BLUE CARBON ECOSYSTEMS OF THE SOUTH PACIFIC: MACBLUE BLUE CARBON FIELD AND TRAINING MANUAL 2024 (FINAL)

Blue Carbon Assessments for SPREP component of the MACBLUE project.

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1 Introduction

1.1 Blue Carbon Ecosystems

Blue Carbon Ecosystems such as seagrasses and mangroves capture and store carbon, acting as highly effective carbon sinks. 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. Protecting and restoring coastal habitats protects these carbon stores and promotes healthy coastal environments that provide many other services to coastal communities such as storm protection and nursery habitat for commercial and recreational fisheries.

1.2 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 fur International Zusammenarbeit (GIZ), The Pacific Community (SPC) and The Secretariat for the Pacific Regional Environment Programme (SPREP). Its aim is to "strengthen coastal biodiversity conservation and management through protection and rehabilitation incentives for coastal carbon sinks in Pacific Island countries." The project requires Blue Carbon assessments in Fiji, Papua New Guinea, Solomon Islands and Vanuatu.

The data collected 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 seagrass and mangrove habitats,
- Evaluate coastal Blue Carbon habitats, and
- To train and build capacity in each of the countries.

1.3 Purpose of this document

A major objective of this project is to train and build capacity in each of the countries. Several existing Blue Carbon methods, guidelines and manuals provide detailed guidance on how to assess carbon stocks in mangroves and seagrass. These have been developed and published by IPCC, UNESCO, International Union for Conservation of Nature amongst others.[1,2] This document provides detail of the country specific methods for undertaking carbon stock, biodiversity and threat assessments that were developed by this project, based on the existing guidelines. The purpose of the document is to be step-by-step guide to undertaking assessments and is intended to be used to support training and capacity building. Specifically, the objectives of capacity building though this project are to:

- Increase in-country capacity to undertake Blue Carbon stock assessments.

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[1] Conservation International, Intergovernmental Oceanographic Commission of UNESCO, and International Union for Conservation of Nature. (2014). *Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows*. UNESCO.

[2] IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

- Refine and recommend a relatively rapid assessment method for carbon and biodiversity assessment in SaMs habitats that is suitable for each country.
- Provide consistent repeatable methods that ensures data collected is comparable and consistent between sites, countries and over time.
- Some sites in this study may become permanent assessment sites, that will be repeatedly measured over time. Ensuring the method used is repeatable is critical for comparison and tracking changes over time.
- Take a 'train the trainer' approach, to ensure capacity can continue to grow following the end of project.

The methods presented in this document are adapted from:

- Blue Carbon Manual, 2019[3]
- 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetland, 2014[4]
- Coastal Wetlands in National Greenhouse Gas Inventories, 2021[5]
- Manual for mangrove monitoring in the Pacific Islands region[6]
- Intertidal Spotchecks: Quick guide to collecting intertidal field validation data for seagrass mapping[7],
- Subtidal spot-check: Quick guide to mapping subtidal seagrass using drop-camera[8], and
- Guidelines for Undertaking Rapid Biodiversity Assessments in Terrestrial and Marine Environments in the Pacific[9]

As well as other methods that are cited throughout.

1.4 Preparation

1.4.1 Community consent (free, prior and informed consent)

- Inform local community about the project prior to the arrival of the field assessment team.
- Seek community permission to undertake the assessment at an agreed time/date.
- Wherever possible hire site specific local community members as guides and support for fieldwork.

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[3] 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.
[4] 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/
[5] 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.
[6] Ellison et al. (2012). Manual for mangrove monitoring in the Pacific Islands region. Secretariat of the Pacific Regional Environment Programme (SPREP).
[7] McKenzie and Yoshida, (2023), Intertidal Spotchecks: Quick guide to collecting intertidal field validation data for seagrass mapping. Seagrass-Watch HQ. Clifton Beach, Queensland, Australia
[8] McKenzie and Yoshida, (2024). Subtidal spot-check: Quick guide to mapping subtidal seagrass using drop-camera. Seagrass-Watch HQ. Clifton Beach, Queensland, Australia
[9] Patrick, Brian, SPREP. (2014). Guidelines for Undertaking Rapid Biodiversity Assessments in Terrestrial and Marine Environments in the Pacific. Wildlands, SPREP, Australian Aid.

1.4.2 Logistics planning

- Check tide times and plan logistics to ensure you have enough time to complete sampling, as some tides are shorter and/or more frequent than others. This table presents some guidelines for when and where to sample based on the tide.

Table 1 Sampling guidelines for when and where to sample based on the tide

	Mangrove sampling logistics	Seagrass sampling logistics
Where crocodile risk is absent	• Sample mangroves on the low tide and/or outgoing tide wherever possible. Commencing 2 hours before low tide can be a good rule of thumb. • Begin sampling near the waters edge and work landward to maximise sampling time available.	• Sample seagrass from land, when the tide is lowest and intertidal seagrass is exposed. • Depending on conditions sub-tidal seagrass can be sampled from a boat or at low tide by wading in shallow water if <30cm deep and conditions are safe. • Do not swim or snorkel.
Where crocodile risk is high	• Sample mangroves on the low tide and/or outgoing tide wherever possible. Choose the lowest tide if present/possible. • Never sample close to the water on an incoming tide. • Focus mangrove sampling on the back of the mangrove areas, farthest from the water's edge. • Avoid areas known to be extremely high risk. Consult community to confirm such locations.	• Do not sample seagrass from the land, as you will be too close to the water's edge. • Sample seagrass from a boat. • Avoid areas known to be extremely high risk. Consult community to confirm such locations.

1.4.3 Equipment

Table 2 Field equipment list

Pencil and copies of data sheet/waterproof paper/ Tablet (with excel field sheets loaded)	GPS + spare batteries
Site map	Chalk
Soil corer	Sample ziplock bags – small and medium size
Grab sampler (optional)	Permanent marker
30ml Syringes, with ends cut off	Camera with GPS + spare batteries
Flat knife or spatula for cutting soil core samples	Underwater camera (optional)
Long ruler (1m)	Binoculars
Cooler bag to keep soil samples cool	Local vegetation species identification guides
50 m tape	Local fauna species identification guides (where relevant)
DBH tape measure	Clipboard
Nally bin and/or dry bags for storage	First aid kit

Table 3 Soil core processing equipment

Food dehydrator with tray layers (and reliable source of power) or oven
Disposable metal pie tins (~7cm diameter)
Sample ziplock bags – small and medium size
Pencil
Permanent marker

2 Consult community for site options

The aim of this assessment is to provide a national Blue Carbon estimate for each country. As such, we need to sample representative locations within a region. Consult the community to identify a selection of suitable and safe sites to visit in the area. Each site will represent one of the categories within three variables of interest: habitat type, geomorphology and land-use conversation (Table 4). The number of sites depends on available time. Roughly one site can be completed per day (i.e. 3 to 4 plots per site). More may be possible in easy to access areas with low or no vegetation cover.

A Prior to arrival identify site locations from available offline maps, aerial photos and your knowledge of the site. Print relevant maps and images to be used for community consultation.

B Seek guidance from the local community on:

a) Location of intact mangrove and seagrass areas

b) Location of degraded and/or converted seagrass and mangrove areas

c) Date when the degradation/conversion occurred (if known)

d) Guidance on potential safety consideration in site selection (e.g. avoid sites in the territory of big crocodile)

C Create maps, with guidance from the community, of the selected sites to take into the field and mark identifiable features that will help orient you in the field and help decide on plot locations.

D Drone flights, if available, can be used to scope mangrove zonation and key features.

Table 4 Sampling design variables and associated categories

Variable	Categories
Habitat type	Seagrass Mangroves
Geomorphology[10]	Riverine Tidal Creek Open Coast Calcareous Island Lagoon
Land-use conversion[11]	Intact Degraded Converted

[10] 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.
[11] 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.

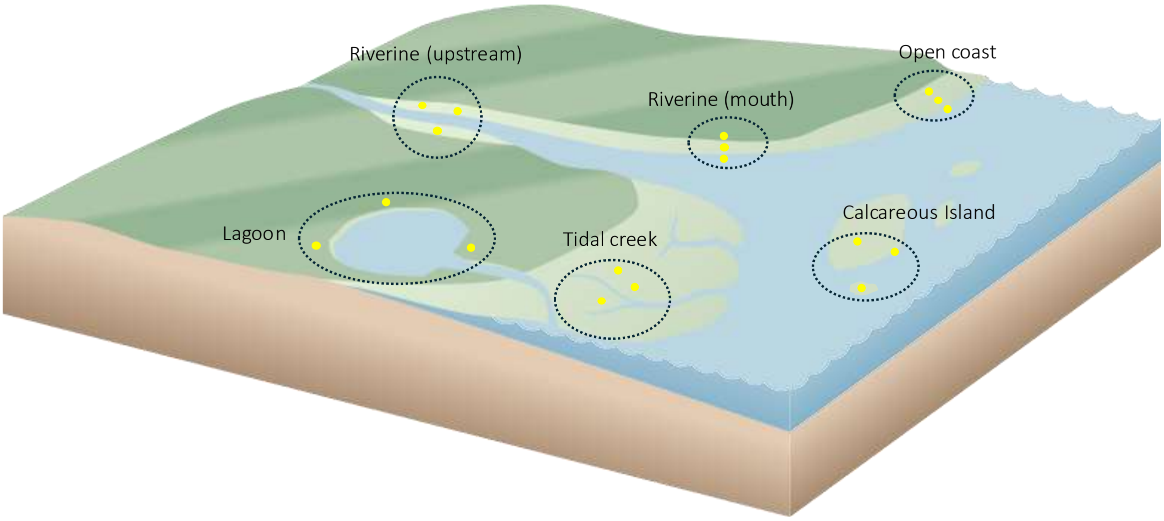


Figure 1 Conceptual diagram demonstrating the different geomorphic settings that should be represented when considering site selection. Black circles represent site options, and yellow circles represent plots within a site. These geomorphic setting categories align with those used in Adame et al (2021) and Durr et al (2011), as they are known to significantly vary in soil carbon.[12,13, 14]

Why geomorphology?

Global studies of mangrove soil carbon[15] have found that mangrove soil carbon significantly varies between geomorphological settings e.g. river delta, lagoon, estuary. This is because in each setting different processes dominate and influence the soil chemistry and mangrove ecosystem, such as tides, river discharge, temperature, precipitation and evapotranspiration. As such, to ensure variation in mangrove soil carbon is appropriately represented by these assessments, geomorphic setting has been included in sampling design.

Why land-use conversion?

Prioritising conservation and restoration efforts for Blue Carbon habitats requires an understanding of 1) avoided carbon emissions due to prevention of loss; and 2) gained carbon stocks due to restoration. Different types of land-use conversions are related to different carbon emission predictions[16]. Specifically, they have been found to vary between land-use changes due to: (a) conversion to commodities, such as agriculture or aquaculture; (b) coastal erosion; (c) clearing; (d) extreme climatic events; and (e) conversion to human settlements[17]. As such, sampling across a gradient of land-use conversion levels has been included in sampling design. This approach will ensure the data collected from this study allows land-use drivers for carbon stocks to be integrated into Nationally Determined Contributions to the Paris Agreement, and support each country's ability to predict and prioritise conservation and management.

[12] 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.
[13] 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
[14] 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.
[15] 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.
[16] 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.
[17] 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

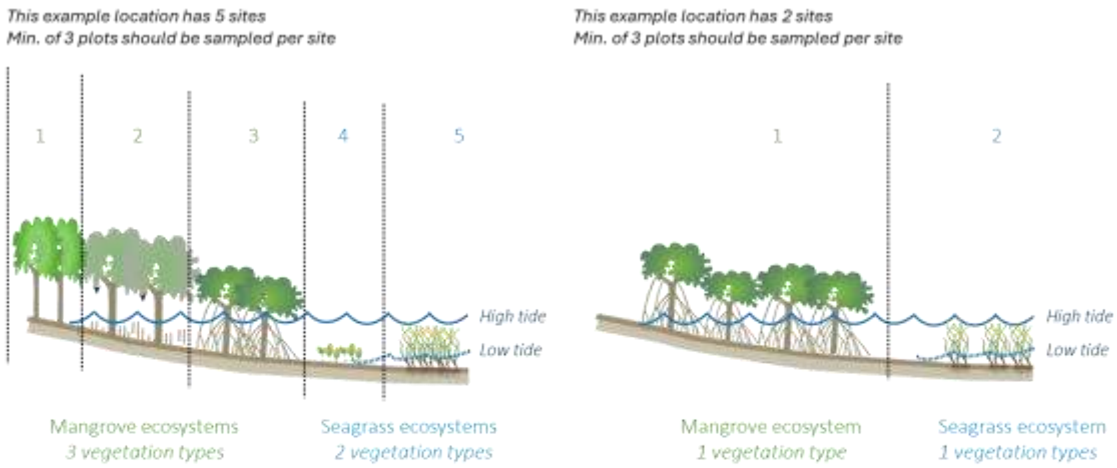


Figure 2 Vegetation type (including structure and species composition) is used to select sites, these two diagrams demonstrate how some locations may require fewer sites than others to ensure variability in carbon stocks is adequately represented by the assessment.

Table 5 The methods describe in this document are to collect for data for three different components of the broader assessment, as depicted by the symbols in this legend.

	Legend
	This symbol depicts methods that contribute data to the carbon stock assessment.
	This symbol depicts methods that contribute data to the biodiversity assessments.
	This symbol depicts methods that contribute data to the threat assessment.

3 Mangrove plot sampling

Mangrove plots should commence on the outgoing low tide. Refer to Table 1 if crocodile risk is high.

3.1 Identify plot areas

A minimum of three plots should be sampled per site (Figure 1 and Figure 2), to ensure that we capture variation at the site. Ensure plots selected are representative of the site (i.e. don't just pick an area where it looks easier!). If no vegetation is present (for example in highly degraded or cleared sites) use distance from the water edge to select plot locations.

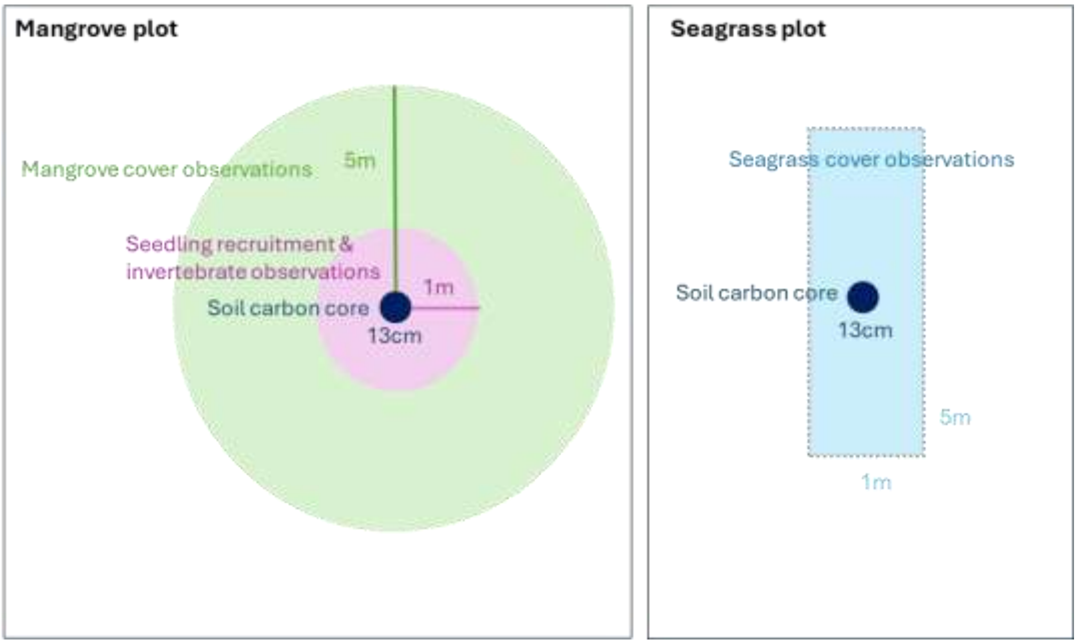


Figure 3 Representation of plot layout, showing core at the centre of each plot and different plot dimensions for mangrove and seagrass plots (note that 3 plots are needed per site as per Figure 1). Mangrove plot size can vary between 2 and 10m radius if mangrove density requires it (note we are seeking to capture a minimum of 20 trees per plot). Ensure plot radius and dimensions are recorded.

The following steps are for one mangrove plot. All of these steps are to be repeated in each plot.

1 Identify the locations of the sample plot within the first mangrove site, selecting areas for each plot that appears to be characteristic and representative of mangroves at the site. One person stands in the centre of the plot and another walks with the measuring tape to end of the plot radius (e.g. 5 m). If required mangrove plot size can vary between 2 and 10m diameter if mangrove density requires it. We are seeking to capture a minimum of 20 trees per plot. Plots can also be rectangular if required, ensure dimensions are recorded.

Record:

- The date, assessor/s and time,
- The general location,
- The site (use a descriptive term, ideally one that matches the local community's description),
- The plot number,

- The GPS location at the centre of the plot by marking a point in the GPS and writing the coordinates on the datasheet for redundancy, and
- The radius of the plot.

2 **Photograph** the plot. Use a wide angle setting on camera, if available. Photograph each plot from the following perspectives:

- looking in the direction of the terrestrial edge of the mangrove forest (face your back to the sea), and
- perpendicular to the coastline, in both directions.

3.2 Carbon measurements and sampling

3 Identify and record the DBHs of all mangrove species present within the plot as per the instructions below.

DBH measuring guidelines:

a. Use DBH side of DBH tape (circumference can be measured instead but remember to record if measuring DIAMETER or CIRCUMFERECE). Callipers may be used for smaller trees.

b. record DBHs of all stems over (live and dead) > 5 cm (~2 cm width), including lianas, palm fronds and standing dead trees. If practical, measure at 1.37 m above the ground – this is the diameter at breast height.

c. Use chalk to mark the trees once recorded

d. Record whether the plant is dead or alive. If dead, note the decay status for the tree (see *decay statuses* below).

e. Record DBH to an accuracy of 0.1 cm

f. Measure the main branch of each tree. If multiple stems are present and split at ground level, measure each separately. If the main branch is above the ground, measure this, even if below breast height

g. For species with stilts (*Rhizophora spp.*), measure DBH above the stilts but below the main branch.

h. For trees with tall buttresses exceeding 1.37 m above ground level, measure directly above the buttress.

i. Avoid measuring on branch whorls or thickenings associated with branching.

j. Record at least 20 trees/plot

Species identification guidelines:

a. Observe the leaves, bark, flowers and fruits (if present) and match to the key features identified in location specific mangrove species guides.

b. As much as possible identify mangroves to species, if not to genus level.

c. If species cannot be matched to one in the Species Guide mark as Sp1, Sp2 etc. Take photos of the plant (the whole plant and close-ups of the leaves (both sides), bark, flowers, fruit and branching pattern, each from different angles). Make note of the presence of stilts or pneumatophores. Remember to record which species number is associated with which photos. Taking a photo of the label on the worksheet before and after the last plant photo is a good way to keep track. If you encounter another plant that looks similar to your previous numbered plants, use the same number for each successive plant.

Decay status of dead trees*:*

a. Status 1 trees are recently dead and maintain many smaller branches and twigs.

b. Status 2 trees have lost small branches and twigs, and a portion of large branches.

c. Status 3 applies to standing 'snags', where most branches have been lost and only the main stem remains. The main stem is often broken.

Source: Kauffman and Donato 2012[18]

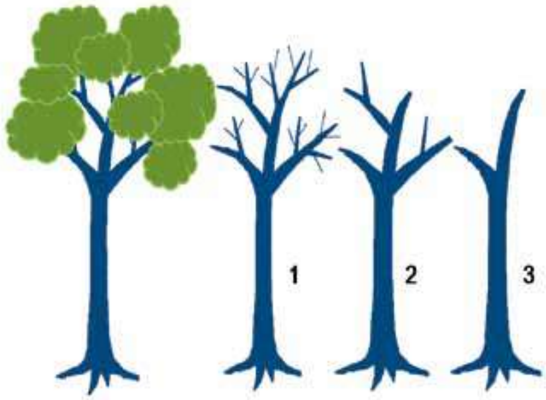


Figure 4 Photos of a team collecting DBH measurements for intact and degraded mangrove plots

5 **Collect soil carbon samples.**

At the centre of the plot collect and sample a single soil core as per the instructions below.

Soil core sampling guideline:

[18] Kauffman, J.B. and Donato, D.C. 2012 Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.

a. At the sampling location, the organic litter and living leaves, if present, should be removed from the surface before inserting the corer.

b. Steadily insert the coring device vertically into the soil until the top of the corer is level with the soil surface. The descent rate of the core has to be kept low (e.g., gentle hammering) to minimise core compaction. If the coring device will not penetrate to full depth, do not force it, there may be a large root or coral fragment in the way; instead try another location. If significant compaction has occurred, take another core nearby. If compaction is unavoidable, record length of sample recovery and core penetration length (depth of the hole) (a compaction correction factor can be calculated by dividing the length of sample recovery by the length of core penetration).

c. Once at depth, twist the coring device to cut through any remaining fine roots. Gently pull the coring device out of the soil while continuing to twist as it is being extracted. This twisting assists in retrieving a complete soil sample.

d. Record soil core depth and depth of hole (if compaction has occurred).

e. Using and spatula (or knife) cut excess sample off the top and along the length of the corer and discard.

f. Place a ruler/measuring tape along side the core device and soil sample, then take a photo of the core (remember to take note which plot this came from – taking a photo of the data sheet before and after core photo is a good technique).

g. Draw a diagram of the layers of the core, noting the depth of each layer.

h. Describe the soil texture of each layer (i.e., sand, gravel, silt, peat, organic matter, shells, grey clay, yellow clay etc)

i. Split the core into the following segments:

   0-15 cm

   15-30 cm

   30-50 cm

   50+ cm

j. Take four 3 cm samples from each segment that are representative of the texture of each segment and place each in a small, sealed bag. Label bags with Location, Site, Plot and sample Depth.

k. Place all four core samples into a larger sample bag and label.

l. Keep samples in a cool, dry place until processing (e.g. cooler bag or ice box)

Figure 5 Photos of a team collecting soil cores for a mangrove site

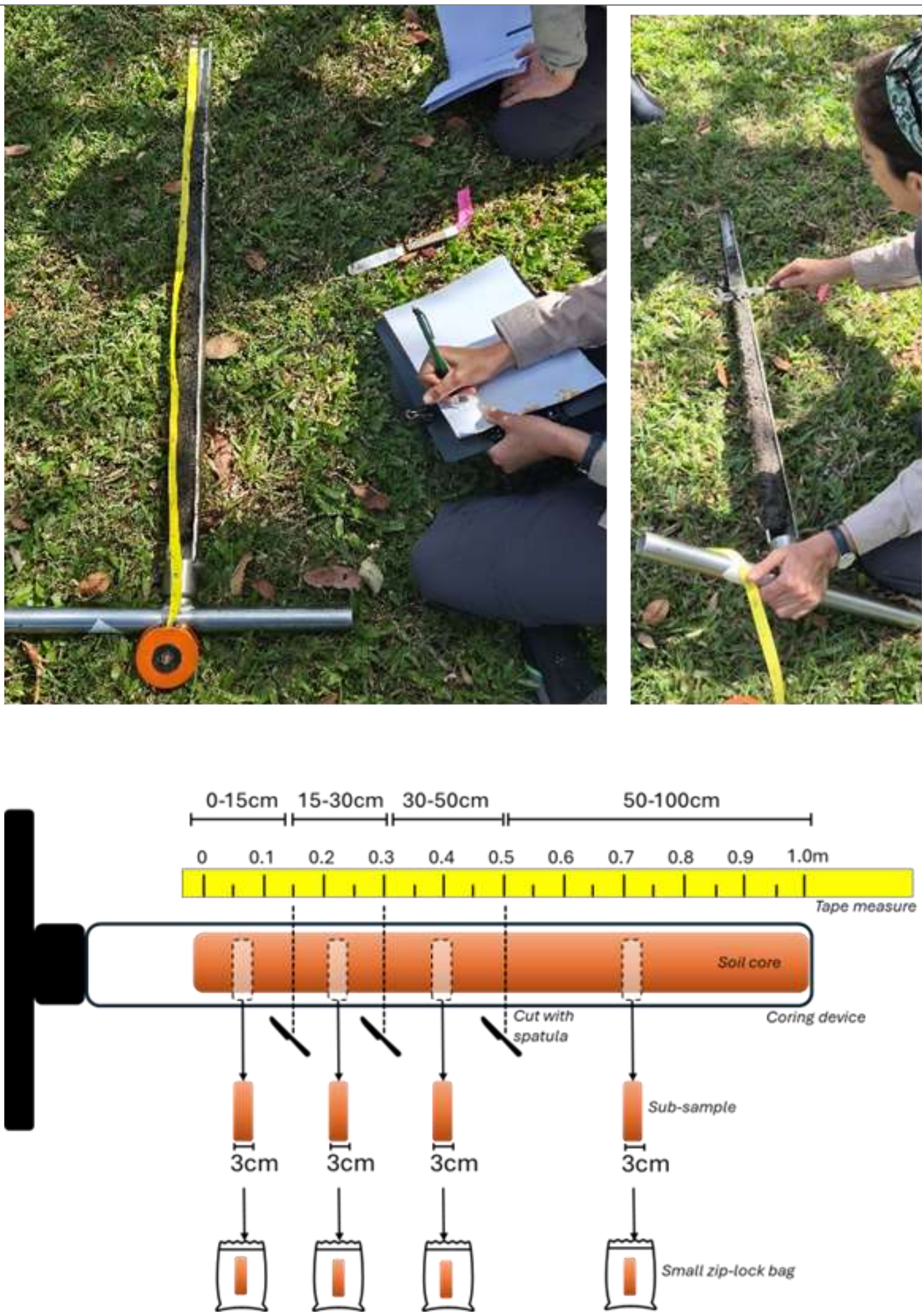


Figure 6 Diagram and photos demonstrating the method for sub-sampling a soil core

3.3 Biodiversity measurements

6 Through-out the day, keep an eye out and record any observations of notable fauna within the site area. Make a tally of the number of different species you observe at each site for:

a. Birds,

b. Marine macrofauna

c. Invertebrates (crustacean, gastropods, bivalves)

Note, this data is to be collected at site level, not plot level.

7 Throughout the day, keep an eye out for additional flora observations, within the site and plot areas:

a. Record a <u>count estimate of seedlings/saplings to 50cm</u> tall across the whole of **plot**, using the following four categories:

- 0-10
- 10-50
- >50
- NA

Anything with woody root structures (stilts for Ryzophore), or if Bergaria, and more than 0.5 m high, it is not counted as a seedling.

b. Record all plant species observed in the **site** area (i.e. create full flora species list)

Outside of the plots, if a new mangrove species is identified, record it. These recordings allow for rare endemic species to be captured, if present but need to be recorded separately to the area-based method.

Note, all the above data is to be collected at site level, not plot level.

8 At the centre of the mangrove plot, in a 1m diameter sub-plot area (preferably within an area that has not been trampled), record the following:

a. Count crab holes and measure their size.

b. Estimate mollusc (gastropods and bivalves) diversity by grouping per size and shape of shells. Estimate abundance of each taxon group; 0-10; 10-50; >50 individuals.

3.4 Threat estimates

9 Estimate canopy cover and disturbance impact using *Table 6*[19] below.

10 Rate the threats listed in Table **7** using the threat indicator and rating descriptions provided in Appendix F (MarECAT) of Cadier et al 2024[20].

Threats are rated from 0 to 5. Rate threats at both the site (i.e. "habitat scale", up to 1000m from the site) and also the landscape/seascape scale (i.e. within 1-5km from site), where relevant. Select ratings using information from discussions with the local community, general observations or images from drone footage.

Table 6 Guide to canopy cover estimates

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

[19] Patrick, Brian, SPREP. (2014). Guidelines for Undertaking Rapid Biodiversity Assessments in Terrestrial and Marine Environments in the Pacific. Wildlands, SPREP, Australian Aid.

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

Table 7 Threat indicators for mangrove and seagrass sites. Modified from Cadier et al. 2024[21]. HS = habitat scale (<1000m from site), LS/SS = landscape/seascape scale (1–5 km from the edge of site).

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

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

4 Seagrass plot sampling

Where crocodile risk is low, intertidal and subtidal seagrass sites can be done on foot around low tide. Depending on depth a boat may be required for subtidal plots. Where crocodile risk is high, all seagrass sites should be sampled by boat.

4.1 Identify plot areas

A minimum of three plots should be sampled per site, to ensure that variation at the site is captured. Ensure plots selected are representative of the site (i.e. don't just pick an area where it looks easier!).

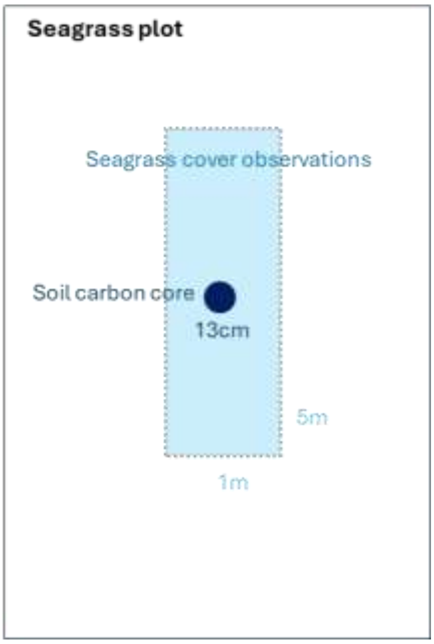


Figure 7 Representation of plot layout, showing core at centre of each plot, noting that three plots are required per site.

1 Walk out to the *intertidal zone* for seagrass and select a 1 x 5m plot area that is representative of the overall area observed on the intertidal bank (refer to diagram Figure 2). Record the GPS location by marking a point in the GPS and writing the coordinates on the datasheet for redundancy.

2 Photograph a 1 x 1m portion of the plot from directly above, ensuring all boundaries of the plot parameter is visible in the photo (Figure 8). Ensure the GIS location tagging is turned on in the camera (if GPS camera available). Measuring tape or ruler may be used for reference, if four-sided quadrat is unavailable.

Figure 8 Example of seagrass quadrat photo showing square quadrat boundary and letter-number combination quadrat label[22]

4.2 Intertidal zone – carbon measurements and sampling

3 Collect soil carbon samples.

Soil core sampling guideline:

Different methods may to used depending on the level of inundation at the time of sampling or sediment characteristics of the seagrass site. Here we present two methods. Others may be used. Most important is to: 1) collect a sediment sample that has been minimally compacted, 2) that the volume and depth of the sample is known and recorded, and 3) that at least one sample is taken at the surface and at depth (even if some digging is required) for each plot. Characterising and capturing the depth of the organic layer is the priority.

PVC pipe sampler method

Figure 9 Examples of PVC pipe samplers, with 2.5 cm diameter holes at 5 cm intervals. Duct tape is placed over the holes when sampling to create suction. A cap or tap can also be placed on the end of the pipe to increase suction. A cut-off syringe is used to sample from the holes.

[22] McKenzie, L. and Yoshida, R. (2023). Quick guide to monitoring seagrass resources. Sentinel sites permanent transects. Seagrass-Watch HQ. Clifton Beach, Queensland, Australia

At the sampling location, the organic litter and living seagrass, if present, should be removed from the surface before inserting the corer.

c. Cover all PVC pipe sampler holes with duct tape.

d. Steadily insert the coring device vertically into the soil until the top of the corer is level with the soil surface. The descent rate of the core has to be kept low (e.g., gentle hammering) to minimise core compaction. If the coring device will not penetrate to full depth, do not force it. If significant compaction has occurred, take another core nearby. If compaction is unavoidable, record length of sample recovery and core penetration length (depth of the hole) (a compaction correction factor can be calculated by dividing the length of sample recovery by the length of core penetration).

e. Once at depth, twist the coring device to cut through any remaining fine roots. Gently pull the coring device out of the soil while continuing to twist as it is being extracted. This twisting assists in retrieving a complete soil sample.

f. Record soil core depth and depth of hole (if compaction has occurred).

g. Place a ruler/measuring tape along side the core device and soil sample, then take a photo of the core (remember to take note which plot this came from – taking a photo of the data sheet before and after core photo is a good technique).

h. Draw a diagram of the layers of the core, noting the depth of each layer.

i. Describe the soil texture of each layer (i.e., sand, silt, organic matter, etc)

j. Take soil sample by inserting syringe into port (or hole) and place in zip lock bag, ensuring that the following depth classes are represented where possible:

    0-15 cm

    15-30 cm

    30-50 cm

    50+ cm

k. Label bags with Location, Site, Plot and sample Depth.

l. Record syringe volume used, and volume of soil collected.

m. Place all four core samples into a larger sample bag and label.

n. Keep samples in a cool, dry place until processing (e.g. cooler bag or ice box)

Figure 10 Using a PVC pipe to sample in an inundated seagrass meadow. A cut-off syringe is used to sample from holes in the PVC pipe corer. Alternatively, a cut-off syringe may be used to sample directly at the sediment surface.

Syringe core only method

Suitable for inundated seagrass areas, where it is safe to wade in the water.

As per above described method for PVC pipe method, however a cut-off syringe (30-60ml) is used to sampling directly into the sediments. Several depths can be sampled in this way, by first sampling from the surface; then digging to next depth, and sampling directly from sediments at known depth. Record volume sampled and depth sampled at.

4 If very dense and significant seagrass biomass is present, consider collecting living biomass cores using the following method.

Important: This is not an essential step because above ground seagrass biomass is not a big percent contribution to carbon stocks and it can be time consuming to collect and dry.

Warning: drying can take up to 48 hours, ensure there is sufficient time for drying if samples are to be collected.

a. Collect all seagrass biomass from surface of soil core (collected in in step above). Place in sealed bag. Label bags with Location, Site, Plot and sample Depth.

Keep samples in a cool, dry place until processing (e.g. cooler bag or ice box). Process within 12 hours by:

b. Rinse seagrass of all soil material, weigh and record seagrass wet weight for each core sample

c. For three samples only per seagrass species, further process samples to determine dry weight (i.e. rinse seagrass of soil materials, dry using dehydrator for 48 hours, record weight before and after dehydration).

The dry weight will be used to calculate a wet weight to dry weight conversion. This avoids the need to get dry weight for all seagrass cores with significant biomass.

4.3 Intertidal zone – biodiversity

6 Record percent cover per seagrass species, coral, macroalgae, sand, mud, rubble, and rocks.

7 Record any fauna present and count number of species of: Fishes, Sea cucumbers, Sea stars, Molluscs, Crustacean

4.4 Intertidal zone – threats

8 Rate the threats listed in Table 7 using the threat indicator and rating descriptions provided in Appendix F (MarECAT) of Cadier et al 2024[23]. As described in above in section 4.1.4.

4.5 Submerged seagrass plots

10 Once on the boat and positioned to roughly align with the intertidal plot location, record the GPS location and write on the field sheet.

11 Set the underwater camera to record and lower the camera on the pole to within a few centimetres of the sea floor over the seagrass meadow. Observe an area approximately 1m x 5m.

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

12 If possible, take a soil core from the boat (do not enter the water due to safety risks), as per the instructions for intertidal zone. The water depth may limit the depth of the sample core in submerged seagrass plots. Aim to collect a core to 1m depth if it is safe to do so, however any depth ≥15cm will provide valuable data.

If a soil core is not possible (due to safety reasons or sediment consistency), take a surface sediment grab sample using the following instructions.

Sediment grab surface sampling from a boat:

a. When over the site, deploy the grab sample as per factory instructions. Try to hold the boat steady to ensure the sampler doesn't drag on the bottom.

b. *Note: The grab sampler model we use automatically collects a sample when in contact with the sediment surface (other models may require that you send a weighted messenger down the line to trigger sample collection).*

c. *Warning 1: For safety reasons always keep hands and feet clear of the 'jaws' prior to deployment.*

d. *Warning 2: Where croc risk is present, stand back from the edge of the boat during deployment/retrieval and DO NOT hang arms, legs or body over the side of the boat.*

e. Collect a surface sediment sample using the grab sampler.

f. Slowly retrieve the grab sampler and gentle place sample into a tray. Try to conserve the integrity of the sample as much as possible.

g. Photograph the sediment sample

h. Describe the sediment texture (i.e., sand, shells, silt, organic matter, etc)

i. Record depth of sample (likely only 5-10cm)

j. Using a 50ml cut-off plastic syringe, take 1 soil sub-samples. Sub-sample only from sections of the grab sample that best represent the sediments in-situ soil density/integrity.

k. Place each sub-sample in a small, sealed bag. Label bags with Location, Site, Plot and sample Depth.

l. Keep samples in a cool, dry place until processing (e.g. cooler bag or ice box)

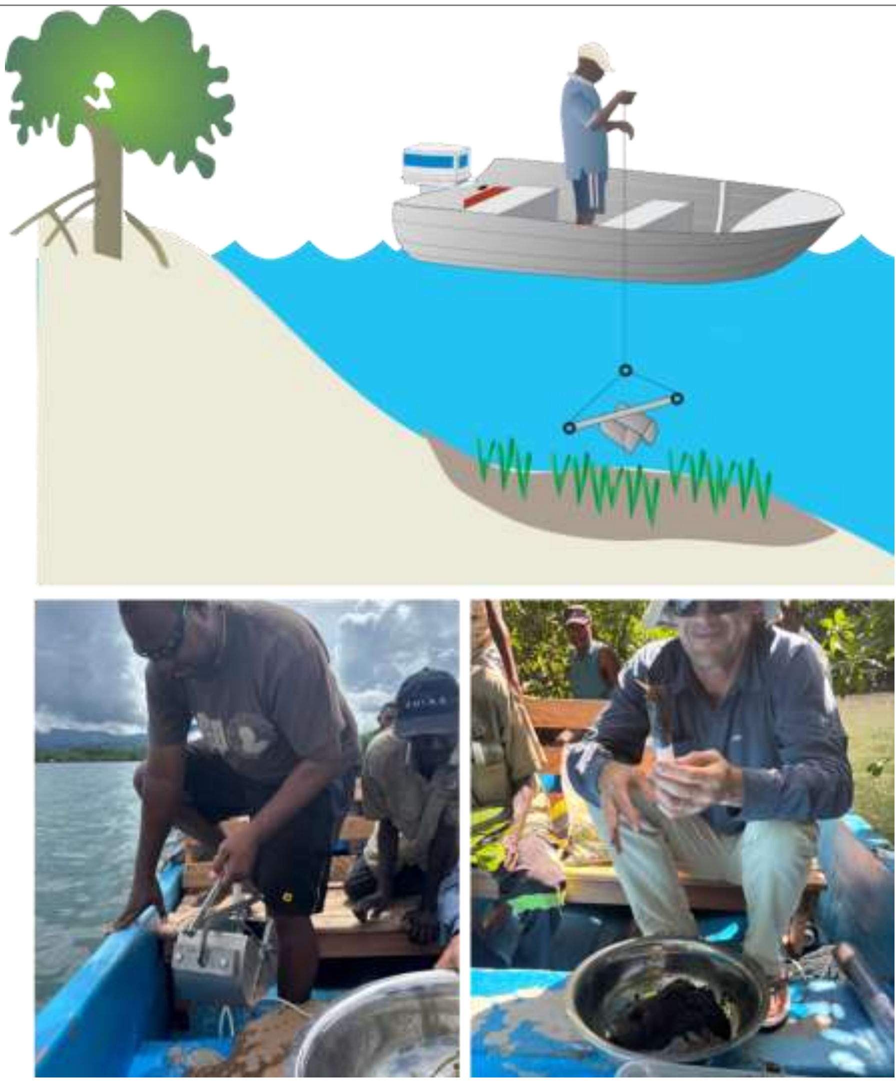


Figure 11 Diagram and photos of sampling submerged sediments using a grab sampler and syringe for sub-sampling.

Figure 12 If available, specialised pole-corers such as this one can also be used for sampling submerged sediments.

13 Photograph the beginning point of the transect from the following perspectives:

a. Looking directing towards the shore.

b. Looking up and down the shore.

		Record the compass bearing that each photo is looking towards.
	14	Record any fauna seen and count the number of species (birds, turtles, dolphins, sharks etc).

5 Processing soil core samples

Soil core samples must be dried within 12 hours of collection.

10 Dry soil samples within 12 hours of collection as per the instructions below.

Soil sample drying guideline for carbon analysis:

- Place one soil sample on one small aluminium pie plate. Label pie plate by writing on the bottom with a blunt pencil (this will create an indent/emboss that will not disappear in the drying process)
- Repeat for all soil samples collected from a single site.
- Place all samples in a food dehydrator or oven at 60 C for minimum of 12-24 hours, or until dry.
- Once dry, store dried samples in labelled sealed (zip lock) storage bags.
- Send all samples to laboratory for processing and carbon analysis.

Note*: If sending soil samples internationally for laboratory analysis, some countries (notably Australia) will require radiation treatment for biosecurity reasons. Radiation treatment does not affect sediment samples to be processed for carbon analysis.*

Figure 13 Photo of soil core samples being prepared for dehydration.

Appendices

Appendix A

Field Sheets

*Required field

SITE DATA - Admin

Country *	
Location*	
Site ID*	
Date *	
Start Time *	
Assessors *	
Photo taken	Whose camera*: Time taken:

SITE DATA – Site Context

Only fill in either Mangrove or Seagrass

Mangrove		Seagrass	
Geomorphology types*	Riverine Tidal Creek Open Coast Calcareous Island Lagoon	Geomorphology types*	Riverine Tidal Creek Open Coast Calcareous Island Lagoon
Land-use conversion*	Intact Degraded Converted	Land-use conversion*	Intact Degraded Converted
Mangrove Strata/ tidal zone*	Seaward/low tide Mid-zone High tide	Seagrass Strata/ tidal zone*	Submerged Intertidal zone
Mangrove Site Notes		Seagrass Site Notes	

Date*: ____________Site ID*: ___________________ *Required field

SITE DATA – Biodiversity

Categories can include flora, birds, marine macrofauna, invertebrates (crustaceans, gastropods, bivalves).

Category *	Species / Genera	Tally/Count	Abundance * 0-10, 10-50, 50-100, 100+	Description	Photo time/ whose camera
e.g. Birds	*Bird 1*	*III or 3*		*White with black head*	*9:40, SN phone*

Date*: ____________Site ID*: ___________________ *Required field

SITE DATA – Biodiversity

Categories can include flora, birds, marine macrofauna, invertebrates (crustaceans, gastropods, bivalves).

Category *	Species / Genera	Tally/Count	Abundance * 0-10, 10-50, 50-100, 100+	Description	Photo time/ whose camera
e.g. Birds	*Bird 1*	*III or 3*		*White with black head*	*9:40, SN phone*

Date*: ____________Site ID*: ___________________ *Required field

SITE DATA – Threats

Threat indicators table: to be filled in where possible in the field. HS = habitat scale (default of 1000 m from the edge of habitat) and LS/SS =landscape/seascape scale (1–5 km from the edge of the habitat depending on the indicator).

Threat Indicator	**Scale** (0 – 5 where 0 = high threat and 5 = no threat)		**Specify threats observed***
	LS/SS*	**HS***	
T1. Major hydrological modifications (LS/SS)		NA	
T2. Minor hydrological modifications (HS)	NA		
T3. Inflow from land activity (HS)	NA		
T4. Sediment resuspension (HS)	NA		
T5. Land Use (LS/SS)		NA	
T6. Sea Use (LS/SS and HS)			
T7. Native habitat conversion (LS/SS and HS)			
T8. Species collection and harvesting (LS/SS and HS)			
T9. Non-preferred species (LS/SS and HS)			
T10. Extreme events (LS/SS and HS)			

Threat Notes:

Date*: ____________Site ID*: ___________________ *Required field

PLOT DATA – SEAGRASS

Plot Number	1	2	3
Plot size	1 x 5 m	1 x 5 m	1 x 5 m
Plot photo	Whose camera*: Time of photo*: Aspect of photo:	Whose camera*: Time of photo*: Aspect of photo:	Whose camera*: Time of photo*: Aspect of photo:
Plot Notes			
Which/whose GPS	Whose GPS*: GPS Number*:	Whose GPS*: GPS Number*:	Whose GPS*: GPS Number*:
SEAGRASS	(circle relevant categories)		
Seagrass % cover*	0-10 51-75 11-30 76-95 31-50 96-100	0-10 51-75 11-30 76-95 31-50 96-100	0-10 51-75 11-30 76-95 31-50 96-100
Algae % cover*	0-10 51-75 11-30 76-95 31-50 96-100	0-10 51-75 11-30 76-95 31-50 96-100	0-10 51-75 11-30 76-95 31-50 96-100
Substrate % cover*	0-10 51-75 11-30 76-95 31-50 96-100	0-10 51-75 11-30 76-95 31-50 96-100	0-10 51-75 11-30 76-95 31-50 96-100
Substrate description*			
Seagrass canopy height (cm)*			

Date*: _____________Site ID*: ____________________ *Required field

Plot 1		Plot 2		Plot 3	
Seagrass species*	**%cover*** (per seagrass species)	**Seagrass species***	**%cover*** (per seagrass species)	**Seagrass species***	**%cover*** (per seagrass species)

Date*: ____________Site ID*: ___________________ *Required field

PLOT DATA – SEAGRASS

Plot Number	4		5		6	
Plot size	1 x 5 m		1 x 5 m		1 x 5 m	
Plot photo	Whose camera*: Time of photo*: Aspect of photo:		Whose camera*: Time of photo*: Aspect of photo:		Whose camera*: Time of photo*: Aspect of photo:	
Plot Notes						
Which/whose GPS	Whose GPS*: GPS Number*:		Whose GPS*: GPS Number*:		Whose GPS*: GPS Number*:	
SEAGRASS	(circle relevant categories)					
Seagrass % cover*	0-10 11-30 31-50	51-75 76-95 96-100	0-10 11-30 31-50	51-75 76-95 96-100	0-10 11-30 31-50	51-75 76-95 96-100
Algae % cover*	0-10 11-30 31-50	51-75 76-95 96-100	0-10 11-30 31-50	51-75 76-95 96-100	0-10 11-30 31-50	51-75 76-95 96-100
Substrate % cover*	0-10 11-30 31-50	51-75 76-95 96-100	0-10 11-30 31-50	51-75 76-95 96-100	0-10 11-30 31-50	51-75 76-95 96-100
Substrate description*						
Seagrass canopy height (cm)*						

Date*: _____________Site ID*: ____________________ *Required field

Plot 1		Plot 2		Plot 3	
Seagrass species*	**%cover*** (per seagrass species)	**Seagrass species***	**%cover*** (per seagrass species)	**Seagrass species***	**%cover*** (per seagrass species)

PLOT DATA – BIODIVERSITY (mangroves only)

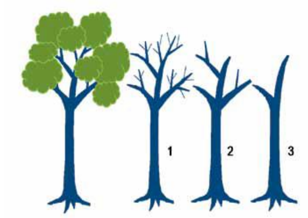
BIODIVERSITY PLOT DATA	Plot 1 (quadrat 1 x 1 m)	Plot 2 (quadrat 1 x 1 m)	Plot 3 (quadrat 1 x 1 m)
Crab hole size (circle relevant categories)	0-5mm 5-10mm 10-20mm 20-50mm 50+mm	0-5mm 5-10mm 10-20mm 20-50mm 50+mm	0-5mm 5-10mm 10-20mm 20-50mm 50+mm
Total Number of Crab holes	0-10 10-50 50+	0-10 10-50 50+	0-10 10-50 50+
Plot invertebrate notes			

BIODIVERSITY PLOT DATA	Plot 4 (quadrat 1 x 1 m)	Plot 5 (quadrat 1 x 1 m)	Plot 6 (quadrat 1 x 1 m)
Crab hole size (circle relevant categories)	0-5mm 5-10mm 10-20mm 20-50mm 50+mm	0-5mm 5-10mm 10-20mm 20-50mm 50+mm	0-5mm 5-10mm 10-20mm 20-50mm 50+mm
Total Number of Crab holes	0-10 10-50 50+	0-10 10-50 50+	0-10 10-50 50+
Plot invertebrate notes			

PLOT DATA - MANGROVE

ADMIN	Notes or circle where option
Site ID	
Plot Number	
Plot radius or dimensions	
Plot photo	Whose camera: Time of photo: Aspect of photo:
Plot notes	
MANGROVE PLOT DATA	
#mangrove saplings & seedlings within plot (<50cm tall)	0-10 / 10-50 / >50 / NA
Mangrove %canopy cover within plot	0-10 / 11-30 / 31-50 / 51-75 / 76-95 / 96-100

Mangrove Tree Data



*Decay status = status 1 - recently dead with many smaller branches and twigs; Status 2 - lost small branches and twigs but maintain a portion of large branches; Status 3 - standing stag: most branches lost, main stem remains

Note: record more than one DBH in one line if multiple stems are recorded for the same tree

Tree Species	Alive or Dead	*Decay status	DBH 1 (cm)	DBH 2 (cm)	DBH 3 (cm)	DBH 4 (cm)	DBH 5 (cm)	DBH 6 (cm)	Diam or Circum
e.g. Rhizophora stylosa	*Alive*	*n/a*	*14.5*	*5.7*	*11.3*	*NA*	*NA*	*NA*	*Diameter*

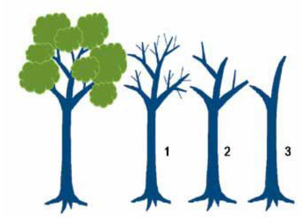
Tree Species	Alive or Dead	*Decay status	DBH 1 (cm)	DBH 2 (cm)	DBH 3 (cm)	DBH 4 (cm)	DBH 5 (cm)	DBH 6 (cm)	Diam or Circum

PLOT NOTES:

PLOT DATA - MANGROVE

ADMIN	Notes or circle where option
Site ID	
Plot Number	
Plot radius or dimensions	
Plot photo	Whose camera: Time of photo: Aspect of photo:
Plot notes	
MANGROVE PLOT DATA	
#mangrove saplings & seedlings within plot (<50cm tall)	0-10 / 10-50 / >50 / NA
Mangrove %canopy cover within plot	0-10 / 11-30 / 31-50 / 51-75 / 76-95 / 96-100

Mangrove Tree Data



*Decay status = status 1 - recently dead with many smaller branches and twigs; Status 2 - lost small branches and twigs but maintain a portion of large branches; Status 3 - standing stag: most branches lost, main stem remains

Note: record more than one DBH in one line if multiple stems are recorded for the same tree

Tree Species	Alive or Dead	*Decay status	DBH 1 (cm)	DBH 2 (cm)	DBH 3 (cm)	DBH 4 (cm)	DBH 5 (cm)	DBH 6 (cm)	Diam or Circum
e.g. Rhizophora stylosa	*Alive*	*n/a*	*14.5*	*5.7*	*11.3*	*NA*	*NA*	*NA*	*Diameter*

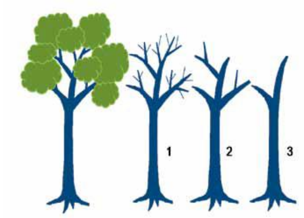
Tree Species	Alive or Dead	*Decay status	DBH 1 (cm)	DBH 2 (cm)	DBH 3 (cm)	DBH 4 (cm)	DBH 5 (cm)	DBH 6 (cm)	Diam or Circum

PLOT NOTES:

PLOT DATA - MANGROVE

ADMIN	Notes or circle where option
Site ID	
Plot Number	
Plot radius or dimensions	
Plot photo	Whose camera: Time of photo: Aspect of photo:
Plot notes	
MANGROVE PLOT DATA	
#mangrove saplings & seedlings within plot (<50cm tall)	0-10 / 10-50 / >50 / NA
Mangrove %canopy cover within plot	0-10 / 11-30 / 31-50 / 51-75 / 76-95 / 96-100

Mangrove Tree Data



*Decay status = status 1 - recently dead with many smaller branches and twigs; Status 2 - lost small branches and twigs but maintain a portion of large branches; Status 3 - standing stag: most branches lost, main stem remains

Note: record more than one DBH in one line if multiple stems are recorded for the same tree

Tree Species	Alive or Dead	*Decay status	DBH 1 (cm)	DBH 2 (cm)	DBH 3 (cm)	DBH 4 (cm)	DBH 5 (cm)	DBH 6 (cm)	Diam or Circum
e.g. Rhizophora stylosa	*Alive*	*n/a*	*14.5*	*5.7*	*11.3*	*NA*	*NA*	*NA*	*Diameter*

Tree Species	Alive or Dead	*Decay status	DBH 1 (cm)	DBH 2 (cm)	DBH 3 (cm)	DBH 4 (cm)	DBH 5 (cm)	DBH 6 (cm)	Diam or Circum

PLOT NOTES: