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A STANDARD FOR ESTABLISHMENT OF PERMANENT SAMPLE PLOTS IN THE MANGROVE FORESTS OF KENYA

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Cover photo: A section of a permanent sample plot set up by KMFRI in a mangrove plantation in Mikindani, Mombasa. Photo courtesy of Bosco Juma- Big Ship, Mombasa.; Boardwalk at Mida Creek, monitoring mangroves in Kilifi Creek, stumps in mangrove area

Other photos used in the document are courtesy of Judith Okello and Hamisi Kirauni of KMFRI.

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Preface

Permanent sample plots (PSPs) have been used in forestry to gather long term data that guide development and review of management plans. Mangrove ecosystems face multiple threats due to both anthropogenic and natural causes, and establishing status and trends would go a long way to guide sustainable management.

KMFRI came up with simple guidelines in 2014 for establishing PSPs in mangroves and has since applied the same in setting up plots in Lamu- Matondoni, Malindi-Marereni, Mombasa-Tudor Creek, as well as in Kwale- Sii Island and Upper Mwena. Borrowing from the lessons learnt over the years while monitoring, the institute has now prepared this standard to facilitate replication of PSPs in all mangrove patches along the coast of Kenya. While the standard has been prepared for Kenya, it could be modified and applied to the Western Indian Ocean (WIO) due to the numerous similarities known to exist in the mangrove ecosystems across the region.

KMFRI takes cognizant of the challenges facing the marine environment and that keep escalating by the day. As a result, the institute has been in the forefront of conducting innovative research to enhance sustainable utilization of all aquatic resources in the country while enhancing their resilience in the face of emerging threats. This standard provides a step by step approach to setting up sample plots in mangroves for collection of long term biodiversity data.

Prof. James Njiru
Chief Executive Officer KMFRI **Signature:** .....

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1.0 Background Information

Mangrove ecosystems are among the most productive systems globally with multifaceted benefits to the human population. Mangroves of Kenya, for instance, have had a long history of exploitation punctuated with government management actions (incl. bans) underpinned by inadequate data and information for effective implementation. Sustainable management of mangrove forests requires an in-depth understanding of the forest ecosystem dynamics capturing both obvious forest cover loss and cryptic degradation. Permanent sample plots (PSPs) allow "same-location" repeated measurements and monitoring of forest conditions thus facilitating appropriate and timely decision-making whenever need be.

They provide consistent 'local conditions' data and are thus considered an accurate method of detecting change between consecutive inventories. PSPs are generally designed to assist in monitoring and assessing stand dynamics such as succession, regeneration, growth, and mortality through estimation of volume increment, growing stock as well as above-ground forest carbon. These plots are important in evaluating vegetation responses to animal impacts, monitoring canopy dieback in tree species, describing the compositional and structural variation, quantifying changes in forest enclosures, and developing models of forest dynamics. Additionally, forest performance following a given conservation measure can also be evaluated and other related parameters be monitored within the PSP to gauge the effectiveness of such interventions.

The utilization and management of mangrove resources in the country had for a long time been built on the foundational belief that mangroves were inexhaustible. As a result, there has been a lag in creating mangrove monitoring programmes compared to the efforts put into terrestrial forests. It was only until the year 2017 that Kenya developed her first-ever management plan that sought to balance the needs of the people and conservation. This PSP guide builds on the ever-growing efforts to streamline mangrove utilization and management in the country led by the Kenya Forest Service (KFS). It is an important tool in guiding the operations of the national mangrove management plan programs specifically on monitoring and conservation.

1.1 Scope of the standard

This standard provides a minimum criterion for the establishment and re-measurement of parameters within permanent sample plots (PSPs) for purposes of evaluating mangrove forest growth and monitoring their health. Although it is desirable to take into consideration the various indicators of mangrove forest health, including general biodiversity, this standard focuses on vegetation performance.

2.0 General Principles for Setting up PSPs

The following are the six principles of setting up PSPs in mangrove forests but generally also apply to any system.

1. Set a clear objective and scope for setting up the PSP. This assists in defining the project boundaries and the positioning of the plots. The project area may range from a single mangrove forest block to a national-scale assessment. It can also be experimental plots or passive monitoring plots depending on the terms and conditions of the supporting institutions.
2. Decide on the stratification of the project area i.e., the sub-population or sections that form homogenous units. This helps in avoiding biased information on forest conditions.
3. Decide on which parameters to measure during the establishment and subsequent monitoring period depending on your objectives or scope of the assessment.
4. Determine the type, number, and location of measurement plots depending on the purpose of the study. Plot size, layouts, and intensity should be designed with accuracy, sampling efficiency, and safety in mind.

5. The plot shapes can be linear plot arrangement that captures inherent variation along the gradient from the seafront cutting across the tidal flat; use circular or nested plots that measure large trees in a 7m radius, and small trees and seedling in the smaller 2m circular plots. The field operator should also ensure that the project area is accessible but far away from human disturbance.
6. Determine the re-measurement frequency depending on the monitoring intervals which is usually 5 years (Pearson, 2005 and 2007), costs and benefits of the sampling with the focus on and rate of the expected change in mangrove forests such as natural disturbances, carbon sequestration, change in land cover due to land use activities.
7. Each plot should have a unique number/code: This code is a unique identifier and can be randomly placed but for standardization purposes, consider having something to define a site, PSP number, and year of establishment. For example, 3 PSPs established in Tudor creek (Td), Mombasa (Mbs) in the year 2022could be coded as: Td/Mbs/1/2022; Td/Mbs/2/2022, and Td/Mbs/3/2022.

3.0 Materials/Equipment Required

Equipment

- =100 m tape measure
- Diameter tape
- A compass
- High precision GPS
- Panga
- Camera
- Diameter tapes

Materials

- Aluminum pegs
- Maps
- Strings/Rope
- Paint/spray paint/dummy tape
- Sapling tags (different colors)

3.1 Procedure

3.1.1 Locating the permanent sample plots

* This could be based on a major survey that helps identify the areas of interest within the larger mangrove patches defined by 2.1.1.
* Using a standing map, select the location of the permanent plot a-priori within the desired cover type and establish a **tie point** that should be an easy-to-find point and is unlikely to change over time.

* A **disturbance-free zone** (DFZ) of about 50 m, also termed a buffer, is necessary to protect the plot from any activity that might influence the standard dynamics or tree growth is necessary. Onsite inspection may also guide the size of DFZ.
* Make **access notes**: record routes and distance from a point that you can easily remember preferably a permanent land feature or house/village- this is the **tie point**. These permanent land features may also be roads, rivers, bridges, and creeks that are found in proximity to the PSP.
* Make a sketch showing this selected **tie point** and include other significant features relevant to the PSP. The sketch and access notes can be updated in the future should there be a change on the permanent feature which was referenced during the establishment.
* Maintain the tie point in every monitoring campaign in case it is destroyed. Make a new one.
* Record the latitude & longitude ± 1 second or UTM ± 20 m of each PSP Such that each can be identifiable in a 1:20 000 scale map.

3.1.2 Main Plot Establishment

* Using the compass, move on a bearing of 45 degrees from the center and locate the NE corner of the tree plot. Lay a transect of 20 m tape to form one side of the plot, ensuring to put a peg mid section.
* Repeat the same steps in locating the other 3 tree posts using the bearing of SE corner 135 degrees corner 225 degrees and NW corner 315 degrees.
* The entry point to the plot should form the 0,0 (X, Y) reference point (Plate1; fig. 1).
* At least two of the diagonal corners must be stem-mapped to 3 living trees marked/ tagged. E.g., by painting (plate 2). This ensures ease of relocation of the corners. Where there are no large trees close enough to the diagonal corners, mark the corners using permanent paint and attach aluminum pegs.

Plate 1. PSP corners are tree mapped and reference tree clearly marked; where there is no tree at the corner, a peg is used (centre image) and; the next nearest tree mapped and clearly indicated as outside the plot (far right image)

Determine the plot boundaries and Azimuth by running strings between diagonal corner posts.

Note: borderline trees are considered if more than half of the stem at breast height falls inside the plot. (see plate 1)

Note: Ensure the plot is a square or rectangle with right angle corners (fig. 1).

In the case of rectangular plots, the length-width ratio should not exceed 2:1

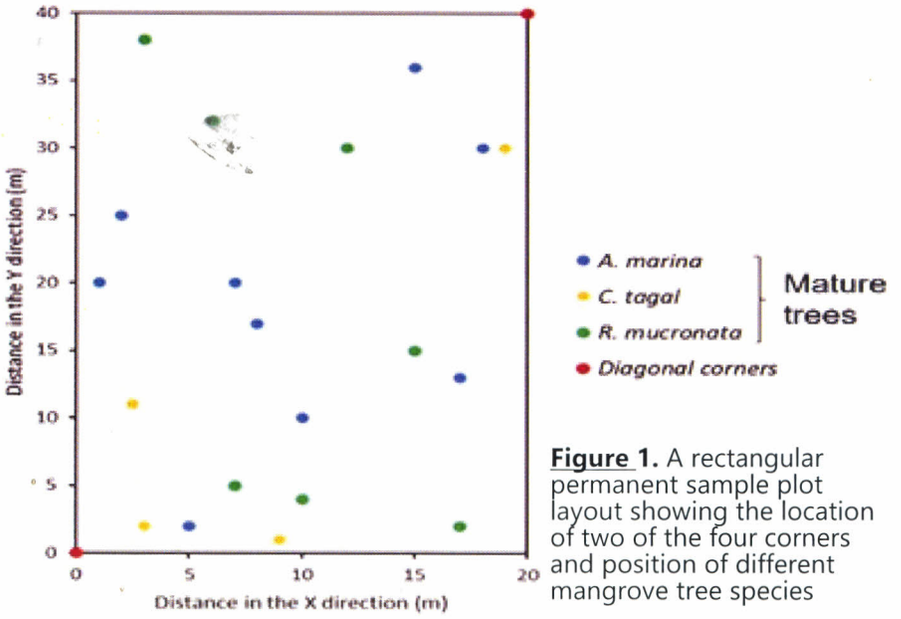


Figure 1. A rectangular permanent sample plot layout showing the location of two of the four corners and position of different mangrove tree species

3.1.3 Establishing a sapling/regeneration plot

Mark the SE corner by placing an aluminum angle post 11.8 m, at an azimuth of 315°, from the plot center. Mark NE and SW corners by running lines north and west respectively from the SE corner to the tree plot. Check the length of plot boundaries. Define the length of boundaries with strings to determine the in and out saplings. Depending on the densities of the natural regeneration, the size of the regeneration band (Fig. 2) could vary from 10m by 40m to 5m by 40m for low and high density respectively.

Note: This must be established even if there is no natural regeneration at the time of setting up the plot.

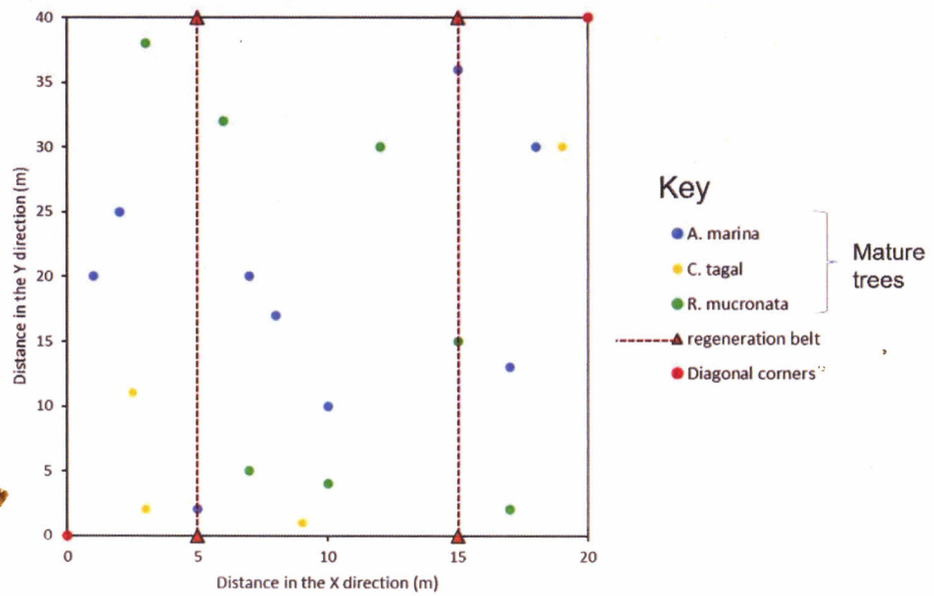


Figure 2. A hypothetical layout of a PSP with a 10 m by 40 m natural regeneration belt laid out at the center of the plot. The position of mature trees within the plot is also shown

Tag the saplings/natural regenerations using material that withstands long-term exposure to variability in environmental conditions characterizing the mangroves. Use different colors to denote the three regeneration classes I, II, and III (plate 2). Ensure that a definite set of criteria (Table 1) is used to categorize a sapling into the various classes to avoid mix-ups during subsequent monitoring campaigns.

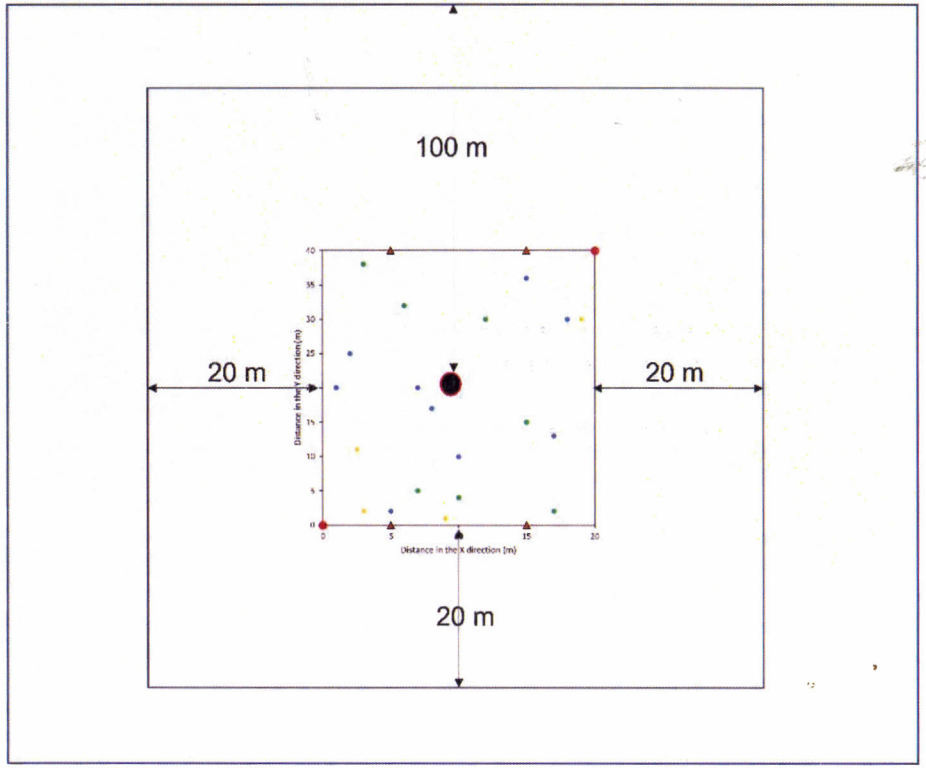
Plate 2. Tagging saplings in a PSP. Here two colors have been used - Red for RCI and blue for RCII.

As a mangrove seedling germinates and develops through the various regeneration classes, there are two sections that can be distinguished. The **hypocotyl** which is the propagule remains and gradually becomes indistinct and develops into woody stem over time; and the **epicotyl** is the section above the hypocotyl which bares leaves (plate 2; Table 1)

3.1.4 Establishment of reservation (buffer) boundary

This is also termed as the disturbance free zone. Run a line using tape and string for 100 m at 360 degrees from the plot center. Using paints (of desired visible color- preferably blue or yellow), mark the trees at 5 m to 10 m intervals for each 20m in each of the cardinal directions creating a square/rectangular-shaped buffer surrounding the plot at eye level (2m above ground) facing away from the plot.

The trees used for buffer corners should be painted using a different color (red) on the two sides facing out from the plot. Also paint NW to indicate the Northwest corner of the buffer NE to indicate the Northeast corner of the buffer, etc. Avoid, if possible, painting dead trees, wind-blown trees, and trees with thick, low-hanging branches. Record the GPS coordinates of all buffer-painted trees.



4.0 Plot Assessment

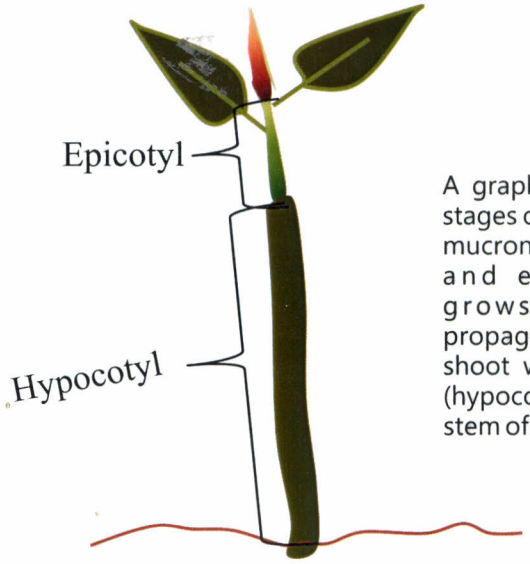
Depending on the objective of setting up the PSP, various forms of data could be collected to inform the conservation and management of a mangrove ecosystem.

It is desirable to collect long-term physico-chemical parameters alongside structural attributes to help explain any associated changes and provide ground for appropriate timely intervention measures where necessary.

Standard data sheets are used but this too may vary from one institution to the other. An organization may also be interested in understanding biodiversity trends by using PSPs. In this case, data on plant species recruitment, tree performance, and faunal composition including avifauna and fish diversity should be collected.

4.1 Mandatory attributes in data sheets

* Name of the site: this is important for placing the PSP in space.
* Names of data collectors: allows for seeking clarification should there be a need in the future.
* Coordinates of the PSP: also important in locating the exact position of the PSP during subsequent monitoring exercises.
* Description of the plot (access notes) this could be as an attachment to your datasheet.
* The data relating to the physical characteristics of that area is collected and recorded in the form attached (Annex II). Additionally, Sediment-Elevation Tables-Horizon Markers (SET-MH) - which are used to measure mangrove surface elevation changes (accretion and shallow subsidence), can be set up within the PSP depending on the PSP objective (see principles).
* Other site attributes of the plot such as slope (±5%), slope position, aspect (±100), and elevation should be recorded to the nearest 50 m.



A graphic presentation of the early stages of development of Rhizophora mucronata, showing the hypocotyl and epicotyl. The epicotyl grows/springs out from the propagule and develops the early shoot while the propagule remains (hypocotyl), later becomes the lower stem of a seedling.

Table1. Criteria for grouping natural regeneration.

Mangrove tree species	Regeneration class	Features to consider	Details
Rhizophora mucronata	RCI	Hypocotyl	Propagule distinct, green
		Epicotyl/Shoot	< 4 pairs of leaves
			<2 internodes
			0-40 cm in height
	RCII	Propagule	Brownish, propagule indistinct
		shoot height	40-150 cm
	RCIII	Total height	>150 cm but DBH <2.5 cm
Ceriops tagal	RCI	hypocotyl	Distinct green -brown propagule
		Epicotyl/shoot	0-40 cm in height
			< 5 internodes
	RCII	Hypocotyl	Indistinct propagule, brown
		Epicotyl/shoot	>5 internodes
			40 - 150 cm in height
	RCIII	Hypocotyl	woody (tree stem)
		Total height	>150 cm height but DBH <2.5 cm
Avicennia marina	RC I	shoot	Tender greenish shoot
		Leaves	< 4 pairs of leaves
	RCII	Shoot	Brownish stem, with at least one branching
	RCIII	Shoot	At least 2 branches and sub -branches
Bruguiera gymnorhiza	RCI	Hypocotyl	Propagule is distinct
		Epicotyl/shoot	< 4 pairs of leaves
			< 2 internodes
			0-40 cm in height
	RCII	Hypocotyl	Propagule indistinct
		Epicotyl	40 - 150 cm in height
			At least some branching
	RC III	Hypocotyl	Woody (tree stem)
		Total height	>150 cm but DBH <2.5 cm

4.2 Accounting for coppice in B. *gymnorhiza*

Bruguiera has been observed to coppice once harvested. Although no comprehensive research has been conducted by KMFRI to understand the general triggers, sometimes the roots also produce shoots that grow to become mature trees (Okello J.A., personal observation- plate 3). Observations have also shown that most of the young shoots emerge from knee roots that display some level of injury or from branch remains that have been cut off.

Since the coppice shoots will grow to become individual trees, the young shoots are considered natural regeneration. RCI constitutes shoots with heights between 5 and 40 cm and have no branching; RCII are those with heights of 40 -150 cm.

Plate 3 From left- A young shoot of **B. *gymnorhiza*** growing from a knee root of a mother tree; Sizeable stems of **B. *gymnorhiza*** noted developing from a knee root; Shoots of **B. *gymnorhiza*** growing from a branch that had been cut. Photos were taken in the mangrove forest of Upper Mwena, South Coast –Kenya (2019) Courtesy of Judith Okello.

Annexes

Annex I : Sample data sheets for collecting vegetation data in PSPs.

DATA SHEET FOR ASSESSMENT OF MATURE TREES IN PSPs

Site name: _____ Plot No/unique code: _____

Plot GPS coordinates_____

Previous monitoring date: _____ Current monitoring date_____

Observers: _____Data Recorder_____

Tree no.	(X,Y)	Species	Height (m)	DBH (cm)	POM	Phenology	comments
Physicochemical parameters:							
Access notes (modifications since plot was set up)							

DATA SHEET FOR NATURAL REGENERATION ASSESSMENT IN PSPs

Site name: _____ Plot No/unique code: _____

Regeneration belt corners X,Y coordinates_____

Previous monitoring date: _____ Current monitoring date_____

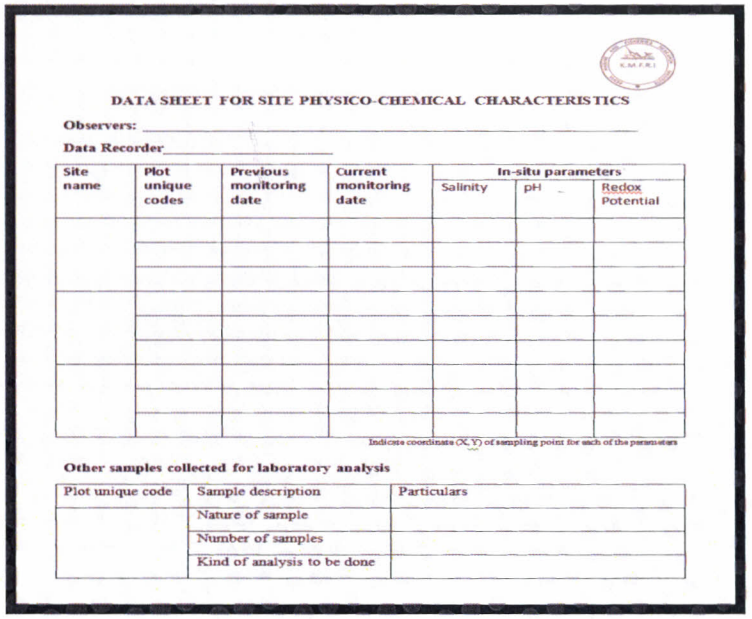
Observers: _____ Data Recorder_____

Tag color	Status	*R.mucronata*	*C.tagal*	*A.marina*	Comment

Status of saplings implies: tags either removed, retained, missing, or dead saplings. Removed implies recruited to the next class. Please indicate whether sapling is recruited to RCII, RCIII or mature. Tag color confirm with previous data to verify which RC the sapling was at the time of tagging. Status of cuttings could be dead or coppicing

Under Status of saplings indicate tags as either removed and replaced with a new one (i.e., recruited to the next class) OR-, retained, OR missing, OR dead saplings. Confirm the existing tag color against previous data and verify which RC the sapling was at the time of tagging.

Annex II: Sample data sheets for collecting



DATA SHEET FOR SITE PHYSICO-CHEMICAL CHARACTERISTICS

Observers: _____

Data Recorder_____

Site name	Plot unique codes	Previous monitoring date	Current monitoring date	In-situ parameters		
				Salinity	pH	Redox Potential

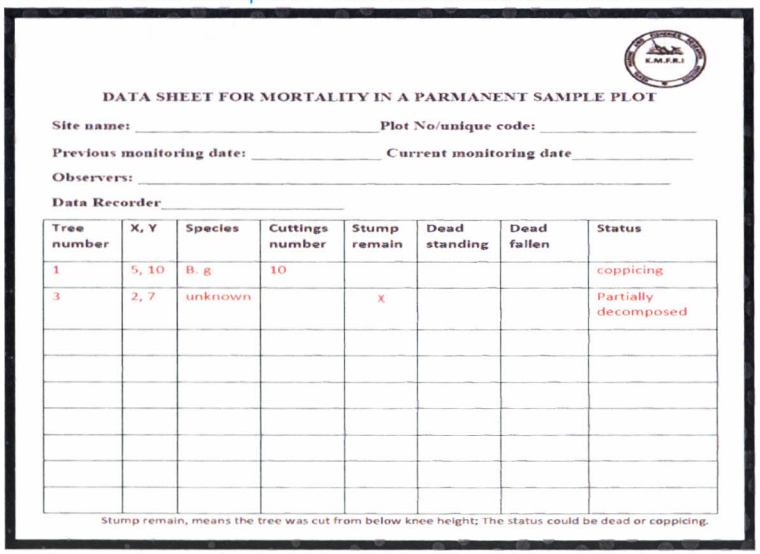
Indicate coordinate (X,Y) of sampling point for each of the parameters

Other samples collected for laboratory analysis

Plot unique code	Sample description	Particulars
	Nature of sample	
	Number of samples	
	Kind of analysis to be done	

Annex III: Sample data sheets for collecting cuttings and tree mortality

In red is an example of what kind of data could be collected



DATA SHEET FOR MORTALITY IN A PARMANENT SAMPLE PLOT

Site name: _____ Plot No/unique code: _____

Previous monitoring date: _____ Current monitoring date_____

Observers: _____

Data Recorder_____

Tree number	X, Y	Species	Cuttings number	Stump remain	Dead standing	Dead fallen	Status
1	5, 10	B. g	10				coppicing
3	2, 7	unknown		x			Partially decomposed

Stump remain, means the tree was cut from below knee height; The status could be dead or coppicing.

Glossary

DBH - Diameter at breast height; In mangrove forests, this is generally measured at 130 cm height or 30 cm above the highest prop root in the case of Rhizophora mucronata. In certain instances where a stand-in question displays retarded growth, the measurement point can be redefined as may be appropriate.

Saplings - this term has been used in the document interchangeably with natural regeneration to mean all young trees with a diameter <2.5 cm and shoot height of between 0-150 cm.

PSP - Permanent Sample Plot; An area within a forest stand that provides geolocated, unique, continuous, and long-term repeat measurement.

References

1.Cherrington, Emil A., et al. "Forest cover and deforestation in Belize: 1980–2010."SERVIR, Cathalac(2010).

2.Gillis, Mark D., A. Y. Omule, and T. Brierley. "Monitoring Canada's forests: the national forest inventory."The Forestry Chronicle.2 (2005): 214-221.

3.Donato, Daniel C., et al. "Mangroves among the most carbon-rich forests in the tropics."Nature Geoscience.5 (2011): 293-297.

4. Picard, Nicolas, et al. "Permanent sample plots for natural tropical forests: a rationale with special emphasis onCentral Africa."Environmental Monitoring and Assessment.1 (2010): 279-295.

5. Priyadi, Hari, P. Gunarso, and M. Kanninen.Permanent Sample Plots, More Than Just Forest Data: Proceedings of International Workshop on Promoting Permanent Sample Plots in Asia and the Pacific Region: Bogor, Indonesia, 3-5 August 2005. CIFOR, 2006.

Fruiting in *Sonneratia alba* at Mida Creek, Kenya 2023. Photo courtesy of Judith Okello