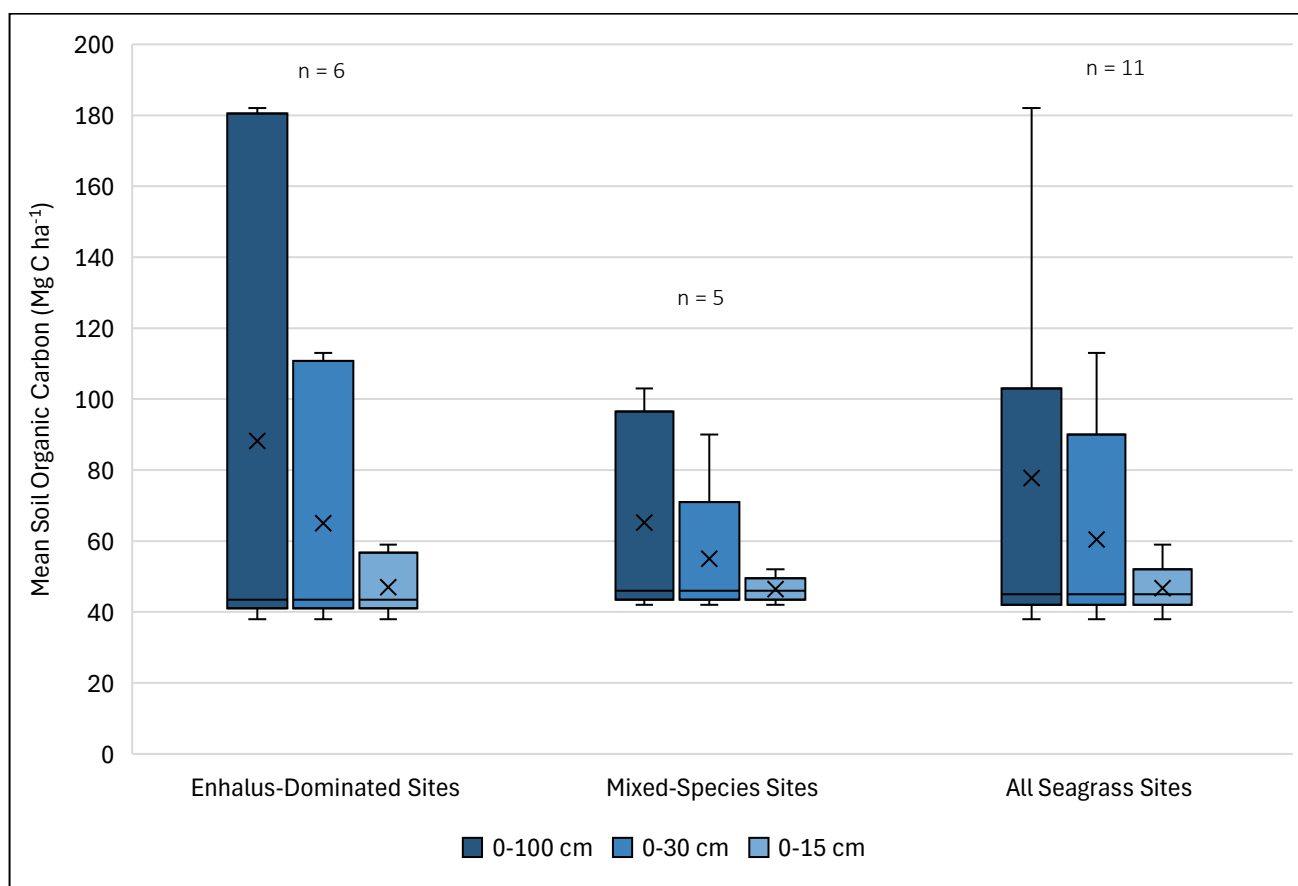


Figure 16. Mean soil organic carbon storage in seagrass meadows of Solomon Islands, shown for all sites combined as well as for *Enhalus*-dominated and mixed-species meadows, across depth intervals of 0–100 cm, 0–30 cm, and 0–15 cm.

The estimated national carbon stock for seagrass ecosystems in Solomon Islands ranged from 1.6 million to 2.7 million Mg C depending on the sampling depth (Table 15). This range highlights the carbon storage capacity of seagrass ecosystems in the region, with deeper cores generally capturing larger carbon pools.

Table 15. Seagrass ecosystem national carbon stock estimates for Solomon Islands, based on areas derived from remote-mapping of seagrass ecosystems. National carbon stocks are calculated based on three soil organic carbon (SOC) depths to provide an upper and lower estimates. SOC for *Enhalus*-dominated and mixed-species meadows are also given.

Seagrass site	Remote-mapping area (ha)	No. of sites	SOC depth (cm)	SOC (Mg C ha ⁻¹)	Carbon stock (Mg C)
All seagrass sites	35,126	11	0-100	78 ± 17	2,739,846
			0-30	60 ± 9	2,107,574
			0-15	47 ± 2	1,650,933
<i>Enhalus</i> -dominated sites	-	6	0-100	88	-
			0-30	65	
			0-15	47	
Mixed-species sites	-	5	0-100	65	-
			0-30	55	
			0-15	46	

4.4 Vanuatu

4.4.1 Vanuatu mangrove carbon stocks

In Vanuatu the ecosystem carbon storage varied across geomorphology and carbon pools (Figure 17 and Figure).

Soil organic carbon (SOC) was the largest carbon pool in all geomorphic settings (Figure 17). There was not significant difference in SOC carbon between Tidal Creek/Open Coast (181 Mg C ha^{-1}), Calcareous Island (320 Mg C ha^{-1}) and Riverine settings (295 Mg C ha^{-1}), due to significant variation within each geomorphic setting.

Above-ground (AG) and below-ground (BG) tree carbon storage (TCS) also varied greatly within geomorphic settings (Figure 17). Riverine settings typically supported higher (191 Mg C ha^{-1}) and more variable AG TCS compared with Calcareous Islands (49 Mg C ha^{-1}). Below-ground TCS represented the smallest carbon pool across all geomorphologies.

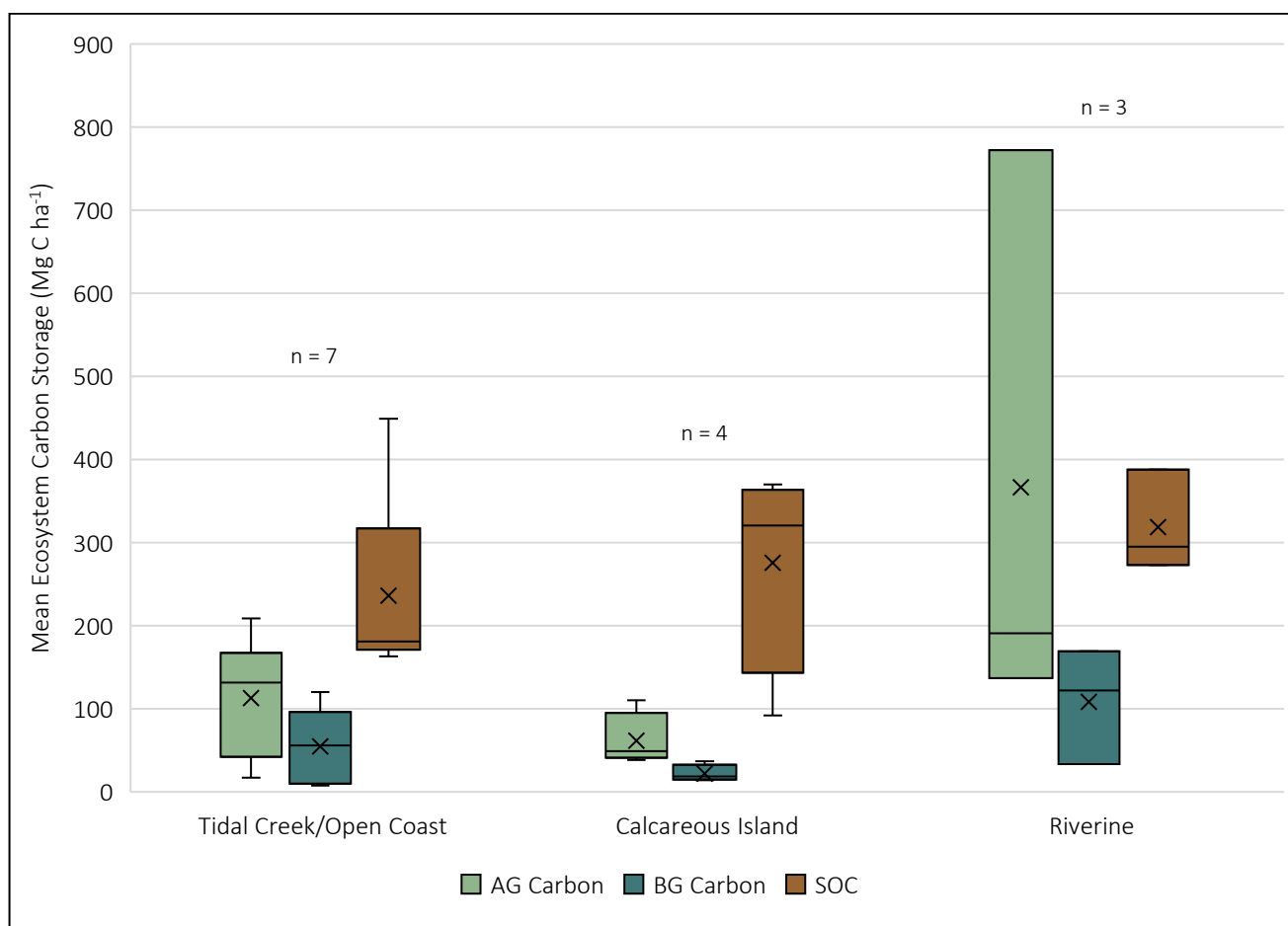


Figure 17. Mangrove mean ecosystem carbon storage in Vanuatu in different geomorphic settings: tidal creek/open coast, calcareous island, and riverine, presented as different carbon pools: above-ground (AG) and below-ground (BG) tree carbon storage and soil organic carbon (SOC), where SOC includes soil sampling depths up to 100 cm.

Across the three geomorphic settings, Calcareous Islands (422 Mg C ha^{-1}) and Tidal Creek/Open Coast (368 Mg C ha^{-1}) had relatively lowest mean TECS, compared to Riverine settings (608 Mg C ha^{-1}) (Figure). Typically, Calcareous Islands have a lower TECS due to their soils being dominated by coarse, carbonate-rich sediments with low organic matter retention, leading to reduced soil organic carbon storage. In contrast, Riverine and Tidal Creek/Open Coast settings receive higher nutrient and sediment inputs from land, promoting greater vegetation growth and organic matter accumulation in both biomass and soil.

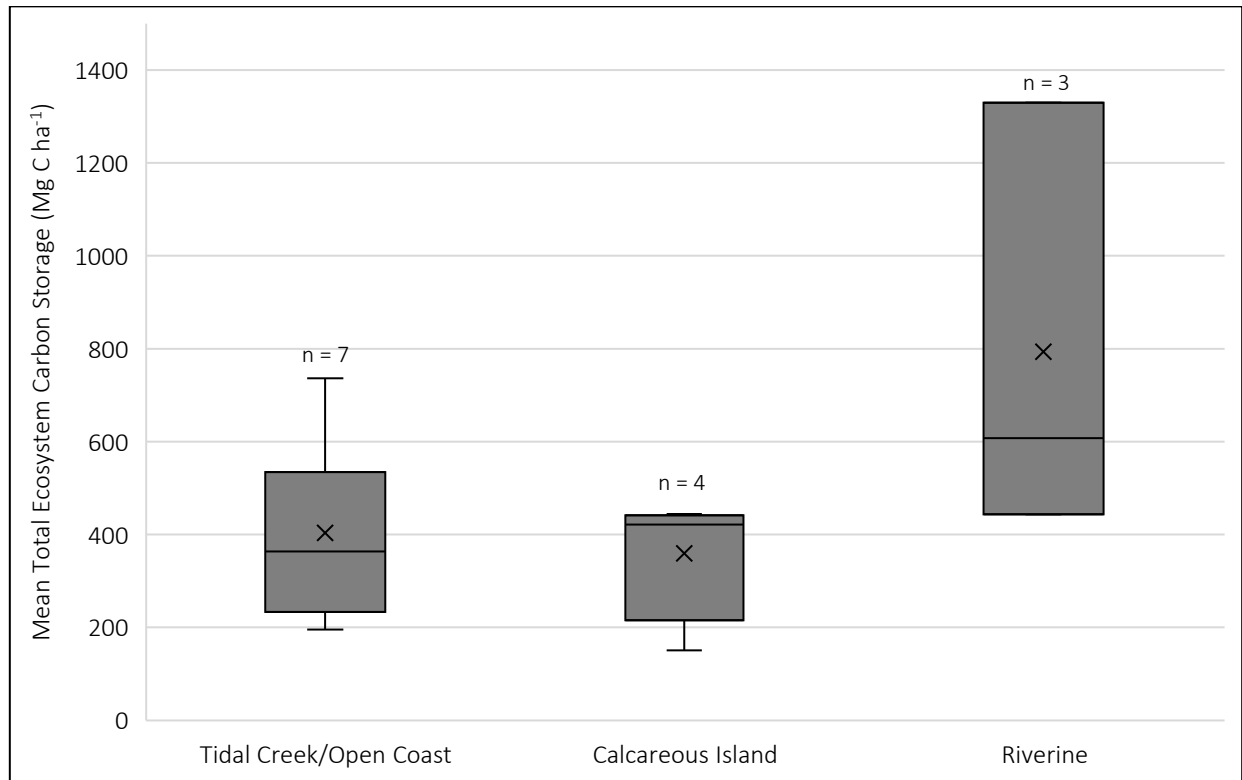


Figure 18. Mangrove mean total ecosystem carbon storage in Vanuatu in different geomorphic settings: tidal creek/open coast, calcareous island, and riverine.

Intact and degraded ecosystems had a mean TECS of 284 Mg C ha⁻¹ and 308 Mg C ha⁻¹ respectively, while converted sites had a lower mean at 177 Mg C ha⁻¹ (Figure). However, these differences were not significant, due to high variability in TECS within the intact and degraded sites likely related to other variables such as hydrodynamics, soil types and species composition.

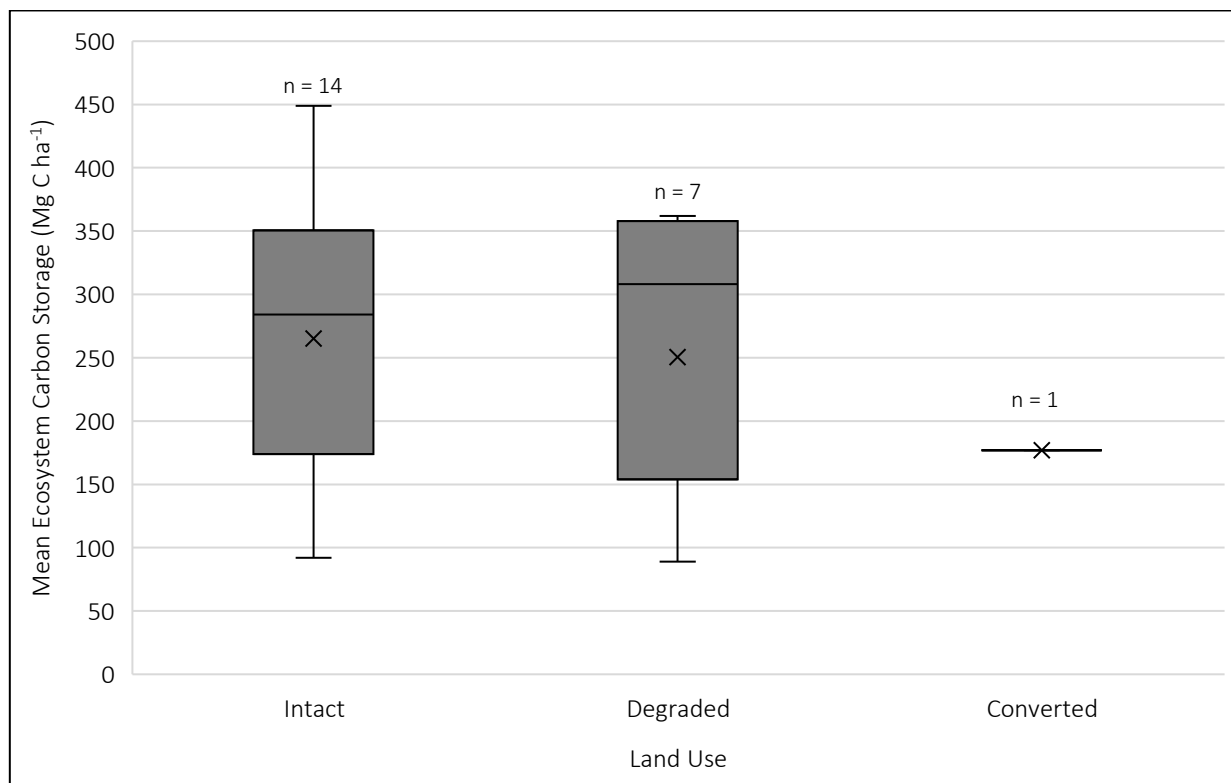


Figure 19. Mean total ecosystem carbon storage in Vanuatu in different land use types: intact, degraded, and converted. There was no significant difference in mean total ecosystem carbon storage across land use types.

Across the different geomorphic settings, Tidal Creek/Open Coast contributed the highest TECS across both depth intervals (Table) and this was primarily due to its larger mapped area. The national mangrove carbon stock estimate for Fiji, across all geomorphic settings, was 0.23 million Mg C for SOC depths up to 30 cm and 0.34 million Mg C for SOC depths up to 100 cm.

Notably, no areas of riverine mangroves were mapped for Vanuatu in this study. While riverine mangroves are known to exist in the country, gaps in available mangrove spatial data resulted in no mapped mangrove areas aligning with rivers classified as small, medium, or large. As improved maps become available through the MACBLUE project, these areas can be updated and revised national stock estimates developed.

Table 16. Mangrove ecosystem national carbon stock estimates for Vanuatu, based on areas derived from remote-mapping of geomorphic settings. Carbon stocks are presented as different carbon pools, including above-ground (AG) and below-ground (BG) tree carbon storage, soil organic carbon (SOC), and total ecosystem carbon stocks (TECS). National carbon stocks are calculated based on two SOC depths to provide an upper (0-100 cm) and lower (0-30 cm) estimate.

Geomorphic setting	Remote-mapping area (ha)	No. of sites	AG tree carbon (Mg C ha ⁻¹)	BG tree carbon (Mg C ha ⁻¹)	SOC depth (cm)	SOC (Mg C ha ⁻¹)	TECS (Mg C ha ⁻¹)	Carbon stock (Mg C)
Calcareous Island	160	4	62 ± 16	22 ± 5	0-100	276 ± 63	360 ± 70	57,600

Geomorphic setting	Remote-mapping area (ha)	No. of sites	AG tree carbon (Mg C ha ⁻¹)	BG tree carbon (Mg C ha ⁻¹)	SOC depth (cm)	SOC (Mg C ha ⁻¹)	TECS (Mg C ha ⁻¹)	Carbon stock (Mg C)	
					0-30	103 ± 8	187 ± 19	29,920	
Tidal Creek/Open Coast	704	7	113 ± 28	55 ± 16	0-100	236 ± 41	404 ± 72	284,416	
					0-30	114 ± 6	282 ± 45	198,528	
Riverine	-	3	367 ± 203	108 ± 40	0-100	319 ± 35	794 ± 272	-	
					0-30	99 ± 14	574 ± 251	-	
Vanuatu Total (0-100 cm)									342,016
Vanuatu Total (0-30 cm)									228,448

4.4.2 Vanuatu seagrass carbon stocks

In Vanuatu, the highest mean carbon stock was found at 0-100 cm depth (87 Mg C ha^{-1}), exceeding that of 0-30 cm (83 Mg C ha^{-1}) and 0-15 cm (45 Mg C ha^{-1}) depths (Figure 20). Across all seagrass sites, the 0-100cm had the highest variability, ranging from 38 to 172 Mg C ha^{-1} . Carbon storage in the uppermost layer (0-15 cm) was consistently low and exhibited minimal variability across all sites.

Among the seagrass sites in Vanuatu, some were dominated by *Enhalus* seagrass. *Enhalus*-dominated sites presented relatively higher mean SOC of 150 Mg C ha^{-1} at 0-100 cm depths (Figure 20). In contrast, mixed-species sites had a lower mean SOC of 77 Mg C ha^{-1} at 0-100 cm depths, however both types of sites were highly variable. This highlights the deeper, more organic-rich sediments which are characteristic of *Enhalus*-dominated areas.

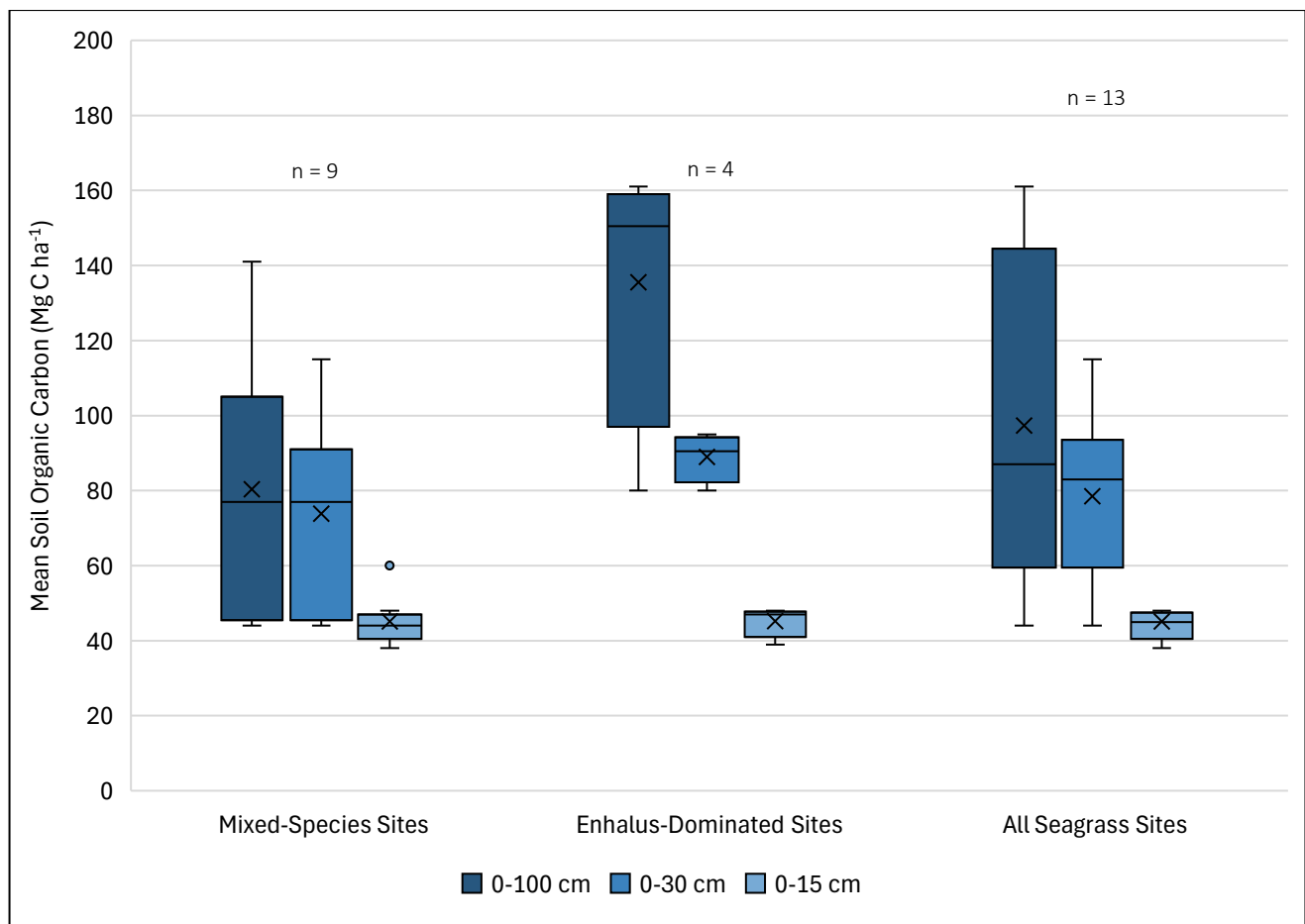


Figure 20. Mean soil organic carbon storage in seagrass meadows of Vanuatu, shown for all sites combined as well as for *Enhalus*-dominated and mixed-species meadows, across depth intervals of 0–100 cm, 0–30 cm, and 0–15 cm.

The estimated national carbon stock for seagrass ecosystems in Vanuatu ranged from 21,105 to 45,493 Mg C depending on the sampling depth (Table 11). This range highlights the carbon storage capacity of seagrass ecosystems in the region, with deeper cores generally capturing larger carbon pools.

Table 17. Seagrass ecosystem national carbon stock estimates for Vanuatu, based on areas derived from remote-mapping of seagrass ecosystems. National carbon stocks are calculated based on three soil organic carbon (SOC) depths to provide an upper and lower estimates. SOC for *Enhalus*-dominated and mixed-species meadows are also given.

Seagrass site	Remote-mapping area (ha)	No. of sites	SOC depth (cm)	SOC (Mg C ha ⁻¹)	Carbon stock (Mg C)
All seagrass sites	469	13	0-100	97 ± 12	45,493
			0-30	79 ± 6	37,051
			0-15	45 ± 2	21,105
<i>Enhalus</i> -dominated sites	-	4	0-100	136	-
			0-30	89	
			0-15	45	
Mixed-species sites	-	9	0-100	80	-
			0-30	73	
			0-15	45	

5 Carbon emissions

This section outlines estimated carbon dioxide (CO₂) emissions resulting from mangrove degradation across the study region. Emissions were derived by comparing carbon stocks at degraded sites with those of intact mangroves within similar geomorphic settings, using both 0-30 cm and 0-100 cm soil depths to capture a range of potential outcomes. These estimates highlight the climate impact of common disturbance types such as cyclones, wood harvesting, and land clearing, and provide insight into the potential emissions reductions achievable through mangrove conservation and restoration. Importantly, the results presented in this report satisfy the requirements for a Tier 2 estimate under the IPCC framework, as they are based on empirical field data and regionally stratified spatial information rather than global default values.

A total of 17 degraded sites across all four countries were assessed in this study, and their associated emissions estimates are presented in the series of tables below. Degradation at each site was attributed to natural or human-induced pressures, including full conversion for industrial or development purposes, with two sites undergoing some level of restoration or conservation. The sites represent three geomorphic setting classifications—riverine, tidal creek/open coast, and calcareous islands. A summary of site characteristics is provided in Table 18 for reference.

Across all sites, soil organic carbon (SOC) represented the largest carbon pool in intact mangrove ecosystems, often exceeding above-ground (AG) tree carbon storage (TCS). However, live TCS contributed the highest proportion of emissions following disturbance, accounting for approximately 54% of total emissions (585 ± 143 Mg C), compared to SOC, which contributed 11% (46 ± 18 Mg C) (Table 19). This pattern reflects the fact that while SOC pools are larger, they may be less immediately affected by certain types of disturbance, and a portion of SOC often remains following degradation or conversion—particularly where soil disturbance is minimal.

At sites where mangroves had been cleared and converted for industry or development, emissions were typically estimated to be 48 to 78% of the original carbon stock, with the exception of one site (Table 22). In contrast, sites degraded due to natural disturbances such as cyclones exhibited relatively low emissions, generally ranging between 0 to 10%, again with one notable exception.

Sites impacted by wood harvesting, a common and culturally significant practice in many communities, showed greater variability, with emissions ranging from 0 to 45%. This variability reflects the site-specific nature of harvesting practices, including differences in intensity, frequency, and the presence of other co-occurring pressures such as erosion or grazing.

Table 18. Summary description of the 17 degraded mangrove sites for which emissions values were calculated in this study, including land-use change information.

Country	Site ID	Site	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphology	Additional site information
Solomon Islands	1	LL2, LL3, LL4, LL7 (LL = Lau Lagoon)	Wood harvesting & cultivation	P	Tidal Creek/Open Coast	Mangrove forests managed for wood harvesting
	2	Sesehura Fa Island (ISF)	Natural disaster (cyclone)	P	Calcareous Island	Significant die back of mangroves in the centre of the Island due to cyclone damage; forest of standing dead trees remain
Vanuatu	3	Nasinu	Hydrological modification	P	Tidal Creek/Open Coast	Hydrological modification caused by cyclone
	4	Sarakata River Mouth 2	Converted (industry)	C	Riverine	Converted to coral aggregate quarry; area reclaimed following loss of mangroves due to cyclone
	5	Port Sandwich 2	Converted (development)	C	Tidal Creek/Open Coast	Cleared for settlement; erosion present
	6	Malatia School, Sarakata River Mouth 1	Natural disaster (cyclone)	P	Riverine	Mangrove forest damaged by cyclone; cattle present; adjacent to a reclaimed area
	7	Maskelyne Islands Peskarus	Natural disaster (cyclone); wood harvesting	P	Calcareous Island	Mangrove forest damaged by cyclone; evidence of wood harvesting. NOTE: Site commenced with higher-than-average carbon stocks for calcareous island settings, as such emissions appear negative, but likely closer to zero.
	8	Manatawora	Agriculture (cattle)	P	Tidal Creek/Open Coast	Mangrove forest and adjacent land cleared for cattle grazing; some areas reclaimed; cyclone damage of remaining mangroves
Fiji	9	Nanuka dredged	Converted (industry)	C	Riverine	Dredge spoil site resulting in terrestrial reclamation; minimal to no mangroves remain
	10	Labasa River 1	Converted (development)	C	Riverine	Cleared for settlement and access
	11	Suva USP restoration site	Restoration	R	Tidal Creek / Open Coast	Mangrove restoration site; established in phases over 3 to 15 years ago; time since original loss unknown.
	12	Ganilau	Urban pollution	P	Tidal Creek / Open Coast	Adjacent to small developments; stormwater inputs (sediment, other pollutants); trash. NOTE: inputs of nitrogen, phosphorus and sediments from urban runoff may have

Country	Site ID	Site	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphology	Additional site information
						increased above- and below-ground biomass to a small degree, potentially enhancing carbon storage, as such emissions appear negative.
	13	Daria (Fringe)	Natural disaster (landslide)	P	Tidal Creek / Open Coast	Ex-seagrass meadow: landslide caused conversion to rubble and calcareous algae, with dense fringe <i>Rhizophora</i> .
Papua New Guinea	14	Sivasat C	Converted (industry)	C	Tidal Creek/Open Coast	Cleared in 2023 for conversion to a storage yard, however project abandoned
	15	Old Mawatta	Converted (development)	C	Calcareous Island	Cleared in 2023 for conversion to a storage yard, however project abandoned
	16	Dolhet Conservation Site 1	Conservation; wood harvesting	R	Tidal Creek/Open Coast	Conservation commenced in 2019; historic and current wood harvesting; area open to community for mud crab and shell harvesting
	17	Maiwara mangroves bay site	Wood harvesting	P	Tidal Creek/Open Coast	Historic and current wood harvesting; some clearing for recreational access

Table 19. Above-ground and below-ground tree carbon storage associated carbon emissions (% and Mg CO₂ ha⁻¹) values for the 17 degraded mangrove sites assessed.

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
Solomon Islands	1	Wood harvesting & cultivation	P	Tidal Creek/Open Coast	4	10 years	641	117	524	82	1,923
	2	Natural disaster (cyclone)	P	Calcareous Island	1	6 -7 years	213	200	13	6	48
Vanuatu	3	Hydrological modification	P	Tidal Creek/Open Coast	1	6 -7 years	168	10	158	94	580
	4	Converted (industry)	C	Riverine	1	6 years	475	0	475	100	1,743
	5	Converted (development)	C	Tidal Creek/Open Coast	1	20 years	168	0	168	100	617
	6	Natural disaster (cyclone)	P	Riverine	2	6 -7 years	475	379	96	20	352
	7	Natural disaster (cyclone); wood harvesting	P	Calcareous Island	1	6 -7 years	84	107	(-23)	(-27)	(-84)
	8	Agriculture (cattle)	P	Tidal Creek/Open Coast	1	6 -7 years	168	75	93	55	341
	9	Converted (industry)	C	Riverine	1	12 years	234	94	140	60	514
Fiji	10	Converted (development)	C	Riverine	1	1 year	234	0	234	100	859
	11	Restoration	R	Tidal Creek/Open Coast	1	Est. 3-15 years	102	24	78	76	286
	12	Urban pollution	P	Tidal Creek/Open Coast	1	Unknown	102	115	(-13)	(-13)	(-48)
	13	Natural disaster (landslide)	P	Tidal Creek/Open Coast	1	Unknown	102	66	36	35	132
	14	Converted (industry)	C	Tidal Creek/Open Coast	1	2 years	249	172	77	31	283
Papua New Guinea	15	Converted (development)	C	Calcareous Island	1	Historic	428	52	376	88	1,380

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
	16	Conservation; wood harvesting	R	Tidal Creek/Open Coast	1	est. 6 years	249	157	92	37	338
	17	Wood harvesting	P	Tidal Creek/Open Coast	1	Historic	249	64	185	74	679
Overall Land Use and Land Cover Changes means					21		255 ± 38 SE	96 ± 23 SE	159 ± 39 SE	54 ± 10 SE	585 ± 143 SE

Table 20. Soil organic carbon (0-100 cm) associated carbon emissions (% and Mg CO₂ ha⁻¹) values for the 17 degraded mangrove sites assessed.

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
Solomon Islands	1	Wood harvesting & cultivation	P	Tidal Creek/Open Coast	4	10 years	419	462	(-43)	(-10)	(-158)
	2	Natural disaster (cyclone)	P	Calcareous Island	1	6 -7 years	387	381	6	2	22
Vanuatu	3	Hydrological modification	P	Tidal Creek/Open Coast	1	6 -7 years	236	154	82	35	301
	4	Converted (industry)	C	Riverine	1	6 years	319	312	7	2	26
	5	Converted (development)	C	Tidal Creek/Open Coast	1	20 years	236	89	147	62	539
	6	Natural disaster (cyclone)	P	Riverine	2	6 -7 years	319	337	(-18)	(-6)	(-66)
	7	Natural disaster (cyclone); wood harvesting	P	Calcareous Island	1	6 -7 years	276	358	(-82)	(-30)	(-301)
	8	Agriculture (cattle)	P	Tidal Creek/Open Coast	1	6 -7 years	236	170	66	28	242
	9	Converted (industry)	C	Riverine	1	12 years	360	140	220	61	807
Fiji	10	Converted (development)	C	Riverine	1	1 year	360	311	49	14	180
	11	Restoration	R	Tidal Creek / Open Coast	1	Est. 3-15 years	349	303	46	13	169
	12	Urban pollution	P	Tidal Creek / Open Coast	1	Unknown	349	356	(-7)	(-2)	(-26)
	13	Natural disaster (landslide)	P	Tidal Creek / Open Coast	1	Unknown	349	103	246	70	903
	14	Converted (industry)	C	Tidal Creek/Open Coast	1	2 years	387	431	(-44)	(-11)	(-161)
Papua New Guinea	15	Converted (development)	C	Calcareous Island	1	Historic	309	319	(-10)	(-3)	(-37)

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
	16	Conservation; wood harvesting	R	Tidal Creek/Open Coast	1	est. 6 years	387	407	(-20)	(-5)	(-73)
	17	Wood harvesting	P	Tidal Creek/Open Coast	1	Historic	387	330	57	15	209
Overall Land Use and Land Cover Changes means						21	333 ± 14 SE	292 ± 28 SE	41 ± 22 SE	14 ± 7 SE	152 ± 81 SE

Table 21. Soil organic carbon (0-30 cm) associated carbon emissions (% and Mg CO₂ ha⁻¹) values for the 17 degraded mangrove sites assessed.

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
Solomon Islands	1	Wood harvesting & cultivation	P	Tidal Creek/Open Coast	4	10 years	129	140	(-11)	(-9)	(-40)
	2	Natural disaster (cyclone)	P	Calcareous Island	1	6 -7 years	123	121	2	2	7
Vanuatu	3	Hydrological modification	P	Tidal Creek/Open Coast	1	6 -7 years	114	85	29	25	106
	4	Converted (industry)	C	Riverine	1	6 years	99	41	58	59	213
	5	Converted (development)	C	Tidal Creek/Open Coast	1	20 years	144	89	55	38	202
	6	Natural disaster (cyclone)	P	Riverine	2	6 -7 years	99	102	(-3)	(-3)	(-11)
	7	Natural disaster (cyclone); wood harvesting	P	Calcareous Island	1	6 -7 years	103	106	(-3)	(-3)	(-11)
	8	Agriculture (cattle)	P	Tidal Creek/Open Coast	1	6 -7 years	114	101	13	11	48
	9	Converted (industry)	C	Riverine	1	12 years	114	88	26	23	95
Fiji	10	Converted (development)	C	Riverine	1	1 year	114	107	7	6	26
	11	Restoration	R	Tidal Creek/Open Coast	1	Est. 3-15 years	110	91	19	17	70
	12	Urban pollution	P	Tidal Creek/Open Coast	1	Unknown	110	108	2	2	7
	13	Natural disaster (landslide)	P	Tidal Creek/Open Coast	1	Unknown	110	103	7	6	26
	14	Converted (industry)	C	Tidal Creek/Open Coast	1	2 years	116	111	5	4	18
Papua New Guinea	15	Converted (development)	C	Calcareous Island	1	Historic	90	88	2	2	7

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
	16	Conservation; wood harvesting	R	Tidal Creek/Open Coast	1	est. 6 years	116	128	(-12)	(-10)	(-44)
	17	Wood harvesting	P	Tidal Creek/Open Coast	1	Historic	116	98	18	16	66
Overall Land Use and Land Cover Changes means					21		113 ± 3 SE	100 ± 5 SE	13 ± 5 SE	11 ± 4 SE	46 ± 18 SE

Table 22. Total Ecosystem Carbon Stock (0-100 cm) associated carbon emissions (% and Mg CO₂ ha⁻¹) values for the 17 degraded mangrove sites assessed.

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
Solomon Islands	1	Wood harvesting & cultivation	P	Tidal Creek/Open Coast	4	10 years	1,060	580	480	45	1,762
	2	Natural disaster (cyclone)	P	Calcareous Island	1	6 -7 years	600	581	19	3	70
Vanuatu	3	Hydrological modification	P	Tidal Creek/Open Coast	1	6 -7 years	404	164	240	59	881
	4	Converted (industry)	C	Riverine	1	6 years	794	177	617	78	2,264
	5	Converted (development)	C	Tidal Creek/Open Coast	1	20 years	404	89	315	78	1,156
	6	Natural disaster (cyclone)	P	Riverine	2	6 -7 years	794	716	78	10	286
	7	Natural disaster (cyclone); wood harvesting	P	Calcareous Island	1	6 -7 years	360	465	(-105)	(-29)	(-385)
	8	Agriculture (cattle)	P	Tidal Creek/Open Coast	1	6 -7 years	404	245	159	39	584
	9	Converted (industry)	C	Riverine	1	12 years	593	234	359	61	1,318
Fiji	10	Converted (development)	C	Riverine	1	1 year	593	311	282	48	1,035
	11	Restoration	R	Tidal Creek/Open Coast	1	Estd. 3-15 years ago	451	327	124	27	455
	12	Urban pollution	P	Tidal Creek/Open Coast	1	Unknown	451	471	(-20)	(-4)	(-73)
	13	Natural disaster (landslide)	P	Tidal Creek/Open Coast	1	Unknown	451	169	282	63	1,035

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	No. of sites	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
Papua New Guinea	14	Converted (industry)	C	Tidal Creek/Open Coast	1	2 years	637	603	34	5	125
	15	Converted (development)	C	Calcareous Island	1	Historic	737	371	366	50	1,343
	16	Conservation; wood harvesting	R	Tidal Creek/Open Coast	1	Estd. 6 years ago	637	564	73	11	268
	17	Wood harvesting	P	Tidal Creek/Open Coast	1	Historic	637	394	243	38	892
Overall Land Use and Land Cover Changes means					21		589 ± 45 SE	380 ± 45 SE	209 ± 46 SE	34 ± 7 SE	766 ± 169 SE

Table 23. Total Ecosystem Carbon Stock (0-30 cm) associated carbon emissions (% and Mg CO₂ ha⁻¹) values for the 17 degraded mangrove sites assessed.

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	N	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
Solomon Islands	1	Wood harvesting & cultivation	P	Tidal Creek/Open Coast	4	10 years	770	257	513	67	1,883
	2	Natural disaster (cyclone)	P	Calcareous Island	1	6 -7 years	336	321	15	4	55
Vanuatu	3	Hydrological modification	P	Tidal Creek/Open Coast	1	6 -7 years	282	95	187	66	686
	4	Converted (industry)	C	Riverine	1	6 years	574	41	533	93	1,956
	5	Converted (development)	C	Tidal Creek/Open Coast	1	20 years	282	89	193	68	708
	6	Natural disaster (cyclone)	P	Riverine	2	6 -7 years	574	481	93	16	341
	7	Natural disaster (cyclone); wood harvesting	P	Calcareous Island	1	6 -7 years	187	213	(-26)	(-14)	(-95)
	8	Agriculture (cattle)	P	Tidal Creek/Open Coast	1	6 -7 years	282	176	106	38	389
	9	Converted (industry)	C	Riverine	1	12 years	348	182	166	48	609
Fiji	10	Converted (development)	C	Riverine	1	1 year	348	107	241	69	884
	11	Restoration	R	Tidal Creek / Open Coast	1	Est. 3-15 years	212	115	97	46	356
	12	Urban pollution	P	Tidal Creek / Open Coast	1	Unknown	212	223	(-11)	(-5)	(-40)
	13	Natural disaster (landslide)	P	Tidal Creek / Open Coast	1	Unknown	212	169	43	20	158
	14	Converted (industry)	C	Tidal Creek/Open Coast	1	2 years	365	283	82	22	301

Country	Site ID	Land-use pressure or change	Pressure (P), converted (C) or restoration (R)	Geomorphic setting	N	Time since LUC	Initial C stocks mean (Mg C ha ⁻¹)	Remained C stocks after LUCs (Mg C ha ⁻¹)	C stocks difference (Mg C ha ⁻¹)	Emissions (%)	Carbon Emissions (Mg CO ₂ ha ⁻¹)
	15	Converted (development)	C	Calcareous Island	1	Historic	518	140	378	73	1,387
	16	Conservation; wood harvesting	R	Tidal Creek/Open Coast	1	est. 6 years	365	285	80	22	294
	17	Wood harvesting	P	Tidal Creek/Open Coast	1	Historic	365	162	203	56	745
Overall Land Use and Land Cover Changes means					21		367 ± 38 SE	196 ± 26 SE	170 ± 40 SE	41 ± 7 SE	625 ± 148 SE

6 Summary, conclusions and recommendations

This study presents the first regionally consistent, field-based estimates of total ecosystem carbon stocks (TECS) for mangrove and seagrass ecosystems across Fiji, Papua New Guinea (PNG), Solomon Islands, and Vanuatu. By applying a standardised Tier 2 methodology aligned with IPCC Wetlands Supplement and the Coastal Blue Carbon Manual, the assessment improves upon previous Tier 1 estimates that relied on global default values.

National carbon stock estimates

Total national carbon stock estimates varied significantly across the region, with Papua New Guinea storing the highest mangrove carbon at 207.8 million Mg C, followed by Solomon Islands with 58.1 million Mg C, Fiji with 23.5 million Mg C, and Vanuatu with just 0.34 million Mg C. Seagrass carbon stocks showed a different pattern, with PNG again leading at 11.2 million Mg C, Fiji at 4.6 million Mg C, Solomon Islands at 2.7 million Mg C, and Vanuatu at 0.045 million Mg C. These differences reflect both the extent of mapped ecosystems and the variability in carbon density across geomorphic settings.

Comparisons with Tier 1 estimates reveal that default values would significantly underestimate carbon stocks in high-carbon systems such as those found in Papua New Guinea and the Solomon Islands.⁵⁵ For example, while IPCC Tier 1 default values suggest 511 Mg C ha⁻¹ for mangroves⁵⁶, our field-based TECS in PNG and Solomon Islands often exceeded 600 to 1100 Mg C ha⁻¹. In contrast, Fiji and Vanuatu showed closer alignment with Tier 1 values, though still benefited from improved spatial resolution of sampling and stratification of carbon estimates by geomorphic setting.

Mangroves contributed more national carbon stocks than seagrass, primarily due to the significantly smaller mapped areas of seagrass. Field assessments revealed substantial gaps in available data for seagrass distribution, suggesting improved mapping would likely increase its estimated contribution to national carbon stocks. While mangroves generally store more carbon, carbon stock levels varied between ecosystems and across countries, reflecting differences in geomorphic settings, species composition and site conditions.

Mangroves in riverine settings typically had higher mean TECS levels than calcareous island settings, however the difference was often not significant due to high variability in TEC between sites.

Emissions estimates

Across all sites, soil organic carbon (SOC) represented the largest carbon pool in intact mangrove ecosystems, often exceeding above-ground biomass (AGB). However, live tree carbon contributed the highest proportion of emissions following disturbance, accounting for approximately 54% of total emissions (585 ± 143 Mg C), compared to SOC, which contributed 14% (152 ± 81 Mg C) (Table 19). This pattern reflects the fact that while SOC pools are larger, they may be less immediately affected by certain types of disturbance, and a portion of SOC often remains following degradation or conversion—particularly where soil disturbance is minimal.

At sites where mangroves had been cleared and converted for industry or development, emissions were typically estimated to be 48 to 78% of the original carbon stock, with the exception of one site (Table 22). In contrast, sites

⁵⁵ Refer to Table 4

⁵⁶ Kauffman, J. B., Adame, M. F., Arifanti, V. B., Schile-Beers, L. M., Bernardino, A. F., Bhomia, R. K., ... & Hernández Trejo, H. (2020). Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological monographs*, 90(2), e01405.

degraded due to natural disturbances such as cyclones exhibited relatively low emissions, generally ranging between 0 to 10%, again with one notable exception.

Sites impacted by wood harvesting, a common and culturally significant practice in many communities, showed greater variability, with emissions ranging from 0 to 45%. This variability reflects the site-specific nature of harvesting practices, including differences in intensity, frequency, and the presence of other co-occurring pressures such as erosion or grazing.

This study presents the first regionally consistent, field-based estimates of total ecosystem carbon stocks (TECS) for mangrove and seagrass ecosystems across Fiji, Papua New Guinea (PNG), Solomon Islands, and Vanuatu. By applying a standardised Tier 2 methodology aligned with the IPCC Wetlands Supplement and the Coastal Blue Carbon Manual, the assessment improves upon previous Tier 1 estimates that relied on global default values.

Key Findings by country:

Fiji

- Mangroves in riverine settings stored the highest total ecosystem stocks (TECS) (593 Mg C ha⁻¹), followed by Tidal Creek/Open Coast (451 Mg C ha⁻¹) and Calcareous Islands (242 Mg C ha⁻¹).
- Seagrass ecosystems stored TECS of 93 Mg C ha⁻¹ in the top 0–100 cm of sediment, with deeper cores capturing significantly more carbon than surface layers.
- National mangrove carbon stocks: 11.8–23.5 million Mg C.
- Seagrass carbon stock ranged from 2.1 to 4.6 million Mg C.
- Tidal Creek/Open Coast settings contributed the highest national mangrove carbon stock due to their larger mapped area.
- Seagrass carbon stocks increased significantly with depth, with 0–100 cm estimates more than double those at 0–15 cm.

Papua New Guinea

- Mangroves across all geomorphic settings stored high TECS: 737 Mg C ha⁻¹ in calcareous island settings, 664 Mg C ha⁻¹ in riverine settings, and 637 Mg C ha⁻¹ in tidal creek/open coast settings.
- Seagrass mean TECS were 123 Mg C ha⁻¹ at 0–100 cm depth, with *Enhalus*-dominated seagrass meadows storing substantially (reaching up to 182 Mg C ha⁻¹) more carbon than mixed-species meadows, due to deeper organic sediments.
- National mangrove carbon stock: 124.1–207.8 million Mg C.
- Seagrass carbon stock ranged from 4.1 to 11.2 million Mg C.
- Tidal Creek/Open Coast settings contributed the most to national mangrove carbon stocks due to extensive mapped area.
- Tier 1 estimates using default values significantly underestimate actual stocks, demonstrating the value of field-based Tier 2 assessments.

Solomon Islands

- Mangroves across all geomorphic settings stored high TECS: 1117 Mg C ha⁻¹ in riverine settings, 1002 Mg C ha⁻¹ in lagoon settings, 1060 Mg C ha⁻¹ in tidal creek/open coast settings, and 600 Mg C ha⁻¹ in calcareous island settings.
- Seagrass ecosystems in Solomon Islands store an average TECS of 78 Mg C ha⁻¹ at 0–100 cm depth, with *Enhalus*-dominated sites slightly higher at 88 Mg C ha⁻¹, though differences were not statistically significant.

- National mangrove carbon stock: 40.9–58.1 million Mg C.
- Seagrass carbon stock ranged from 1.6 to 2.7 million Mg C.
- Tidal Creek/Open Coast settings contributed the most to national mangrove carbon stocks due to larger mapped areas.
- Tier 1 estimates using default values significantly underestimate actual stocks, demonstrating the value of field-based Tier 2 assessments.

Vanuatu

- Mangroves in riverine settings stored the highest TECS: 794 Mg C ha⁻¹ in riverine settings, 404 Mg C ha⁻¹ in tidal creek/open coast settings, and 360 Mg C ha⁻¹ in calcareous island settings.
- Seagrass ecosystems in Vanuatu store an average of 97 Mg C ha⁻¹ at 0–100 cm depth. *Enhalus*-dominated seagrass sites had higher mean carbon stocks (up to 150 Mg C ha⁻¹ at 100 cm depth), suggesting deeper, more organic-rich sediments.
- National mangrove carbon stock: 0.23–0.34 million Mg C.
- Seagrass carbon stock ranged from 21,105 to 45,493 Mg C.
- Riverine mangroves were not mapped due to data gaps, likely underestimating national carbon stocks.
- Tidal Creek/Open Coast settings contributed the highest TECS due to their larger mapped area.

Limitations and recommendations

- **Integrate updated mangrove and seagrass maps:** Mangrove and seagrass extent mapping used in this study is currently being updated under the MACBLUE project, however was not available at the time of reporting. There were significant limitations to the older mangrove extent maps used, and they have likely underestimated the total carbon stocks. Re-calculating the national carbon stocks using updated mangroves areas from more comprehensive mapping is highly recommended.
- **Emissions Estimates:** The emissions presented in this report reflect upper-bound estimates, based on the assumption that all lost carbon is released as CO₂. However, in practice, a portion of this carbon may be redeposited in adjacent ecosystems or transported to the deep ocean. While correction factors to account for these dynamics are under development, they were not applied in this analysis.
- **Geomorphic Classification:** To account for environmental variability, this project applied an approach that classified mangroves based on geomorphic setting. Sites were grouped into four geomorphic categories: Riverine, Tidal Creek/Open Coast, Calcareous Island, and Lagoon. These settings reflect differences in hydrology, sediment type, and ecological function, which are known to affect carbon dynamics. Past studies such as, Adame et al. (2013)⁵⁷, Rovai et al. (2018)⁵⁸, and Kauffman et al. (2020)⁵⁹ have found that riverine mangroves typically store substantially more soil organic carbon than open coast or island settings due to higher sedimentation rates and nutrient inputs. Our study found relatively low or limited variation in total ecosystem carbon stocks (TECS) between these geomorphic groupings. This may be because the carbon stocks at the sites within each geomorphic class, may have been more

⁵⁷ Adame, M. F., Kauffman, J. B., Medina, I., Gamboa, J. N., Torres, O., Caamal, J. P., & Herrera-Silveira, J. A. (2013). Carbon stocks of tropical coastal wetlands within the karstic landscape of the Mexican Caribbean. *PloS one*, 8(2), e56569.

⁵⁸ Rovai, A. S., Twilley, R. R., Castañeda-Moya, E., Riul, P., Cifuentes-Jara, M., Manrow-Villalobos, M., & Pagliosa, P. R. (2018). Global controls on carbon storage in mangrove soils. *Nature Climate Change*, 8(6), 534–538.

⁵⁹ Kauffman, J. B., Adame, M. F., Arifanti, V. B., Schile-Beers, L. M., Bernardino, A. F., Bhomia, R. K., & Hernández Trejo, H. (2020). Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. *Ecological monographs*, 90(2), e01405.

strongly driven by local land use, disturbance history, and species composition, which may have masked broader trends. Improving site classification using more detailed geomorphic and ecological data could better capture variability.

Appendix **A**

Spatial dataset inventory

A.1. Spatial dataset inventory

Spatial data file name	Country	Projection	Date	File type	Source	Description
FIJI_Gau_Island_Mangrove	Fiji	EPSG:4326 / WGS 84	09/08/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Gau Island, Fiji.
FIJI_Kadavu_Island_Mangrove		EPSG:4326 / WGS 84	23/05/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Kadavu Island, Fiji.
FIJI_Lau_Islands_Mangrove		EPSG:4326 / WGS 84	09/08/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Lau Islands, Fiji.
FIJI_VanuaLevu_Island_Mangrove		EPSG:4326 / WGS 84	23/05/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Vanua Levu, Fiji.
FIJI_VitiLevu_Island_Mangrove		EPSG:4326 / WGS 84	23/05/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Viti Levu, Fiji.
Fiji Admin Boundaries		EPSG:4326 / WGS 84	2024	Polygon	Alluvium International	Modified version of the Global International Boundaries shapefile demonstrating Fiji's national boundaries.
PNG_mangroves_2022	Papua New Guinea	EPSG:3832 / WGS 84	2022	Raster	SPC (Client supplied)	Raster file of modelled distribution of mangrove ecosystems throughout Papua New Guinea.
PNG_mangroves_2022		EPSG:4326 / WGS 84	2022	Polygon	Alluvium International	Vectorised version of client supplied PNG_mangroves_2022 raster file of modelled distribution of mangrove ecosystems throughout Papua New Guinea.
PNG Admin Boundaries		EPSG:4326 / WGS 84	2024	Polygon	Alluvium International	Modified version of the Global International Boundaries shapefile demonstrating Papua New Guinea's national boundaries.
Mangroves	Solomon Islands	EPSG:4326 / WGS 84	23/05/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Vanuatu. Converted from EPSG:4781 – Solomon 1968 to EPSG:4326/WGS 84 for consistency.
Solomon Islands Admin Boundaries		EPSG:4326 / WGS 84	2024	Polygon	Alluvium International	Modified version of the Global International Boundaries shapefile demonstrating Fiji's national boundaries.

Spatial data file name	Country	Projection	Date	File type	Source	Description
Mangroves_site	Vanuatu	EPSG:4326 / WGS 84	02/07/2024 (Date supplied)	Polygon	SPC (Client supplied)	Modelled distribution of mangrove ecosystems throughout Vanuatu. Converted from EPSG:32758/UTM zone 58s to EPSG:4326/WGS 84 for consistency.
Vanuatu Admin Boundaries		EPSG:4326 / WGS 84	2024	Polygon	Alluvium International	Modified version of the Global International Boundaries shapefile demonstrating Fiji's national boundaries.
GloRiC	Global	EPSG: 4326 / WGS 84	2019	Line	HydroSHEDS	The Global River Classification (GloRiC) provides river types and sub-classifications for all river reaches contained in the HydroRIVERS database. GloRiC has been developed by utilizing the river network delineation of HydroRIVERS combined with the hydro-enviromental characteristics from the HydroATLAS database and auxiliary information. Version 1.0 of GloRiC provides a hydrologic, physio-climatic, and geomorphic sub-classification, as well as a combined river type for every river reach, resulting in a total of 127 river reach types. It also offers a k-means statistical clustering of the reaches into 30 groups. The dataset comprises 8.5 million river reaches with a total length of 35.9 million km. River classes were determined based on "Reach_type" attribute from this dataset. The 2nd digit of the class number in the attribute represents the reduced hydrologic class (i.e., river size category). • Large River = 4 as the second digit • Medium River = 3 as the second digit • Small River = 2 as the second digit • Very Small River = 1 as the second digit. Large River and Medium River features were buffered to 500 m. Small River and Very Small River features were buffered to 300 m.
Geomorphic map	Global	EPSG:4236 / WGS 84	2020	Polygon	Allen Coral Atlas	The Allen Coral Atlas is a global-scale coral reef habitat mapping project that is using Planet Dove 3.7m resolution daily satellite imagery (in combination with wave models and ecological data) to create consistent global coral reef habitat maps with the purpose of supporting science and conservation.
Global International Boundaries – USGS	Global	EPSG:4326 / WGS 84	2024	Polygon	FieldMaps	International boundaries in two versions using US DoS LSIB for boundaries and U.S. Geological Survey for coastline data.

