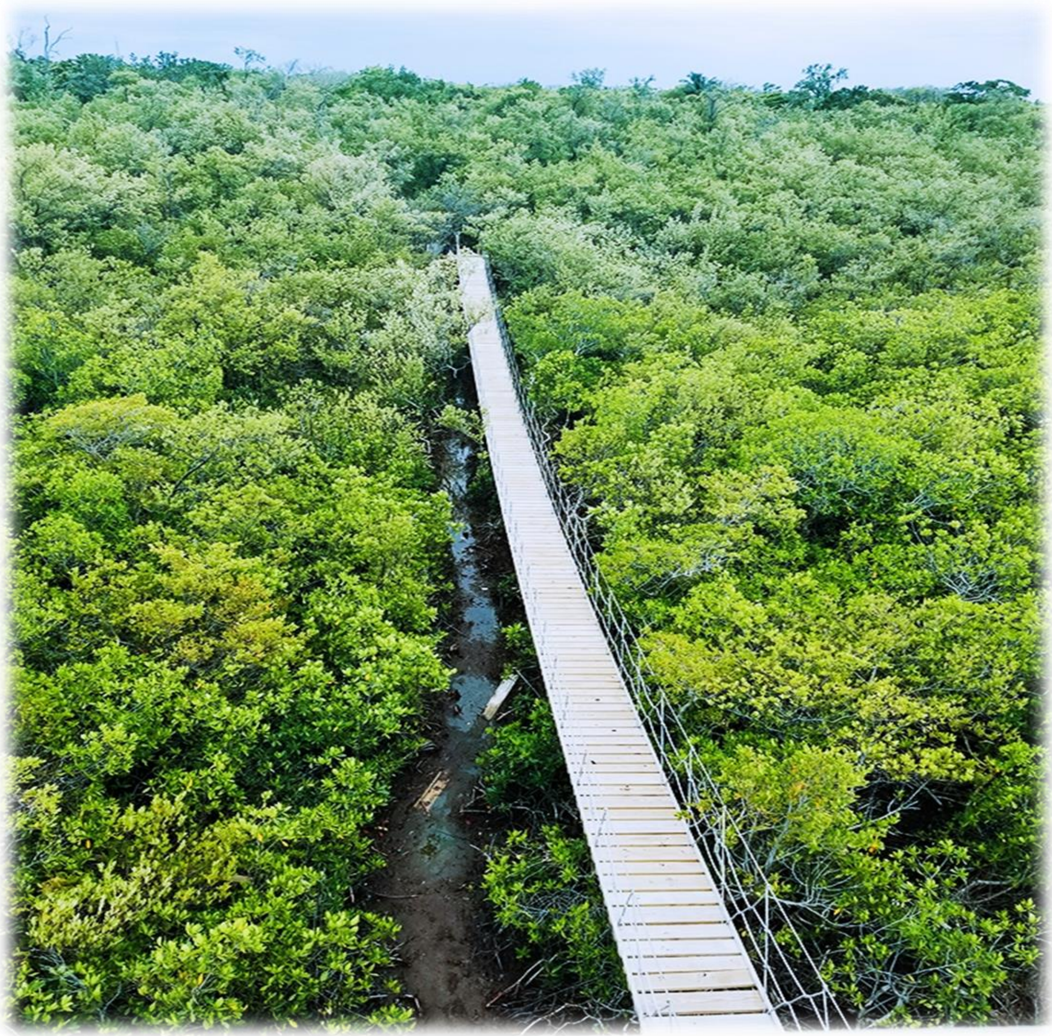
Field Plan for Mangrove Rapid Assessment



Nadia Bood, WWF

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Field Plan for Mangrove Rapid Assessment

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1. Introduction

Mangroves, a remarkable group of diverse plants, have evolved to dominate coastal tidal zones worldwide. These ecosystems vary in form, from 60-meter-tall trees to smaller dwarf shrubs. Adapted to saline and oxygen-deficient environments, mangroves feature unique characteristics like pneumatophores for gas exchange and complex root systems. These adaptations not only enable mangroves to thrive but also create essential habitats for diverse aquatic and terrestrial species. Mangroves are pivotal in preventing soil erosion, enriching the nutrient cycle, and supporting a wide range of biodiversity, including significant marine and terrestrial fauna (Bunting et al., 2018; Chowdhury et al., 2017; Sippo et al., 2018). Their role in carbon dioxide sequestration is increasingly recognized, with their capacity to capture carbon exceeding that of other terrestrial ecosystems such as tropical rainforests (Hamilton & Friess, 2018; J.B. & D., 2012). The Western Indian Ocean is notable for its diversity, hosting around 52 species and 40% of the global mangrove cover. Latin America, Africa, and Oceania are also key regions, with Latin America alone representing 20% of the world's mangrove area (Ricklefs & Latham, 1993).

In Belize, mangroves are dominated by three species: the red mangrove (*Rhizophora mangle*), the black mangrove (*Avicennia germinans*), and the white mangrove (*Laguncularia racemosa*). Each species contributes uniquely to the ecosystem. All mangroves with their characteristic prop roots are important for coastal protection water quality and are habitat for diverse wildlife. Despite their ecological importance, Belize's mangroves face significant threats, mainly from human-induced factors like clearing for development, erosion, and the impacts of climate change (Canty et al., 2018; Cherrington et al., 2010). This highlights the urgent need for effective assessment and monitoring strategies to identify local threats and prioritize restoration efforts.

This field plan has the objective of providing detailed technical guidance for assessing the restoration feasibility of sites across Belize. Specifically, the fieldwork aims to verify information on mangrove condition, drivers of loss and degradation and climate vulnerabilities of potential mangrove restoration sites across Belize. The technical guidance provided draws upon established literature and field experience to provide a method for verifying spatial data and collecting both qualitative and quantitative information. This guide describes the different biophysical factors to be measured in the field, outlining specific data collection methods, materials, data storage methods, and timeline to undertake the fieldwork.

2. Background

Belize's nationally determined contribution (NDC) sets out targets and actions designed to enhance the resilience of critical ecosystems and populations; including timebound quantitative targets for mangrove protection (an additional 12,000 ha) and restoration (at least 4,000 ha) by 2030. To achieve this, a 5-year National Mangrove Restoration Plan for Belize (hereafter the Plan) is being developed which will identify critical areas for restoration on public and private lands as well as contribute to achieving national protection targets. The Plan includes 9 stages (Figure 1) and is led by a multi-sectorial working group integrated by the Belize Forest Department, the World Wildlife Fund Mesoamerica, and Griffith University, Australia.

Conducting field studies to verify information on-the-ground is part of stage number 4 in the development of the Plan. This stage will help validate data on mangrove loss and degradation, and cross-check information on the drivers of loss and climate vulnerabilities that have been identified through the desktop review (stage number 2) and community consultations (stage number 3). The overarching objective of this field plan is to describe in detail the protocol that will be used to support the field studies required as part of stage number 4 in the development of the Plan.

Figure 1. The 9 stages for developing Belize's National Mangrove Restoration Plan.

National-level community consultations were held during October-November 2023 to gather local knowledge around mangrove loss and degradation, ecosystem services, opportunities for restoration, potential and future threats, and previous experiences with restoration. We used participatory mapping to collect this data, where participants used a combination of activity sheets and maps to identify relevant areas in the maps (Figure 2). Consultations included close to 200 participants across 7 workshops, 6 in-person and 1 online. Communities represented included: San Pedro, Caye Caulker, Consejo, Chunox, Copper Bank, Sarteneja, Corozal Town, Dangriga, Hopkins, Seine Bight, Placencia Village, Independence, Monkey River, Punta Negra, Punta Gorda Town, Barranco Village and Belize City. Members of local NGOs, community associations and local government representatives were also present during the workshops. To identify potential restoration sites across Belize we developed a grid consisting of 2,201 hexagons of 200 ha each. This grid overlaps all areas in Belize where there are mangroves according to the Belize Mangrove and Littoral Forest Cover (1980-2019) (CZMAI, 2019). We used this grid during the consultation process to ensure we had a consistent spatial scale at which to assess the restoration potential of different sites across Belize.

Figure 2 Participatory mapping exercise, where local community members provided their input regarding mangrove loss and degradation, ecosystem services, drivers of loss, opportunities for protection and restoration and previous experiences in restoration.

2.1. Site selection

Priority sites to visit were identified through a 4-step process:

1. We analyzed remote sensing products together with the community inputs obtained from the participatory mapping exercise described above (Table 1). This baseline information allowed us to identify mangrove condition, drivers of degradation, and insights on the land tenure of potential restoration sites. From the analysis of this information, we identified a total amount of 6,666 ha of degraded mangroves across Belize.
2. We then classified mangrove degradation extent into two categories: ‘within protected areas and inside abandoned shrimp farms’ (774 ha) and ‘outside protected areas’ (5,892 ha). The outside protected areas category encompasses areas that require further analysis to assess the feasibility of implementing restoration actions. For this fieldwork, we focused on those locations to better understand the condition and land tenure of those sites.
3. Focusing only on the ‘outside protected areas’ category, we conducted an Overlapping Features Analysis (ArcGIS pro-3.1) to identify where two or more baseline layers overlapped. As an agreement across the working group, we prioritized visiting sites to validate community perceptions of mangrove restoration opportunity. We identified a total of 1,097 ha (104 hexagons) of degraded mangroves as perceived by the community that overlapped with at least one more of our baseline layers.
4. We selected xxx ha (xx hexagons) as final sites to visit based on accessibility, representativeness across coastal planning regions and avoiding previous sites from recent ground truthing efforts from the Forest Department and the Smithsonian Institute.

Table 1. Layers used to identify mangrove condition across Belize.

Layer	Source
Abandoned shrimp farms	Dwight Neil (2024, personal communication); Von Unger et al (2021); Coastal Zone Management Institute & Authority (2019)
Community inputs (previous and future restoration)	National consultation process (2023); Dwight Neil (2024, personal communication); Israel Correa (2024, personal communication)
Cyclone damage in the last 5 years (measured using NDVI)	Amaral et al (2023)
Previous ground truthing from Blue Carbon analysis	Morrissette et al (2023)
Abandoned coastal infrastructure	Coastal Zone Management Institute & Authority (2019)
Cleared land that is not adjacent to infrastructure	Von Unger et al (2021)
Community-identified areas of mangrove clearing	National consultation process (2023)

3. Field methodology

3.1. Survey design

For each priority hexagon, we will survey three square plots (5m * 5m) along a transect, each plot will be separated by 20 meters. The transects will be located in areas that are representative of the vegetation within the hexagon but will be ultimately constrained by accessibility. Transects will preferably be located perpendicular to the ocean (Figure 3). Within these plots we will collect physiographic, biophysical, ecological, and anthropogenic data for an on-the-ground assessment of the condition of priority potential restoration sites (Table 2). All measurements will be done at low tide.

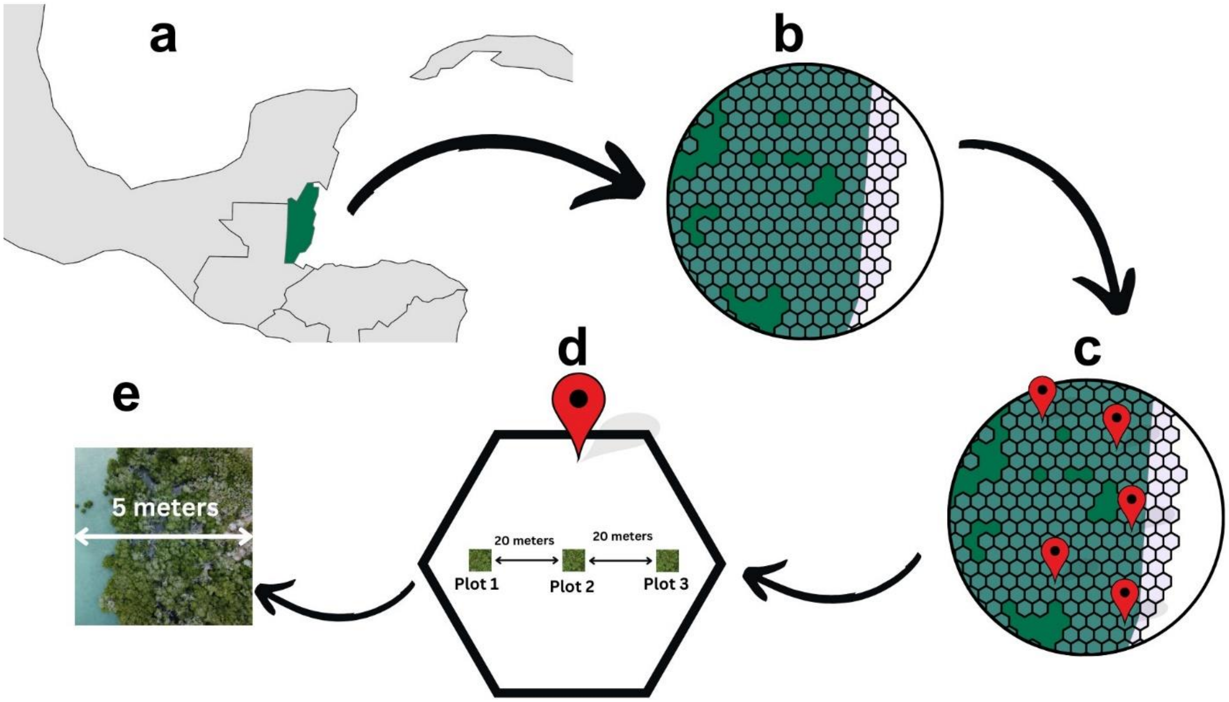


Figure 3 Geographical context and data collection methodology (a) A map showing Belize in dark green within Central America, (b) Pre-made hexagonal units, each covering 200 hectares, will be used to assess the overall condition of mangroves in Belize, (c) Pre-identified priority hexagonal units will be selected. In each selected hexagon, three plots will be deployed for data collection, (d) Due to varying conditions, these plots will be spaced 20 meters apart, either aligned in a single transect line or positioned according to the site's accessibility, (e) Each square plot, with length of 5 meters, will be used to collect field data.

3.2 Factors to measure

Table 2. Summary table of factors to measure for each hexagon, definition, and specific categories for assessment.

Factor	Subcategory		Definition	Categories
Geomorphic Data	*Carbonate Systems		Systems formed by calcium carbonate accumulation from marine life.	• Lagoonal (L) • Open coast (O)
	*Terrigenous Systems		Systems influenced by river and land-based sediment, rich in nutrients.	• Deltaic (D) • Estuarine (E) • Lagoonal (L) • Open coast (O)
	Field categories to cross-check geomorphic spatial dataset		Water body influence	• River • Freshwater creek • Tidal creek • Lagoon • Ocean • Reef
			Substrate	• Clay • Sandy • Carbonate
Physiographic Setting	Mangrove Types		Types of mangroves distinguished by their specific location and environment.	• Fringing (F) • Interior (I) • Overwash (O) • Dwarf (DW)
Biophysical	Redox Potential		Measurement of soil oxidation-reduction status.	Use of redox potential probe
	Salinity		Assessment of salt concentration in water	Measurement with salinity meter or conductivity meter
	**Elevation		Assessment of elevation relative to sea level.	Distance to the ocean and GPS measurements
Ecological	Forest structure	Species Composition	Identification of mangrove species.	• Red Mangrove (*Rhizophora mangle*) • White Mangrove (*Laguncularia racemosa*) • Black Mangrove (*Avicennia germinans*)
		Mangrove height	Average height of mangroves in an area.	• short (<2m) • medium (2-5m) • tall (>5m)
	Vegetation Health	Canopy retreat	Presence of dying or dead trees.	• 1 none (0%) • 2 low (>0 to 30%) • 3 moderate (>30% to 60%) • 4 severe (>60%)
		Mangrove density	Mangrove trees per area.	• Dense (overlapping canopies) • Medium (touching canopies) • Sparse (spaced canopies)

		Seedling density	Number of mangrove seedlings per area.	• none (0/m^2) • few (1/m^2) • some (2-3/m^2) • many (>3/m^2)
Pressures	Degradation Factors	Factors causing mangrove degradation: - Dredging - Erosion - Highways or roads - Urban development - Clearing - Plastic or rubbish pollution - Recreation - Extreme weather events - Resource extraction - Land tenure - Other		• 0% (no impact) • <5% (minimal impact) • 5-25% (low impact) • 25-50% (moderate impact) • 50-75% (high impact) • >75% (severe impact)
	Barriers to Migration	Human-made and natural obstacles affecting mangrove migration. - Small roads - Agriculture - Aquaculture - Highways - Urban development - Sand dunes - Salt pans or lagoons		• 0% (no impact) • <5% (minimal impact) • 5-25% (low impact) • 25-50% (moderate impact) • 50-75% (high impact) • >75% (severe impact)

*To be identified prior to the fieldwork
**To be identified post fieldwork

3.2.1 Geomorphic data

Geomorphology focuses on how landforms influence their distribution and health. We will use the typology described in Worthington et al. (2020). Which divides geomorphic systems in Terrigenous and Carbonate.

Terrigenous systems, influenced by river and land-based sediment, are nutrient-rich and muddy, fostering diverse mangrove forests. Subtypes include:

- **Deltaic**: Recognize these by their expansive fan-shaped plains at shorelines, rich in minerogenic materials. They're dynamic and fertile, dominated by river processes.
- **Estuarine**: Look for these in funnel-shaped channels with bidirectional tidal flows. They accommodate mangroves adapted to fluctuating salinity and sediment conditions.
- **Terrigenous Lagoonal**: Distinguish these from Carbonate Lagoons by their riverine influence and mix of fresh and marine waters, creating varied sedimentation and nutrient dynamics.

- **Open Coast**: Compare these higher energy environments to the sheltered Carbonate Open Coasts. Expect dynamic sediment movements and stronger wave action, influencing mangrove ecology.

Carbonate mangrove systems are formed by calcium carbonate accumulation from marine life like corals and shellfish. They are characterized by nutrient-poor, clear waters and sandy or rocky substrates. These systems typically host mangroves adapted to low nutrients and stable conditions. They are divided into:

- **Lagoonal Systems**: Observe these in organogenic environments behind sand or shingle barriers. These conditions influence specific growth patterns in mangroves.
- **Open Coast Systems**: Identify these in sheltered environments on oceanic islands, often protected by coral reefs and carbonate banks. These low-energy areas offer unique challenges and resources for mangroves.

We will pre-identify the geomorphic setting for our targeted potential restoration sites using the database provided in Worthington et al. (2020). In the field, we will verify this information at the plot level using information on the water body influencing the site (Figure 4) and substrate type (Table 3).

Mangrove ecosystems are shaped by the water around them. Freshwater from rivers and creeks lowers the water's salinity, supporting mangroves that need less salt. Saltwater from the ocean and tidal creeks increases it, making conditions right for salt-tolerant mangroves. Where fresh and saltwater mix, like in lagoons, the environment is brackish and changes with tides and weather, affecting which mangrove species can live there. Mangrove ecosystems are also influenced by the type of ground they grow on. Sandy soils have large, loose particles, leading to quick drainage and less water for mangroves that can't handle dry conditions. Clay soils are tight and sticky, holding water and nutrients but also making it hard for mangrove roots to get air. Carbonate soils, made from broken-down coral or shells, can vary but generally drain better than clay.

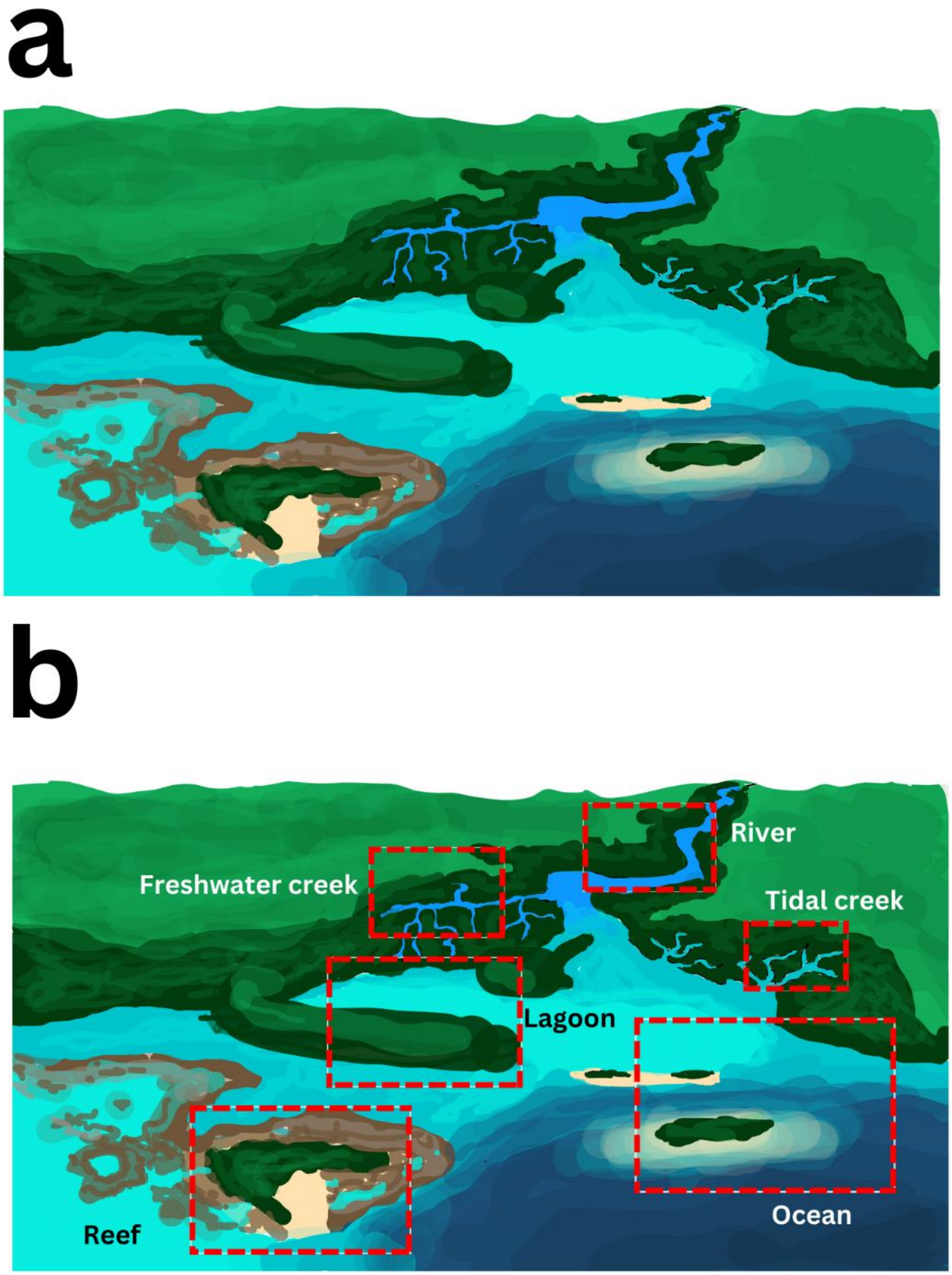


Figure 4 (a) Diagram of mangrove distribution along varying influences of water and substrate (b) and field categories to cross-check with geomorphic spatial dataset.

Substrate type	Diagram
Sand	
Clay	
Carbonate	

Table 3 Different substrate types where mangroves can be present.

3.2.2 Physiographic setting

Physiographic setting encompasses the geomorphic and sedimentary environment and significantly impacts both the structural and functional characteristics of mangroves (Table 4). Physiographic setting is shaped by factors such as climate and tidal amplitude and the geomorphic context. Furthermore, it influences vital ecosystem functions, including carbon storage, coastal protection, and fisheries support. The physiographic setting also affects critical aspects like soil organic carbon density and guides the choice of suitable rehabilitation techniques. We will use the physiographic categories as described in "*The Ecology of Mangroves*" by Lugo and Snedaker (Lugo & Snedaker, 1974) :

- **Fringing Mangroves**: Found along the edges of protected shorelines and islands, fringing mangroves exhibit distinct zonation patterns. They are heavily influenced by tidal movements. The dense and well-developed prop root systems of these mangroves are crucial for trapping organic debris, contributing to coastal protection and ecosystem stability.
- **Interior Mangroves:** These mangroves are typically found in inland areas along natural drainage depressions that channel runoff from the land towards the coast. They are often influenced by the daily tidal fluctuations in adjacent coastal areas. They are typically composed of older, smaller mangrove plants, suggesting an environment with limited nutrient availability, which may constrain their growth and development.
- **Overwash Mangroves**: These mangroves are located on smaller islands and land projections within shallow bays and estuaries. A key characteristic of this type is their regular submergence during high tides, which significantly influences their environmental conditions and species composition, often dominated by species like *Rhizophora mangle*.
- **Dwarf Mangroves:** This type of mangrove forest is found along flat coastal fringes. Despite their small stature, the plants in these forests are often quite old. The limited size of these mangroves suggests a nutrient-limited environment, as they exist in locations with minimal external nutrient inputs, indicating a unique adaptation to these specific conditions.

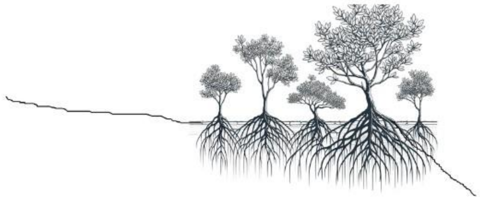
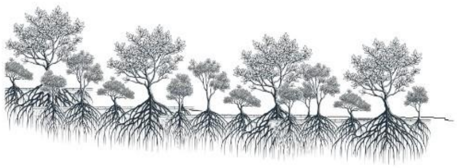
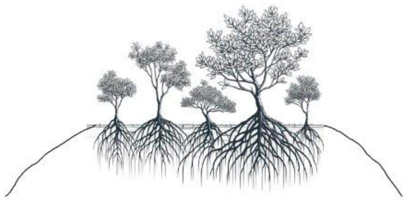
Physiographic setting	Diagram
Fringing	
Interior	
Overwash	
Dwarf	

Table 4 Physiographic Setting of Mangroves: Diagram showcasing various physiographic settings of mangroves, including Fringing, Interior, Overwash and Dwarf mangroves (Lugo & Snedaker, 1974).

3.2.3. Biophysical

3.2.3.1 Redox

The soil oxidation-reduction is indicative of pollution and inundation frequency. Measuring redox potential in mangrove ecosystems begins with the use of a redox potential probe, which typically consists of a platinum electrode paired with a reference electrode. The probe is inserted into the top 2 cm. Three measurements are required to obtain a final average value for each plot.

3.2.3.2 Salinity

Salinity is indicative of water circulation. The primary tool is a salinity meter (conductivity meter), which directly measures salt concentration in water or soil samples. The meter, once calibrated, is used to take readings directly in the water. Regular calibration of the meter is essential to ensure accurate measurements. Three measurements are required to obtain a final average value for each plot.

3.2.3.3. Elevation

Elevation of an area is a proxy for tidal inundation (important for determining the suitability for mangrove growth) and the opportunity for landward migration. GPS data will be used to measure elevation. Data on elevation can also be inferred by measuring the distance between the plot and the ocean.

3.2.4 Ecological

3.2.4.1 Forest structure

- **Species composition**

  Only individuals with a stem diameter of >2.5 cm within the plot are going to be counted.

  Red Mangrove (*Rhizophora mangle)*:

  Characteristics: This species is distinguished by its prop roots, which offer stability in soft sediments and aid in gas exchange. Adapted to a range of water conditions, it thrives in brackish, fresh, and hypersaline environments.

  Habitat: Predominant in the lower to mid-intertidal zones along shoreline edges.

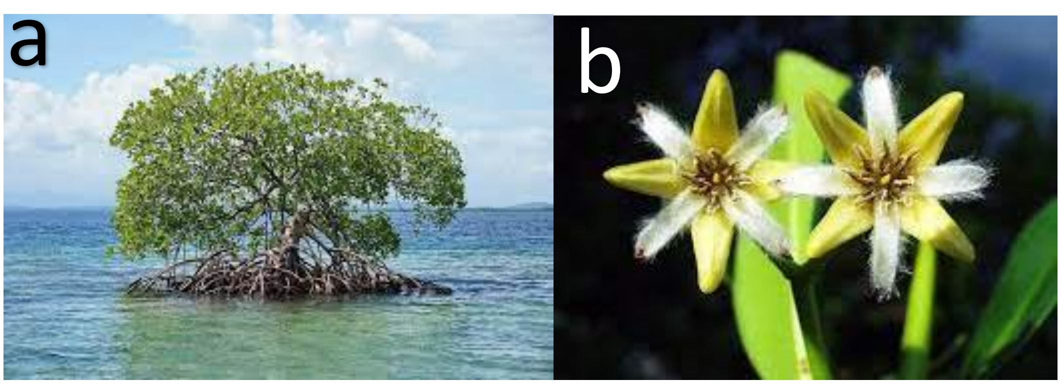


Figure 4 Adult Red Mangrove (a) and flower (b). Mature trees can be from 6 to 15 meters tall. This species can be found in brackish to hypersaline conditions.

White Mangrove (*Laguncularia racemosa*):

Characteristics: This species is identifiable by its light bark, small leaves, and small yellow flowers. It often develops pneumatophores or knee-like roots. The flexible biomechanical structure of *L. racemosa* enables it to withstand strong winds and it may produce prop roots in flooded or anaerobic soil conditions.

Habitat: Often found in brackish waters at slightly higher elevations on the shore compared to other mangrove species.

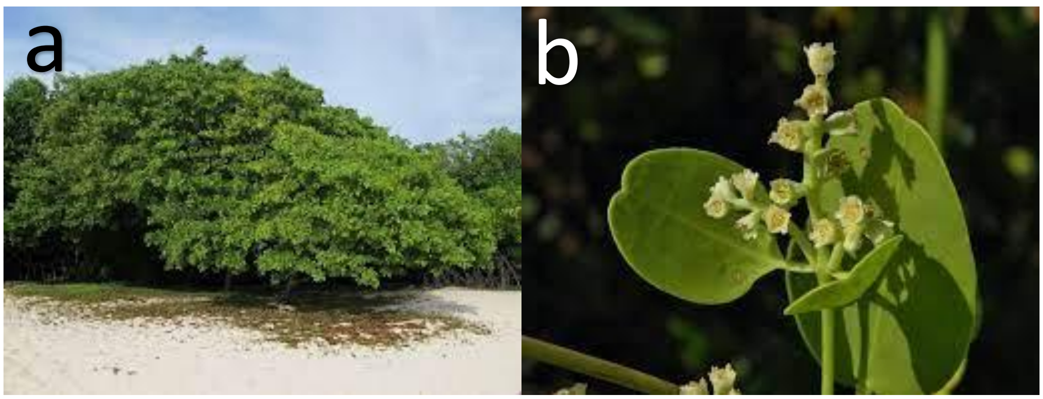


Figure 5 White mangrove depicted in its adult form (a), identified by its 5-15 cm long leaves, and small yellow flowers (b). This species often develops pneumatophores or knee-like roots and healthy mature trees are between 9-12 meters.

Black Mangrove (*Avicennia germinans*):

Special Characteristics: dark bark and leaves with a silvery underside, it features pencil-like pneumatophores up to 30 cm above the soil, coupled with a salt excretion mechanism for high salinity tolerance, visible salt crystals can be seen on the underside of the leaves.

Habitat: Inhabits brackish waters and can survive in hypersaline conditions, usually located at higher elevations in the upper intertidal zone.

Figure 6 Adult black mangrove (a) with pencil-like pneumatophores, and leaves with a silvery underside (b).

- **Mangrove Height:** Estimate and record the average canopy height in each mangrove area. Use the laser rangefinder ARTBULL L5-650 to estimate height. Classify the height as:
  - **short** (<2m)
  - **medium** (2-5m)
  - **tall** (>5m)

3.2.4.2. Vegetation health

We will base the assessment of mangrove health on the "State of the Mangroves Report 2008" by Mackenzie and Duke (2011) :

- **Canopy retreat**: This condition involves thinning or diminishing of the tree canopy, evident through fewer leaves and dying branches. It signals ecosystem stress, typically due to environmental changes like water quality, salinity, temperature, or physical disturbances. Assessment involves observing and categorizing the extent of dead trees in the area.
  - **1** none (0%), no signs of retreat in the mangrove population.
  - **2** low frequencies (>0 to 30%), this is the initial stage of concern where a small but noticeable portion of the trees show retreat.
  - **3** moderate frequencies (>30% to 60%), this category signifies a more serious condition.
  - **4** severe (>60%), this is a critical level of stress and suggests severe environmental challenges or disturbances.
- **Mangrove Density:** Assess space available between trees and canopies into the following categories:

- **Dense** overlapping canopies
- **Medium** visible spacing between stems with touching as opposed to overlapping canopies.
- **Sparse** clear spacing between individual trees and canopies

- **Seedling Density**: Assess the density of mangrove seedlings (trees of less than 0.5m in height) within 1 m^2 of the plot center. Classify seedling density as:
  - **none** (0/m^2)
  - **few** 1/m^2)
  - **some** (2-3/m^2)
  - **many** (>3/m^2)

3.2.5 Natural and anthropogenic pressures

3.2.5.1. Degradation threats

This aspect involves identifying the cause of degradation within the mangrove site. Degradation categories include dredging, erosion, highways, urban development, clearing, plastic pollution, recreation, extreme weather events, resource extraction, other.

- **0 (No Impact):** Assign this score when there is no evidence of degradation factors like dredging, erosion, development, deforestation, or adverse weather events, indicating a pristine or undisturbed mangrove ecosystem.
- **1 (Minimal Impact):** Give this score when degradation factors are present but affect less than 5% of the area. This minimal level suggests only slight interference with the mangroves' health and stability.
- **2 (Low Impact):** Use this score when degradation factors impact 5-25% of the area. This level of impact indicates a low but noticeable effect on the mangrove environment.
- **3 (Moderate Impact):** Apply this score when degradation factors affect 25-50% of the mangrove area. This level of impact points to a moderate degree of harm to the mangrove ecosystem.
- **4 (High Impact):** Allocate this score when degradation factors impact 50-75% of the area. This substantial level indicates a high degree of disturbance and a significant threat to the mangrove's health and survival.

- **5 (Severe Impact):** Use this score when degradation factors impact over 75% of the mangrove area. This severe level of impact denotes extreme disturbance, posing a critical threat to the mangrove's existence and ecological function.

3.2.5.2. Barriers to Mangrove Migration

Barriers to mangrove migration, both human-made and natural, play a significant role in influencing the health and migration patterns of mangrove ecosystems. Human-made barriers include agricultural areas, small roads, highways, and urban developments. Natural barriers encompass features like sand dunes, salt pans, and lagoons.

Scoring for the impact of barriers on mangrove migration is based on the evidence of such barriers, with 5 being no impact and 0 being high impact:

- **0 (No Impact)**: Assign this score when there is no evidence of barriers (0%), indicating free and unobstructed migration pathways for mangroves.
- **1 (Minimal Impact)**: Give this score when barriers are present in less than 5% of the area, suggesting minimal interference with mangrove migration.
- **2 (Low Impact)**: Use this score when 5-25% of the area has barriers, indicating a low level of obstruction for mangrove movement.
- **3 (Moderate Impact):** Apply this score when 25-50% of the area is affected by barriers, pointing to a moderate level of impediment to mangrove migration.
- **4 (High Impact)**: Allocate this score when 50-75% of the area has barriers, showing a high level of restriction on mangrove migration.
- **5 (Severe Impact)**: Use this score when over 75% of the area contains barriers, indicating severe limitations on the natural migration of mangroves.

3.3. Materials and data collection

3.3.1. Field equipment

In field surveys the following equipment will be used:

- 5m, 50m tape
- 2 ribbons 5m long
- 4 sticks with ribbons on tops
- printed datasheets
- pencils
- sharpener
- eraser
- clipboard folders
- chalk
- 1m^2 quadrant (maybe a ribbon one that can be extended)
- redox meter
- salinity meter
- spray bottle with fresh water
- cloth
- icepack
- laser rangefinder
- GPS

3.2. Data storage

Excel template provided

4. Project management

Administrative coordinator

- Co-identify final site selection
- Coordination of logistics (e.g. field support, accommodation, food, transportation (ground and sea))
- Data entry

Technical coordinator

- Field technical coordinator (verification of high-quality data collection)

5. Overall Timeline (example)

	Months				
	May		**June**	**July**	**August**
	1-15	**16-29**	**1-30**	**1-15**	**1-31**
Co-identification of priority sites for ground truthing					
Training sessions (field support)					
Field work					
Data entry into database					

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