KENYA FORESTRY RESEARCH INSTITUTE

Mangrove Tree Nursery Manual

A guide for mangrove restoration practitioners in Kenya








KENYA Forest Service

KMFRI Kenya Marine and Fisheries Research Institute

SAVE OUR MANGROVES NOW!

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Mangrove Tree Nursery Manual

A guide for mangrove restoration practitioners in Kenya

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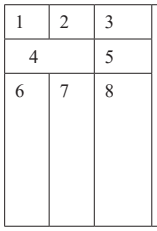

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This mangrove tree nursery manual was published by Kenya Forestry Research Institute (KEFRI), in collaboration with Kenya Marine and Fisheries Research Institute (KMFRI) and Kenya Forest Service (KFS), with funding from the Government of Kenya (GoK) and WWF-Kenya through Save Our Mangroves Now!3 Project.

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FOREWORD

Recognizing the importance of mangroves and the threats they face, the Government of Kenya, through the Kenya Forest Service (KFS) and various stakeholders, developed the National Mangrove Ecosystem Management Plan (NMEMP 2017-2027) to ensure synergy among actors and streamline conservation efforts of mangrove forests. The NMEMP, developed in compliance with the Forest Conservation and Management Act 2016, provides for various aspects of mangroves including; community involvement, sustainable utilization and conservation, and research. Among the issues limiting implementation of these programs is the lack of clear and standardized guidelines.

This manual has been prepared to answer the needs cited under the conservation and utilization programme of the NMEMP. The Kenya Forestry Research Institute (KEFRI) developed this manual informed by; field experiments, secondary materials, observations, experiences, and citizen science. Preparatin of this manual was done in collaboration with the National Mangrove Management Committee, Kenya Marine and Fisheries Research Institute (KMFRI), Kenya Forest Service (KFS) and World Wide Fund for Nature-Kenya (WWF- Kenya), with funding from the Government of Kenya (GoK) and Save Our Mangroves Now!3 Project.

The manual serves as a guide for establishing and managing mangrove nurseries in Kenya, and is a supplementary document to the National Mangrove Ecosystem Restoration Guidelines. The manual aims to empower practitioners and managers of mangroves to produce high-quality, healthy seedlings with improved survival and growth rates upon out-planting, by addressing users' questions and providing informed guidance on seedling production and nursery management. The manual targets mangrove ecosystem management and restoration stakeholders, including non-governmental organizations (NGOs), community-based organizations (CBOs), and governmental agencies.

While laying emphasis on the need to only have mangrove nurseries where and/or when necessary, the manual offers a step-by-step narration of mangrove nursery establishment, including; site selection, collection of propagation materials (seeds or propagules), soil media for seedlings, nursery setup, and sowing. The manual further guides users on: nursery maintenance practices such as shading, nursery pest

and disease management, grading and sorting of seedlings, seedlings preparation for out-planting, monitoring and record keeping. This manual concludes by providing guiding principles to adopt and practices to avoid when establishing mangrove nurseries. Information in the manual is presented in a simple way with necessary photographs and illustrations. Through collaborative efforts, this manual seeks to contribute to the restoration and conservation of Kenya's mangrove ecosystems, preserving coastal environments for future generations while enhancing resilience and livelihoods of coastal communities.

God bless you.

Jane W. Njuguna (PhD)
Director, Kenya Forestry Research Institute

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We also recognize the exceptional contributions of the Community Forest Associations (CFAs) representing communities living adjacent to the mangrove ecosystems. Their provision of vital information and local insights was instrumental in shaping this manual.

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While it is impossible to acknowledge individually all those who contributed to this project, KEFRI extends its heartfelt gratitude to all stakeholders for their diverse and invaluable roles in making this manual a success.

ABBREVIATIONS

CBEMR	Community Based Ecological Mangrove Restoration
CBO	Community-Based Organization
CFAs	Community Forest Associations
COBEC	Community-Based Environmental Conservation
FAO	Food and Agriculture Organization of the United Nations
NGO	Non-Governmental Organization
GoK	Government of Kenya
Ha	Hectares
IPM	Integrated Pest Management
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
KMFRI	Kenya Marine and Fisheries Research Institute
MHWS	Mean High Water Springs
MTL	Mean Tide Level
NMMC	National Mangrove Management Committee
NMEMP	National Mangrove Ecosystem Management Plan
PPT	Parts Per Thousand
sp	Species
UNEP	United Nations Environment Program
WIO	Western Indian Ocean
WWF-Kenya	World Wide Fund for Nature-Kenya

GLOSSARY

Conservation	Sustainable management of natural resources to prevent exploitation, degradation, and destruction.
Dibler	A pointed wooden stick used for making holes in the ground for sowing seeds or planting small bulbs and seedlings with small soil balls.
Epigeal germination	Type of seed germination where cotyledons rise above the soil surface. The part of stem below the cotyledons elongates and lifts the cotyledons out of the soil to begin to photosynthesize
Ebb	Movement of tide as it flows outward, away from the shore, lowering the water level.
Hardening off	Process of gradually toughening seedlings while in the nursery to prepare them for normal field conditions. If gradually given less water and exposed to more sunlight, the seedlings are more likely to survive after outplanting.
Hypocotyl	Part of a seedling's stem below the cotyledons (seed leaves) and immediately above the root.
Hypogeal germination	Type of seed germination where cotyledons remain below the soil surface. The part of stem above the cotyledons grows and pushes the first true leaves above the ground
Inundation	Process of flooding or the submersion of land by water. This can occur due to natural events such as heavy rainfall, storm surges, high tides, or the overflow of rivers and lakes.
Intertidal zone	Also known as the littoral zone, is the area of shoreline that is exposed to the air at low tide and submerged underwater at high tide. It is the region between the high and low tide marks and is subject to periodic changes in water levels due to tidal movements.
Mangroves	Salt-tolerant trees and large shrubs that thrive in the intertidal regions of tropical and subtropical coastlines, roughly between 30˚N and 30˚S. The term "mangrove" describes both the plants and the ecosystems they form.
Mother trees	Healthy mature trees with superior desired characteristics. They contribute significantly to genetic diversity of the forest by producing seeds that lead to new generations of trees.

Natural regeneration	Process where ecosystems, particularly forests e.g mangroves, naturally re-establish themselves without human intervention. This occurs through natural dispersal and germination of seeds or propagules, followed by growth and development of seedlings into mature trees.
Outplanting	Moving of mature seedlings from a nursery for planting in the field or a restoration site
Tree nursery	A place where young trees or plants are propagated and grown before transplanting
Pneumatophores	Specialized aerial roots that enable plants like mangroves to respire in waterlogged soils
Pricking out	Transfer of tiny seedlings from seed sowing beds or trays where they have germinated to soil filled bags. This step is typically done after seedlings have developed their first set of true leaves and are sturdy enough to handle the process
Propagation	Process of growing new plants from seeds, cuttings, or any other plant parts.
Propagule	A reproductive structure in plants that is capable of developing into a new individual. In the context of mangroves, a propagule is a specialized seed or seedling that can detach from the parent plant and establish itself independently in a suitable environment.
Restoration	Process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.
Root pruning	Process of preventing root penetration into the sediment below the potting material.
Seedlings	Young plants, especially those grown from seeds.
Tidal range	Vertical difference between the high tide and the low tide.
Viviparous	A form of reproduction in which the embryo develops inside the body of the parent

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1.0 INTRODUCTION

1.1 Background

Mangroves are coastal ecosystems characterized by salt-tolerant trees and shrubs that grow in intertidal areas that are regularly flooded by seawater. The mangrove ecosystems are found within the tropical and subtropical coastlines, spanning more than 108 countries and covering approximately 136,000 square kilometres (Bunting *et al.*, 2018; Spalding & Leal, 2021). Despite occupying only 0.4% of the world's forested area (FAO, 2016), mangroves provide essential services such as: carbon storage and sequestration; coastal protection and erosion control; biodiversity conservation and provision of critical habitats for numerous species e.g. fish; and support to ecotourism activities. However, mangroves face significant threats due to degradation resulting in global loss of 1-2% annually (Hamilton & Casey, 2016). Increased demand for mangrove products has led to their overexploitation. Fortunately, recent efforts have slowed the global loss to approximately 0.16% annually due to conservation interventions, recognising mangroves as effective climate change mitigators (Flint *et al*., 2018; Friess *et al.*, 2019).

Restoration and protection of mangroves are prioritised interventions for climate change mitigation and adaptation (Howard *et al*., 2017; Taillardat *et al.*, 2018). Kairo *et al*. (2008) indicated that reforestation has the potential to restore lost mangrove forests, thereby sustaining the supply of mangrove goods and services. However, reforesting degraded areas through planting should be done as a last resort, where natural regeneration is not feasible, embracing the principles of Community Based Mangrove Ecological Restoration (CBEMR).

1.2 Mangroves of Kenya

1.2.1 Occurrence and Species

Mangroves are found in patches along the coast of Kenya, which spans approximately 640 km from latitude 1°40' north at the Somali border to latitude 4°40' south at the Tanzanian border. The mangrove trees thrive in creeks, protected bays, estuaries, and lagoons (Kirui *et al*., 2013; Bosire *et al*., 2016). There are 61, 271 ha of mangrove forests in Kenya, representing 3% of gazetted forest and 1% of state land (GoK, 2017).

Kenya is home to nine species of mangrove trees, out of the sixty-four species found globally. The most frequently occurring species are; *Rhizophora mucronata*, *Ceriops tagal*, and *Avicennia marina*. Other species include *Bruguiera gymnorrhiza*, *Sonneratia alba*, *Xylocarpus granatum*, *Xylocarpus moluccensis*, *Heritiera littoralis*, and *Lumnitzera racemosa*.

1.2.2 Zonation

The mangrove environment is harsh; being characterised by regular tidal inundation, shifting sediments, as well as variable and often high salinities (Kathiresan & Bingham, 2001). The unique adaptive features in mangrove trees include; salt tolerance mechanisms (possession of pneumatophores for gaseous exchange, salt exclusion, salt secretion mechanisms), specialised root structures (e.g., prop roots), reproductive strategies (e.g. viviparous seed development), efficient nutrient retention mechanisms (Alongi, 2014), and physiological plasticity, all of which contribute to mangrove resilience and ecological success (Ramesh *et al*., 2024) in different tidal zones.

The various mangrove tree species have unique adaptations that allow them to thrive in a particular zone under variable flooding and salinity stress conditions imposed by the coastal environment through specialised adaptations (Bundotich *et al*., 2009; Ramesh *et al*., 2024). As a result, mangroves (sometimes not always) display typical zonation patterns of the Sonneratia - Rhizophora-Avicennia community. Sonneratia typically occurs on the seaward side while Rhizophora-Bruguiera-Ceriops occupy the mid-zone and the dwarf Avicennia-Lumnitzera-Xylocarpus complex occurs on the landward side (Figure 1). Knowledge of mangrove species zonation is essential in determining suitable areas for planting different species.

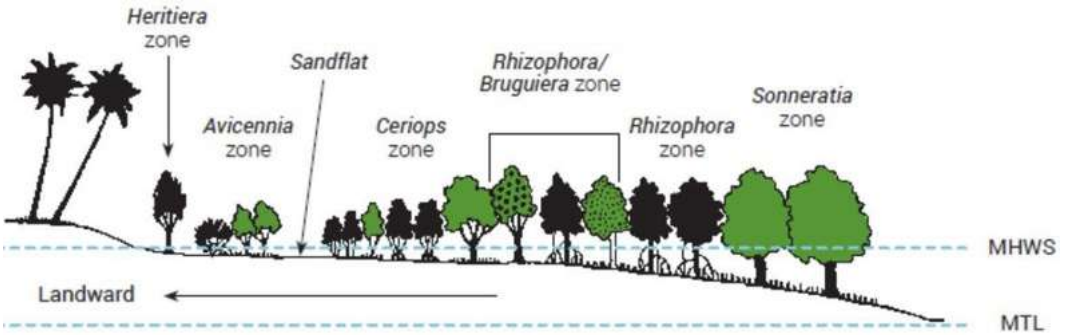

Figure 1: Mangrove zonation *(Source: UNEP-Nairobi Convention/USAID/WIOMSA, 2020)*

1.3 Rationale of the Manual

Despite their relatively small geographic extent (Leal & Spalding, 2024), mangroves deliver a remarkable suite of ecosystem benefits. These range from tangible goods to essential environmental functions. Additionally, mangroves contribute to cultural heritage. Unsustainable extraction of tangible goods like; poles, woodfuel, and wood for timber, results in degradation of mangrove ecosystems. The resultant degradation is worsened by other factors such as climate change, sewerage disposal, oils spills, and pests and diseases (Chemuku *et al.,* 2023).

In recognition of the importance of mangroves and the threats they face, the Government of Kenya, has embraced mangrove restoration as a priority in the National Mangrove Ecosystem Management Plan (NMEMP 2017-2027). This Plan prioritizes mangrove conservation and restoration, while emphasizing synergy among actors involved.

The threats and continued loss of natural forests translate to a scarcity of propagules for natural regeneration and rehabilitation programs (Holl, 2012). In areas where mangroves have been heavily degraded or lost, natural regeneration may not be able to restore these ecosystems effectively. Thus, establishing mangrove nurseries is essential when natural regeneration is unreliable and human intervention is required. This approach is especially crucial in regions with; challenging soil conditions, a lack of nearby seed trees, or irregular seeding patterns that do not align with the ideal planting seasons. By offering temporary storage for surplus seedlings and propagules produced during fruiting seasons, mangrove nurseries can enhance the availability of seedlings year-round, thereby supporting more effective restoration efforts.

The nurseries provide controlled environments conducive to seed germination and early growth, and by cultivating diverse species, the nurseries enhance genetic diversity, bolstering ecosystem resilience.

Mangrove nurseries are integral to effective restoration initiatives, safeguarding these vital coastal ecosystems for future generations. The nurseries are essential hubs for nurturing mangrove seedlings and vital for restoring and conserving mangrove ecosystems. They provide controlled environments conducive to seed germination

and early growth, ensuring a steady supply of healthy seedlings for restoration projects. By cultivating diverse species, nurseries enhance genetic diversity, bolstering ecosystem resilience. The survival rate of nursery-raised seedlings in restoration areas is higher than the direct planting of seeds/propagules (Ravishankar & Ramasubramanian, 2004). This is because they develop a well-established root system before being outplanted into degraded areas. In addition, quality control measures ensure good health and vigor. Moreover, nurseries facilitate site-specific adaptation, preparing seedlings for the local environment before outplanting.

This manual therefore aims to guide practitioners in mangrove rehabilitation and restoration. The manual provides information on reproductive biology of mangrove species in Kenya; nursery types and site selection; and mangrove nursery establishment and management including seedling preparation for outplanting. The manual also provides best practices highlighting common mistakes to avoid when establishing and managing mangrove nurseries.

2.0 MORPHOLOGICAL CHARACTERISTICS AND REPRODUCTIVE BIOLOGY OF MANGROVE TREE SPECIES

Mangrove trees exhibit peculiarities in sexual reproduction through both seed and propagule production, in a process referred to as vivipary. There are two types of vivipary, true and crypto-vivipary. True vivipary refers to a situation where the embryo penetrates through the fruit pericarp and grows to a considerable size before dispersal, while crypto-vivipary is a condition in which the embryo grows continuously, but does not emerge from the fruit before dispersal. Some mangrove species exhibit non-vivipary. While true vivipary is exhibited in *Ceriops tagal*, *Rhizophora mucronata*, and *Bruguiera gymnorrhiza*, crypto-vivipary is exhibited in *Avicennia marina*. Non-viviparous species include; *Lumnitzera racemosa*, *Sonneratia alba*, *Xylocarpus granatum*, *Xylocarpus moluccensis*, and *Heritiera littarolis* (Aluri, 2022). This peculiar characteristic trait could be considered an adaptive feature to overcome the harsh tidal environment that would otherwise impede seedling establishment. The morphological characteristics and reproductive biology of mangrove tree species are described as follows:

2.1 *Sonneratia alba* Sm.

Sonneratia alba is an evergreen tree with a broad, spreading crown. It is found in a seaward zone with a deep muddy substrate where the frequency of inundation is maximum. The tree is surrounded by thick, blunt conical pneumatophores (vertical roots arising from shallow, horizontal roots)

Family: Lythraceae
Common name: Apple mangrove
Local name: Mlilana

Flower:
Large, showy, and white with numerous long stamens. Flowers found at the ends of twigs, usually in groups of one to three. Each flower has six petal strands, green on the outside and pinkish-red on the inside, with a cup-shaped base.

Fruit and seed:
globular berry-like fruit with numerous small falcate seeds in a spongy pulp

Germination and seedling establishment:
When mature, the fruit splits and seeds spread along the water current to establish seedlings in the muddy substrate. The seed has a low viability of less than three months

Propagation:
Seed; can also be vegetatively propagated by air layering

2.2 *Avicennia marina* (Forssk.) Vierh.

Avicennia marina is common and often dominant constituent of mangrove swamps and a pioneer of new mud banks, forming monospecific clumps or stands in highly saline muddy sand. It is a fast-growing and fast-regenerating, hardy species. This species exhibits wide physiological tolerance to salinity, being able to survive in fresh stagnant water as well as in seasonally dry conditions with very high salinity. Studies done by MacFarlane *et al*. (2003) and Abou Seedo *et al*. (2017) revealed that *A. marina* excels in bioaccumulating heavy metals like copper, lead, and zinc, making it a vital biological indicator of soil pollution. Its ability to monitor environmental contamination enhances ecosystem health and stability by mitigating the impacts of heavy metal exposure.

Family: Acanthaceae
Common name: Gray or white mangrove
Local name: Mchu

Flower: Flowers range from white to a golden yellow, are less than 1cm across, and occur in clusters of three to five. Pollinated by insects and honeybees

Fruit and seed: The fruit contains large cotyledons surrounding the new seedling stem. This produces a large, fleshy seed, often germinating on the tree and falling as a seedling.

Germination and seedling establishment:
Germination is epigeal. The seeds start germinating while still attached to the tree, but the embryo stays within the fruit until fruit fall.

Propagation: seed

2.3 *Ceriops tagal* (Perr.) C.B.Rob.

Ceriops tagal can grow to a height of 25 metres (80ft) with a trunk diameter of up to 45 cm (18 in). The growth habit is columnar or multi-stemmed and the tree develops large buttress roots. Its habitat is in brackish water areas in tidal zones.

Family: Rhizophoraceae
Common name: Spurred mangroves
Local name: Mkandaa

Flower: Flowers are small, white, leathery occurring in terminal clusters of 2-10

Fruit and seed:
Fruit green, oval berry, leathery, from which a seedling grows while the fruit is still on the tree. This forms a long slender tube with a heavy end pointed at the ground. Mature propagules have a brown body and light yellow/orange collar with nodes* at the propagule end while unripe propagules are green and have no visible colored collar.

Germination and seedling establishment:
A thin, ridged hypocotyl (propagule) drops from the fruit when mature and roots in the mud, Germplasm material is a viviparous fruit that develops an emerging hypocotyl while still on the tree.

Propagation: Propagule

2.4 *Bruguiera gymnorrhiza* (L.) Lam.

Bruguiera gymnorrhiza can grow up to 30m tall, with the base enlarged by the buttresses formed by prop roots. The bark is black, rough, fissured, and in a regular checkered pattern. The tree has knee shaped roots which are prominent. Leaves are crowded at the ends of branches; often reddish beneath, without black dots on the underside.

Family: Rhizophoraceae
Common name: Orange or oriental mangrove
Local name: Muia

Flowers: Flowers solitary, large, up to 3.5 cm long, regular, red to scarlet. Big solitary flowers red to scarlet (calyx); fruits cigar-shaped with red calyx cap.

Fruit and seed development: Vivipary. Propagule with hypocotyl up to 25-30cm long and 1.5-2cm in diameter, cigar-shaped, slightly angular, apex blunt

Germination and seedlings establishment: Propagules have pointed ends; when they fall off the tree they stick in the mud and grow.

Propagation: Propagule

2.5 *Rhizophora mucronata* Lam.

Rhizophora mucronata is a evergreen tree, with a pyramidal crown. The tree has numerous and thick aerial stilt roots developed from the trunk and branches. The species is found in brackish and saline environments such as depositing shores and marshes along tidal creek banks, estuaries, and low coastal areas flooded by daily high tides. It prefers deep, soft mud rich in humus and well inundated by tidal waters. This species is often well developed in wet climates

Family: Rhizophoraceae
Common name: Red mangrove
Local name: Mkoko

Flowers: Cream to yellowish, with four sepals and four white, hairy petals.

Fruit and Seed development: Brown-green, elongate ovoid, and have a wrinkled base. When mature, the propagule has a rough surface and a yellow cotyledonary collar. The seeds are viviparous. As they mature, the propagules change from dark green to pale green.

Germination and Seedlings establishment:
Seeds germinate within the fruit while still attached to the parent tree, with a radicle protruding from the fruit. When mature, the propagules detach from the parent tree and fall into the water below. If they land at low tide, they can embed themselves in the soft mud, or they may float away to colonize new areas, eventually settling and taking root in suitable substrates.

Propagation: Propagules

2.6 *Xylocarpus granatum* J.Koenig

Xylocarpus granatum is a shrub or tree that usually grows to between 5 to 15m tall, and exceptionally to 20m. The plant is usually evergreen, though it can become briefly deciduous in some areas with seasonal climates. It grows in the higher intertidal zone, usually found in estuaries and often associated with *Sonneratia alba*.

Family: Meliaceae
Common name: Cannonball mangrove
Local name: Mkomafi

Flowers: White and fragrant.

Fruit and seed:
Big hard spherical fruit with 10-15 big pyramidal seeds. The fruits are large up to 30- 40 cm, heavy woody spherical capsuler. The fruit shatters on impact after its falls from the tree releasing several seeds.

Germination and seedlings establishment:
Seeds may start to germinate while still floating.

Propagation: Seeds

2.7 *Xylocarpus moluccensis* (Lam.) M. Roem.

Xylocarpus moluccensis is a evergreen tree that stands tall, reaching heights of up to 25 m, with a trunk diameter typically measuring around 50 cm. Its bark is smooth and tinted in shades of grayish-brown, encasing a sturdy frame. The leaves are distinctively leathery and glossy, shaped in elliptical or oblong forms, each ending in a pointed tip. The leaves are arranged oppositely along the branches, creating a dense canopy.

Family: Meliaceae
Common name: Cedar mangrove
Local name: Mkomafi Dume

Flowers: Small and creamy white or pale yellow, arranged in panicles. The flowers cluster at the branch tips.

Fruit and seed: The fruit which resembles cannonballs, are large, spherical, roughly the size of a baseball or cricket ball, with a tough, woody exterior. Several seeds are nestled within fibrous pulp. These seeds are irregularly shaped and surrounded by a spongy, fibrous aril aiding in flotation, allowing water dispersal.

Germination and seedlings establishment:
Upon reaching a suitable environment, the seeds germinate by absorbing water and developing roots (radicle), followed by seed leaves (cotyledons), establishing the seedling in muddy or sandy mangrove soils.

Propagation: Seeds

2.8 *Heritiera littoralis* Dryand. ex Aiton

Heritiera littoralis trees occur sporadically on the terrestrial edge of the mangroves and do not form distinct zones. Commonly known as the looking-glass mangrove or dungun. It is a buttressed, slow-growing, low-branched, evergreen tree with a wide, dense crown of thick, horizontal branches.

Family: Malvaceae
Common name: Beach tulip-oak
Local name: Msikundazi

Flowers:
They are small, unisexual, yellowish-greenand bell-shaped

Fruit and seed development: Fruit is green when unripe and flattened oval brown nuts with a single seed mature.

Germination and seedlings establishment:
The nut has a spongy structure with a ridge, enabling it to float in water to aid dispersal. The seeds germinate readily in muddy substrates. It displays hypogeal germination with the ventral side of the fruit downward.

Propagation: Seeds

2.9 *Lumnitzera racemosa* Willd.

Lumnitzera racemosa is a small evergreen tree compared to other species, characterized by its thin, brittle branches, is commonly found in mangrove swamps, muddy or sandy fringe areas, and estuarine and backwater mangroves (Manohar, 2021). It often grows alongside *C. tagal* and *A. marina* in highly saline conditions (up to 82 ppt) and poorly irrigated zones with low organic matter (Buttarazzi *et al*., 2024). The flowers are pollinated by day-active wasps, bees, butterflies, and moths (Raju *et al.*, 2014). Its fruits are dispersed by water (Tomlinson, 1986).

Family: Combretaceae
Common name: White-flowered black mangrove
Local name: Kikandaa

Flowers:
Small white flowers densely arranged in spike-like racemes. These flowers attract insect pollinators, particularly bees, facilitating cross- pollination

Fruit and Seed development:
Small, woody, capsule- like fruits, each containing a single seed. These seeds are relatively large and buoyant, adapted for water dispersal

Germination and Seedlings establishment:
Germination often occurs in the upper intertidal zone where there is appropriate salinity, moisture, and temperature. Seeds exhibit hypogeal germination. Once germinated, seedlings swiftly develop root systems to anchor themselves in muddy or sandy substrates.

Propagation: Seeds

3.0 NURSERY TYPES AND SITE SELECTION

3.1 Types of Mangrove Nurseries

Mangrove nurseries are classified into two main types i.e. Floating (Inand) and Flooded (Intertidal) Nurseries. This classification is based on their location across the tidal range as illustrated in Figure 2.

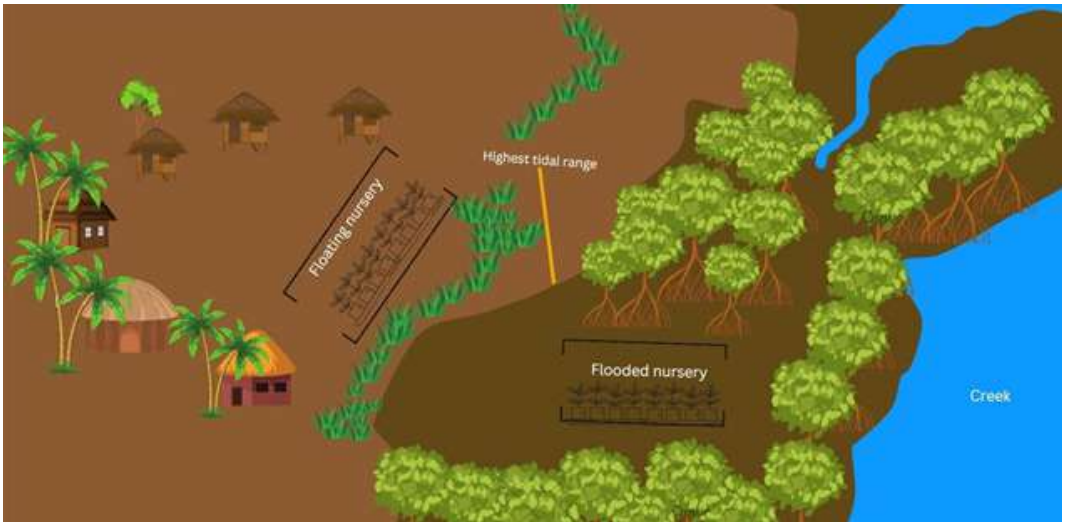

Figure 2. An artistic impression of a mangrove forest, adjacent village and the position of the floating and flooded nursery
(Sketch by Julius Sila and Emmanuel Karisa)

i. Floating /Inland nursery

The floating nursery is also referred to as **inland nursery** or **permanent nursery**. This type of nursery is located on dry land where watering is done manually. The floating mangrove nursery resembles a typical terrestrial tree nursery. This is a permanent nursery in design, and it is work-intensive. This type of nursery is:

- established above the highest tidal range and may require watering.
- meant to supply seedlings for long-term big afforestation projects.
- meant to raise mangrove seedlings that have difficulties in establishing in the flooded nurseries such as *Avicennia marina* which is predated on by grapsid crabs.

Floating nurseries can accommodate a relatively high number of seedlings without interfering with the mangrove ecosystem. Plate 1 shows an image of a floating type of nursery.

Plate 1. An example of a floating nursery, sown with *Bruguiera gymnorhiza* and *Rhizophora mucronata* at Mokowe, Lamu.

ii. Flooded /Inertidal nursery

The flooded nursery is also referred to as **intertidal** or **temporary nursery**. This type of nursery is established in low intertidal zones with regular flooding of seawater. It is a temporary nursery that supplies seedlings for a short-term period and does not require a lot of effort to establish and maintain. Plate 2 shows an image of a flooding type of nursery

Plate 2: *Ceriops tagal* flooded nursery at Mtangawanda, Lamu

3.2 Mangrove Nursery Site Selection

Mangrove nursery site selection and setup involve choosing an appropriate location and establishing a nursery where mangrove seedlings can be grown and nurtured before being transplanted to the restoration sites. The process ensures that young mangrove seedlings have the best chance of survival and growth once they are outplanted.

To identify potential sites for the nursery, it is essential to conduct a preliminary survey based on factors such as proximity to the restoration area, accessibility, minimal human disturbance, security needs, and resource availability. Evaluate each potential site through thorough field assessments. Engagement with local communities, authorities, and stakeholders is recommended to gather their input and ensure the necessary local support. Based on results of the site assessments and consultations, the site for the nursery is thus selected. The following section outlines various categories of factors to be considered in mangrove nursery site selection and setup.

i Site characteristics

Various factors are linked to the characteristics/features of a site. A summary of site characteristics that should be considered in siting flooded and floating nurseries are provided in Table 1.

Table 1: Considerations when selecting flooded or floating mangrove nursery locations

Characteristic	Flooded nursery	Floating nursery
Tidal influence	The site should have appropriate tidal influence, ensuring seedlings are regularly inundated but not constantly submerged.	The site should be away from the tidal influence.
Salinity levels	Moderate salinity levels are ideal. Extreme salinity can hinder seedling growth. Regular inundation, shade and rainfall are essential for maintaining moderate salinity levels.	The site should as much as possible be surrounded by a live fence (hedge). This helps reduce water loss from seedlings thus moderating salinity levels.
Water quality	Water should be free of pollutants and contaminants that could harm the seedlings. The site should also be situated in a safe area that is sheltered from pollution such as oil spills and waste dumping.	Water should be sourced from nearby creeks/channels that are free of pollutants and contaminants that could harm the seedlings.
Land use compatibility	Ensure the nursery does not conflict with local land uses and has the support of the community.	Ensure the nursery does not conflict with local land uses and has the support of the community.
Existing vegetation	A site with healthy mangrove vegetation indicates suitable conditions for growth.	Existing trees should provide light shade and shelter seedlings from strong winds.
Slope and drainage	Choose a site with a gentle slope to prevent water stagnation and logging, which would kill the seedlings.	Choose level or gently sloping ground. The nursery should be located in an area that can be accessed during rainy seasons. Avoid waterlogged conditions that can destroy the nursery after floods.

ii. Protection from natural hazards

Natural hazards are environmental phenomena with potential impact on the environment.

- Some of the natural hazards in mangrove nurseries that might affect nursery operations include storms, waves, and pests and diseases.
- Flooded mangrove nurseries should be situated in sheltered areas away from strong wave action which could destroy seedlings.
- An integrated pest management (IPM) approach should be used for handling pests and disease occurrences in the nursery to prevent spread and damage.

iii. Accessibility

The ideal location of a nursery should be close to the restoration area to minimize the cost associated with transporting seedlings. The site should be

- accessible by both land and sea to facilitate the easy transportation of materials and seedlings.
- near communities where labor can be sourced for maintenance and monitoring purposes, ensuring that there is a readily available workforce to support the ongoing needs of the project.

iv. Human and environmental impact

- The selected area should have minimal human disturbance to reduce the risk of damage to the nursery.
- To ensure security, the nursery should be fenced to protect it from wildlife, livestock, and other potential disturbances. It is recommended to avoid areas that are prone to such disruptions and
- Fencing will ultimately depend on the type of nursery and the specific site conditions.

4.0 NURSERY ESTABLISHMENT STEPS

Establishing a mangrove nursery involves creating a controlled environment where mangrove seedlings can grow and develop before being transplanted to their natural habitats. It entails planning, site selection and preparation, nursery infrastructure setup, soil collection and potting, seed collection and propagating, nursery management and hardening off for outplanting (Figure 3).

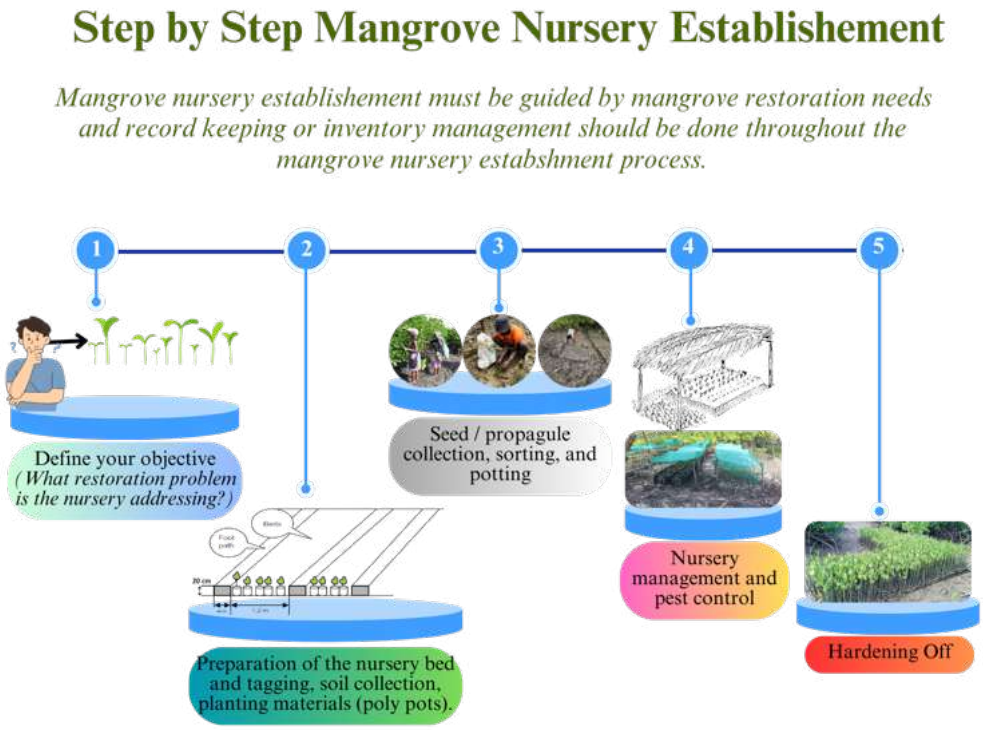

Figure 3. A general illustration of the steps involved in establishing a mangrove nursery.

4.1 Planning and Preparation

Careful planning and implementation informed by a restoration plan is necessary to ensure the nursery's success and sustainability.

- A restoration plan will guide the mangrove species and quantities required to be raised in a particular nursery for a given area or site. This will also inform the choice of nursery type and its size, defined by the quantity of seedlings required.
- Engage the necessary parties specifically; KFS, CFA leadership, the community, and critical partners. This is essential for compliance and access to required support which enhances success.

- Provide training on mangrove propagation, nursery management, and conservation to those involved (optional if the majority have been trained).
- Identify the necessary inputs required for establishment of the nursery and plan accordingly. These entail; personnel, planting materials, soil media, tools and equipment, and time.

4.1.1 Nursery tools and equipment

Establishing and maintaining a mangrove nursery requires a variety of tools and equipment. Equipping your tree nursery with the right tools and equipment is essential for efficient operation and successful seedling production. The tools will vary depending on the type of nursery. The following is a list of necessary materials, tools and equipment for a tree nursery, categorized based on their function:

- Site preparation and maintenance tools: hand cart, machete, bush knife, hoe, rake, spade
- Seed/ planting material collection: seed carrying bags/ baskets, pruning shears
- Propagation/planting equipment: potting bags/tubes, propagation beds, seed trays, dibblers
- Soil preparation tools: hoes, spades/shovels, rakes, wheelbarrow, carrying containers/ baskets, buckets
- Shade and protection equipment: fencing materials e.g fitos, poles, shade nets, fronds e.g. palm leaves
- Construction tools: hammer, saw, nails, sisal ropes/twines, wooden stakes, poles
- Watering equipment: watering cans, water storage tanks, (sprinklers - optional)
- Pest management: forceps, sprayers, traps, soft brush for manual removal of pests
- Safety and Personal Protective Equipment (PPE): gloves, mud boots, first aid kits, hats
- Monitoring and documentation tools: notebook, pen, nursery data forms, files, smartphone/camera, plant tags/ labels, linear tape, caliper, salinity meter
- Transport and Handling Equipment: handcarts, trolleys, crates/ seedling carriers

4.1.2 Nursery calendar

A mangrove nursery calendar is an essential tool for planning necessary actions like acquiring planting materials, supplies, and equipment. The date scheduled for a restoration activity is critical while establishing a nursery. The date for sowing seeds can be calculated backwards from the anticipated date of outplanting, considering the number of days required for germination and seedling development until the right stage for planting for each species. Note that different mangrove species have different seeding seasons and requirements for planting out in the field. When possible, plan for restoration activities during rain seasons, when salinity levels are low, to enhance survival rate of seedlings. The calendar contains major activities undertaken in a nursery until the seedlings are ready to take to the field, as indicated in Table 2. The calendar can be modified depending on; the mangrove species, seeding season, and restoration schedule.

Table 2: A sample nursery calendar for common mangrove species

Species	Seed collection, potting, sowing	Watering, monitoring, records	Hardening off	Outplanting
Avicennia marina	April	Daily	July	August
Ceriops tagal	March	Daily	June	July
Rhizophora mucronata	March	Daily	June	July
Bruguiera gymnorrhiza	March	Daily	June	July
Sonneratia alba	September	Daily	December	January

4.2 Site Selection and Preparation

- Informed by the type of nursery, select an ideal location to set up your nursery as guided in Section 3.2.
- Clear all natural vegetation and remove stumps, leaving some shade trees. This is not always the case in flooded nurseries as cutting down existing mangrove trees should NOT be encouraged. Only remove stumps and debris, including dead logs and stems brought in by the tides.

- If the area is not flat, make terraces at this stage to improve site drainage
- If a natural windbreak does not exist (in the case of floating nursery), plant some trees for future shade.

4.3 Nursery Layout

An ideal nursery should have the following major components: fence, seed germination beds, potting shed, hardening off beds and water source. However, this may vary depending on the location and type of nursery.

4.3.1 Floating Nursery layout

The following components are essential in the layout of a floating nursery:

Seed Germination Bed:

A seed germination bed, also known as a seedling bed, is a specially prepared area where seed pots are arranged to allow seedlings to grow strong before being transplanted to the mangrove restoration site. Preparation of the seed germination bed should be as follows:

- Level the site of the beds and firm the soil
- Determine the size of the seedling bed based on the number of seedlings you plan to grow
- Mark out the beds' shapes and sizes. Each bed should ideally be 10m x 1m, with 1m paths between each row for ease of access and care.
- Construct a shade over seed germination beds to protect the young seedlings from intense sunlight
- Label/Tag the nursery beds using unique IDs for purposes of record keeping and monitoring
- Potting Shed:
- The potting shed is a sheltered area where soil is aggregated, cleaned of debris, and potting bags are filled.
- If constructing a shade, ensure it is at least 3m x 4m in size. However, you may also utilize the existing tree shade in the designated area.

Hardening Off Beds:

- The hardening off beds are where potted seedlings are left to acclimatize to increased sunlight exposure just before outplanting.
- Where the seed germination beds also function as hardening beds, begin removing the roofing shade gradually to expose the seedlings to sunlight one month before outplanting.
- Ensure that potted seedlings are not moved around until they are ready for out-planting.

Fence:

- Protect the nursery from external disturbances, such as livestock, by erecting a fence around the nursery. This will help ensure the safety and security of your seedlings.

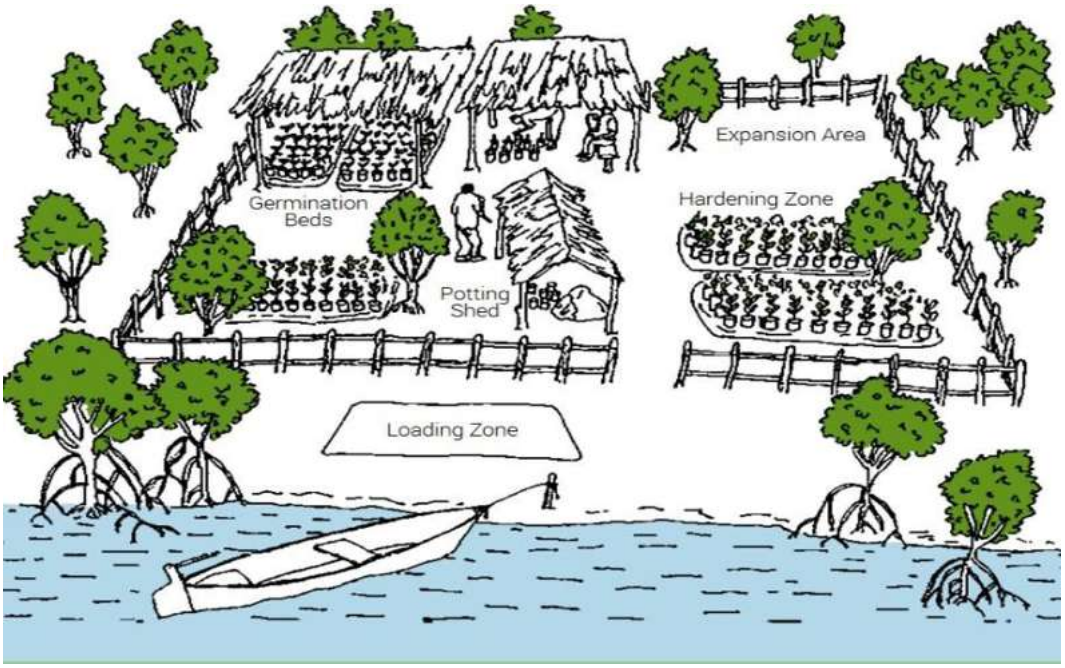

Figure 4: Typical layout of a floating mangrove nurseries
(Source: UNEP-Nairobi)

4.3.2 Flooded Nursery layout

In setting up a flooded nursery, take into consideration the following components:

Seed Germination Beds:

- Begin by digging out troughs to a depth of approximately ¾ the height of your seed pots. These troughs will serve as the seed germination beds, which help to hold the seed pots from movement. To further secure the seed pots, especially in areas prone to tidal waters, use wooden planks pegged into the ground to prevent them from topplings (Plate 3).
- Prepare multiple beds where there are many required seedlings and space allows. For efficient operation, each bed should measure approximately 10m x 1m, with a 1m wide path between adjacent beds for easy access.
- Due to limited space within mangroves, the germination beds can also serve as hardening-off beds.
- Ensure that the potted seedlings are not moved until ready for out-planting.
- Label/Tag the nursery beds using unique IDs for purposes of record keeping and monitoring

Shade structure:

- Construct a shade structure over seed germination beds to protect the young seedlings from strong direct sunlight. This can be made from locally available materials (Plate 4)

Potting shed:

- Choose a sheltered area where soil aggregation, debris cleaning, and potting bag filling can be efficiently carried out. In this type of nursery, potting is typically done under the shade of mangrove trees, as the soil media is collected from this area.

Hardening Off:

- One month before out-planting, remove the roofing shade to expose the seedlings to full sunlight to acclimatize gradually.

Fence:

- Protect the nursery from external disturbances, such as livestock. This can be done by social fencing or installing a physical fence if feasible.
- The need for a physical fence may vary depending on the nursery's location within a mangrove area and the presence of potential disturbances. Assess the surroundings to determine if fencing is required.

Plate 3: Laying out seedling beds for a flooded nursery

4.4 Collection and Storage of Planting Materials

Planting materials from mangrove trees may be seeds or propagules from selected mother trees. Collect only mature, healthy seeds or propagules (see Table 3 for maturity indicators) in the required quantities to minimise overharvesting and wastage of germplasm. The collection should not exceed 25% of propagules in a tree. The collected planting materials may be stored if not being sown immediately. Using wildlings as nursery planting materials is not recommended due to risks of root damage leading to low survival, reduced genetic diversity, pest and disease spread, inconsistent growth rates, and ecological disruption. The collection process should generally follow the steps outlined in Figure 5.

Plate 4: A shade structure for *Bruguiera gymnorhiza* flooded nursery

Figure 5: Collection of planting material and storage process

It is crucial to understand the nature and maturity indicators of the planting materials, as well as the peak collection period for each species. The collection of propagules or seeds from various mangrove species must be carefully timed to coincide with the peak seeding season of each specific species (Table 3). However, the peak periods may vary from site to site and by season.

Table 3: Maturity indicators of different mangrove tree species, peak collection periods and optimum conditions for storage

Species	Indicators of maturity	Mature planting material	*Peak availability period	Optimum storage conditions
Rhizophora mucronata	The propagule is green; Ring-like mark below the cap; Yellow collar; Length >30cm		March - June	Cool and wet, for a maximum of 30 days
Avecinia marina	The seed coat is light yellow; it becomes wrinkly and often opens.		April - May	Cool and wet, for a maximum of 5 days
Ceriops tagal	Cotyledonary color is light yellow collar; Propagule is dark green/brown; Ring-like mark below the cap; Length >20cm		February - March	Cool and wet, for a maximum of 15 days
Sonneratia alba	Shiny dark green or yellowish soft fruit; Floats in water; Fruit diameter >4cm; and can contain up to 130 seeds.		September - November	Cool and wet, for a maximum of 5 days
Bruguiera gymnorhiza	Reddish brown propagules which drops without the cap; Length >15cm		April - July	Cool and wet, for a maximum of 10 days
Xylocarpus granatum	Dark brown fruit that floats on water.		May - July	Dry cool condition

Species	Indicators of maturity	Mature planting material	*Peak availability period	Optimum storage conditions
Xylocarpus moluccensis	Green brownish fruit, diameter up to 12 cm		May - July	Dry cool condition
Heritiera littoralis	A dark brown, smooth woody fruit, oval-like elongated shaped		May - July	Dry cool condition
Lumnitzera racemosa	Reddish brown dry fruit; slightly elongated, resembling a tiny capsule 1-2 cm long;		May - July	Dry cool condition
****The peak period for the availability of propagules/seeds provided in this table may vary from site to site and by season.*** ***Source: Modified from UNEP-Nairobi Convention/USAID/WIOMSA 2020***				

4.4.1 Soil for raising mangrove seedlings

Soil is the most common substrate for growing mangrove seedlings. The best soil is the one collected from areas where the specific mangrove species naturally thrive. However, this may not always apply especially in large scale floating nurseries where large quantities of soil are required.

The soil used in mangrove nurseries should resemble the natural habitat of the respective mangrove species, providing the right balance of nutrients, salinity, and moisture content. The soil should be well-draining yet capable of retaining enough moisture to support seedling growth. The soil may sometimes be mixed with organic matter or compost to enhance fertility and support root development. Steps for soil collection for mangrove nursery establishment are outlined in Figure 6.

Figure 6: Soil collection steps for mangrove nursery establishment

4.4.2 Potting

Potting involves filling seedling containers with soil substrate to support their growth in mangrove nurseries. While polythene bags have been commonly used, alternative potting materials have also been observed in community nurseries. These include; hand-woven palm leaf bags, poly-coated kraft bags, recycled milk packets, plastic bottles, recycled yoghurt cans, and non-woven nursery bags (Plate 5). Each material offers unique advantages and disadvantages depending on the growth period before outplanting. For instance, polythene bags suit species requiring more extended periods in the nursery, while biodegradable options work well for shorter durations in the nursery. The Government of Kenya has phased out plastic-based materials to use biodegradable ones. Trials have been going on to test the suitability of various biodegradable bags to provide the required standards for adoption.

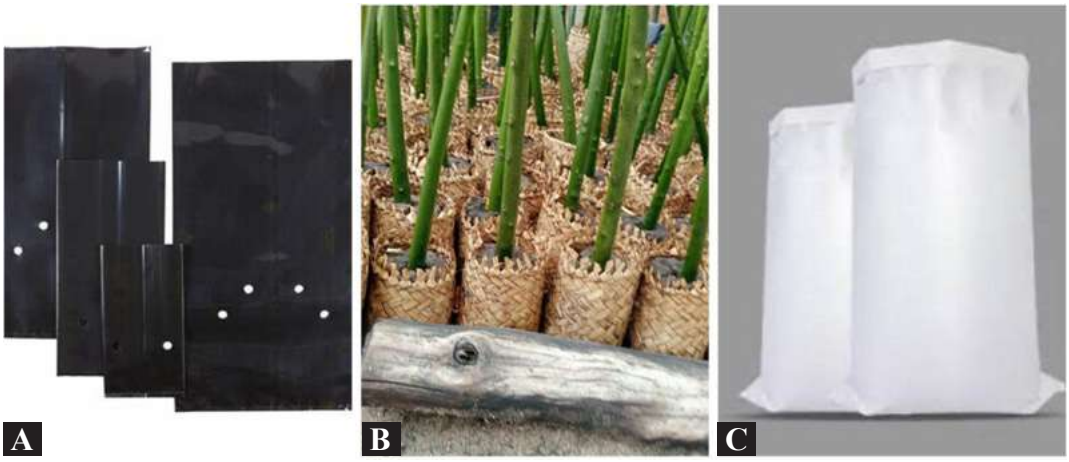

Plate 5: Left to right - Different potting materials used in mangrove nurseries in Kenya (A-polythene bags, B-biodegradable hand-woven palm leaf bags, C-polycoated kraft bags)

Different species require different pot sizes: Bags of 4'' x 6'' are suitable for small-sized seedlings like *A. marina, C. tagal*, and *L. racemosa*, whilst larger bags measuring 5'' x 8'' or more are suitable larger seedlings of species such as *R. mucronata*. This will provide enough space for the roots and prevent them from becoming curled or malformed after 2-3 months (30-35 cm height) of growth in the bags. Small holes should be made at the bottom for unperforated bags to allow excess water to drain.

To ensure maximum germination percentage and survival of potted seedlings, fill the potting tubes with appropriate soil as described in section 4.4.2. Make sure the bag is filled to the brim and firmly pressed to avoid water stagnating on the top. Once filled, let the pots stand for at least one tidal cycle to allow the soil to stabilize, and arrange them in the dug-out beds so that at least two-thirds (⅔) of the bag's height is below ground level for stability. To safeguard against potential displacement by tidal waters, the boundaries of the seedbeds should be fortified with wooden pegs (Plate 6).

Plate 6: Seedbeds fortified with wooden bars and pegs in Mkunumbi, Lamu County

4.4.3 Sowing

Sowing involves placing planting/propagation material in soil-filled potting bags. While propagules do not require pre-treatment before sowing, seeds and fruits of some mangrove species need pre-treatment to facilitate germination. The following section describes pre-treatment where necessary, and sowing of the seeds/propagules of various mangrove tree species. Sowing should be carried out in the early morning or late afternoon when temperatures are cool. The pots should be watered before sowing. Seeds can be sown directly into potting bags or sown first in seed beds and then germinants pricked out and transplanted into potting tubes.

i. ***Rhizophora mucronata, Ceriops tagal,*** and ***Bruguiera gymnorrhiza***

Rhizophora mucronata, C. tagal, and *B. gymnorrhiza* do not require pre-treatment before sowing. Sow the propagules upright in the center of the potting tube with soil media by gently inserting the root part to a depth of between 5 to 8 cm into the soil (Plate 7). The depth will depend on the species type and size of the propagule. Proper depth is essential because planting too shallow can expose the propagule to drying out or damage while planting too deep can hinder growth and lead to rot. *R. mucronata* takes 28-38 days to germinate (shoot), *C. tagal* takes 16-22 days, and *B. gymnorrhiza* 17-19 days depending on nursery type (Plate 8).

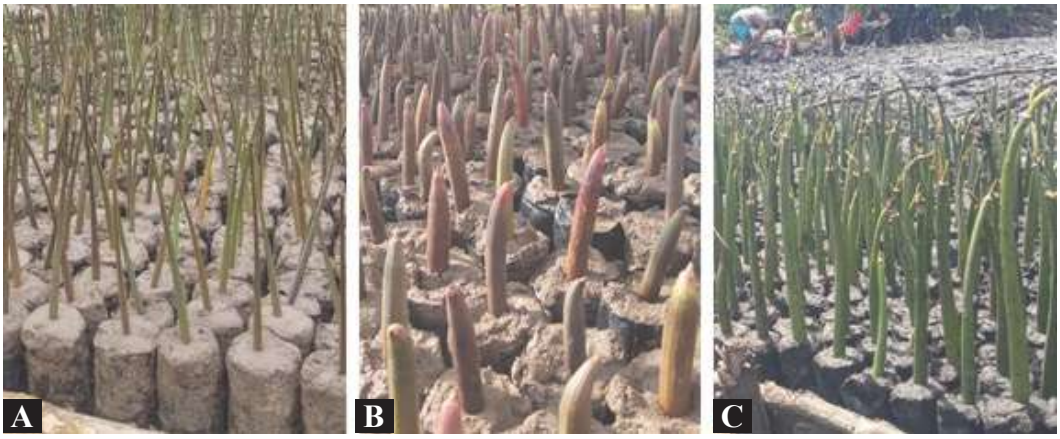

Plate 7: Freshly sown propagules of *Ceriops tagal* (A), *Bruguiera gymnorrhiza* (B) and *Rhizophora mucronata* (C)

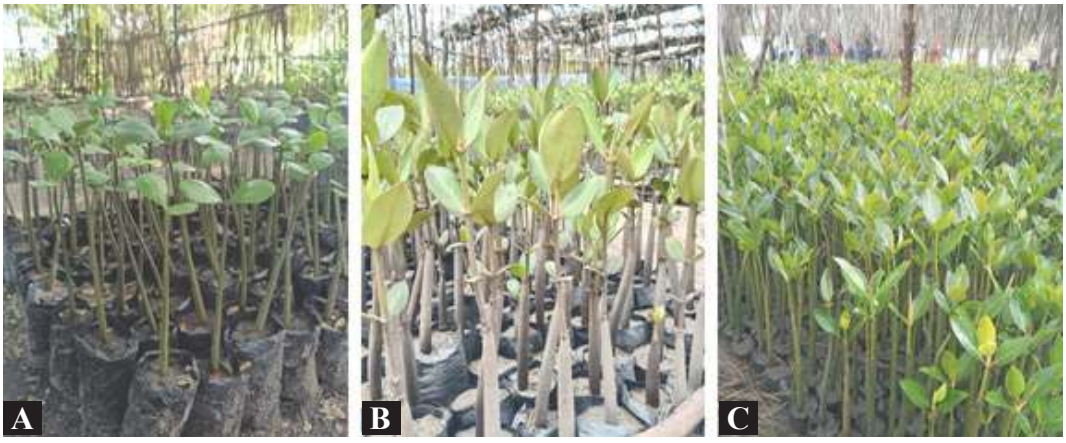

Plate 8: Germinated propagules (seedlings) of *Ceriops tagal (A), Bruguiera gymnorrhiza (B)* and *Rhizophora mucronata (C)*

ii. *Avicennia marina*

Soak the seeds in fresh water overnight for hydration and seed coat removal. Soaking is optional as the seeds are typically ready to germinate upon dropping. Insert the seeds directly into the potting tubes with the pointed end (radicle end) facing down and the broader end slightly exposed above the soil surface (Plate 9). Germination takes between 6 - 8 days, depending on nursery type. Sowing should preferably be done in floating nurseries as seed predators, primarily grapsid crabs, feed on the seeds raised in flooded beds.

Plate 9: Propagation of ***Avicennia marina***
A-freshly sown seeds in potting bags; B-epigeal germination in ***Avicennia marina***; and C-seedlings during the early stages of growth

iii. *Sonneratia alba*

Air dry mature fruit for twelve hours and extract the seeds manually. Wash the seeds to remove the pulp and air-dry for one hour or more depending on the intensity of the sun. This helps prevent fungal growth and other pathogens. Soak the dried seeds in fresh water for 24 hours. Due to their small size seeds of S. alba (Plate 10) are first sown in a seed bed before pricking out into the potting bags.

Plate 10: *Sonneratia alba* seed extraction process
(A-Washing off the pulp, B-air drying and C-soaking in cold water)

Establish a seedbed in an area with a soft, muddy substrate, preferably in *S. alba* zonation, where there is an adequate supply of tidal water. In cases where flooded seedbeds are not feasible, construct floating seedbeds using available materials. Use substrate collected from *S. alba* zonation or a sandy-clay soil mixture in the seedbeds. Plant the seeds with the pointed end facing downward into the substrate, ensuring they are buried about halfway. Ensure the seedbeds are in a shaded area and regularly watered to keep the soil moist. S. alba takes 8 to 12 days to germinate, after which the seedlings are pricked out.

Pricking out of *Sonneratia alba* seedlings

Pricking out is transferring germinated seedlings from the seedbed into the filled potting tubes. This is a sensitive procedure and may result in mass mortality of germinated seedlings. Therefore, keen attention should be paid to the pricking out steps. Seedlings should be pricked out after they have developed at least two leaves and are large enough to handle. The following are the basic steps:

1. Water the seedlings a day before pricking out to make separating the roots easier. In flooded nurseries, the exercise can be performed soon after the tides ebb.
2. Gently lift one seedling at a time using a "dibler" to lever out as many roots as possible. Always hold seedlings by the leaf, not the stem, as the stem is easily crushed which would kill the seedling.
3. Keep the roots moist by placing them in a container (bowl) of clean clean water (not polluted).
4. Transplant the seedlings into individual tubes filled with appropriate soil. The surface should be level and gently firmed.
5. Make a hole with the dibler and lower the seedling into it, almost to the base of the leaves. Firm it in carefully, ensuring the seedling remains upright.
6. Place the seedlings under shade to grow.
7. Water pricked-out seedlings immediately and thereafter daily, early morning and late evening, using a watering can or horse pipe with a fine rose.

iv. *Xylocarpus granatum* and *X. moluccensis*

Air dry the fruit until it exposes the seeds and then remove them manually from the seed coat (Plate 11). The seed viability diminishes rapidly during storage and as such should be sown as soon as they are removed and plant directly in the potting bags. The seeds can be soaked in fresh water for about 24 hours to help soften the seed coat and improve germination rates. Insert ⅔ of the seed into the soil with the radical facing downwards (convex side facing up) and cover lightly with soil. Use fresh water to consistently keep the soil moist; *X. granatum* seedlings are sensitive to saline conditions in their early stages. Germination of either species, takes 3-12 weeks, achieving about 70% rate with seedlings reaching a height of 50 cm within 3 months.

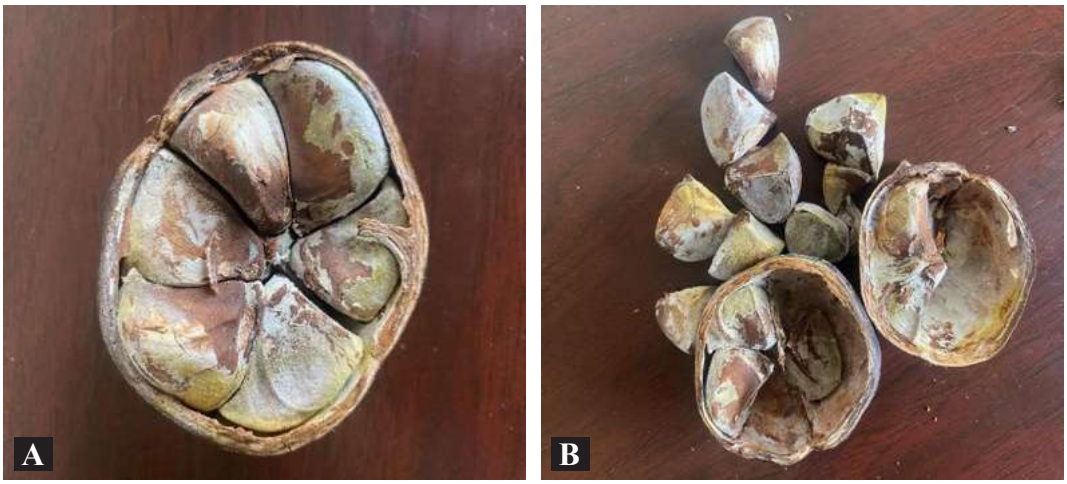

Plate 11: (A) A dry *Xylocarpus granatum* fruit exposing seeds (B) Seeds removed from the seed coat ready for sowing

v. *Heritiera litoralis*

The extracted seed are brown, ellipsoid, flattened, 3cm long. In case the seeds have a hard outer coat, gently scarify the seeds by nicking them with a knife to help with water absorption (Plate 12). Soak the seeds in freshwater for 24-48 hours to soften the seed coat and enhance germination. The pre-treated seeds are directly sown into potting bags or in seedbeds by placing them gently on the soil surface with the radicle facing downward and covered lightly with a mixture of sand and loam soil. Water the seeds regularly to keep the soil moist but not waterlogged. Germination takes a minimum of about 2 weeks (Plate 13).

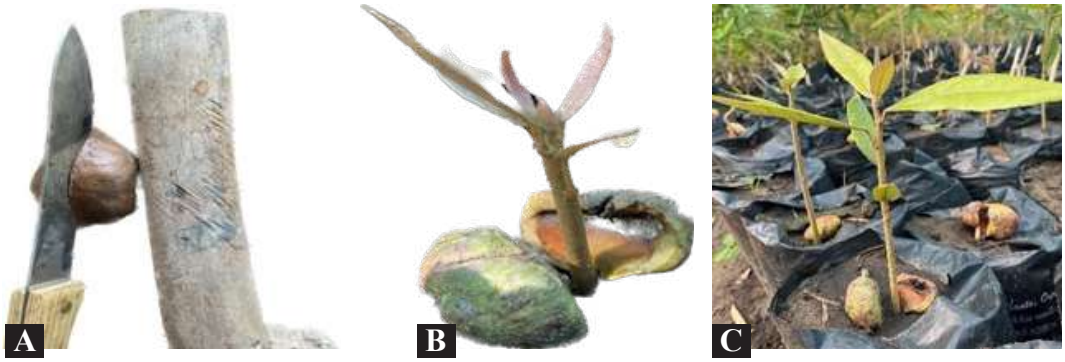

Plate 12: An illustration of *Heritiera littoralis* seed extraction using a knife and freshly germinated seeds

Sometimes *H. litorralis* may be sown on seedbeds before transferring into the potting bags. This is done in floating nurseries.

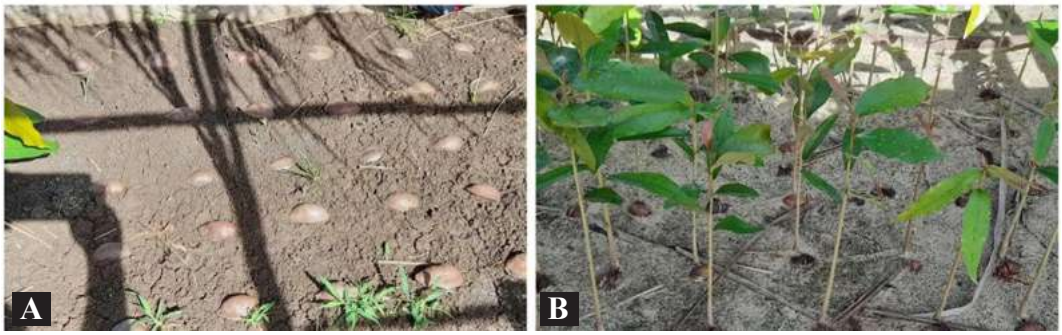

Plate 13: *Heritiera litorallis* sown in a floating nursery

vi. *Lumnitzera racemosa*

Limited research has been conducted on the propagation dynamics and nursery techniques for *L. racemosa*. Raju *et al*. (2014) found that this mangrove species' fruit germination and seedling establishment are highly influenced by salinity sensitivity, leading to notably low natural regeneration vigor. These findings suggest a need to optimize salinity conditions for successful attempts of sexual propagation of *L. racemosa*. Perera *et al*. (2020) also demonstrated that a closely related species, *Lumnitzera littorea*, was successfully propagated through air-layering in 26 weeks. This insight from Perera *et al.* (2020) offers a valuable research prospect for developing specific nursery protocols to propagate *L. racemosa* in Kenya.

5.0 NURSERY MANAGEMENT

Nursery management is essential for healthy growth and production of quality seedlings. Practices and activities undertaken in a nursery involve the following: Watering to meet the specific moisture needs of the plants; Shading to protect young seedlings from intense sunlight, wind, and heavy rainfall; IPM to safeguard the nursery stock by employing strategies to control pest populations while minimizing harm to the surrounding ecosystem; Fencing to deter herbivores and prevent disturbance; Grading and sorting to ensure uniformity in the stock; and Monitoring of conditions, with detailed records maintained to track progress and identify any issues that may arise.

5.1 Watering

Watering is important in ensuring healthy growth and survival of young mangrove seedlings. Saltwater or brackish water is highly recommended to mimic the natural environment within the mangrove rehabilitation areas.

Tidal flows facilitate regular watering in flooded nurseries. The set-up of nursery beds should allow the tidal waters to flow easily in and out to ensure proper drainage of the pots and the beds.

In floating nurseries, manual watering with appropriately saline water is essential. Where fresh water was used during the initial stages of germination, it requires to be reduced gradually with a mixture of saline water. Watering should be done twice daily for tender seedlings, i.e. early in the morning and late in the evening. The frequency of watering should be gradually reduced as seedlings approach planting to enable them acclimate to varying moisture conditions.

5.2 Shading

A shade is necessary to protect young seedlings from extreme environmental conditions such as intense sun or heavy rainfall. However, the shade must be gradually reduced as the seedlings grow to acclimatize before outplanting. Mangrove seedlings growing under full shade grow tall faster and become slender and weak. Seedlings raised under these conditions may not survive when outplanted. Mature mangrove trees and other locally available materials like fronds (twigs and leaves)

are commonly used to shade young seedlings. However, shade nets are also used for both types of nurseries but more ideal for permanent large-scale nurseries. When putting up shade structure, take note of the following

- The shade structures should have a minimum height of 1.5 m for ease of access and maintenance of seedlings.
- The shade should be 40-50 % after germination, after which it can be gradually reduced before outplanting; otherwise the seedlings will experience shock when moved directly from shade to the field.
- Shade should be wholly removed when seedlings are about 3-4 months old, depending on the mangrove species

5.3 Nursery Threats and Pest Management

Healthy mangrove seedlings should be free of pests and diseases. However, mangrove nurseries can be affected by various pests and diseases, and livestock which can hinder the growth and survival of young seedlings.

The common mangrove nursery pests found in Kenya are: mealybugs, bag worms, caterpillars, leaf miners, scale insects, barnacles, Rhizophora whiteflies, Littoraria sp, Balanus sp. Detailed description of attack on mangrove by various pests and their control methods are provided in Annex I

It is recommended that an integrated pest management approach be used to handle pests and disease occurrences in the nursery. The principle of this approach is that several methods are available that should be applied in a series or combination, depending on the circumstances under which the challenge presents itself. Each method presents an opportunity to bring the reported incidence down to a manageable level since eliminating the causal organisms is often uneconomical and unnecessary. Integrated pest management includes using highly targeted chemicals, such as pheromones, to disrupt pest mating or mechanical control, such as trapping or weeding (Hubert *et al*., 2021). The key steps in the process include:

- Setting action thresholds
- Monitoring and identifying pests and diseases (requires hands-on training)
- Prevention

Regular monitoring of nursery pests and diseases (surveillance) is necessary and achievable. From the data collected, undertaking a cost-benefit analysis can inform the nursery managers when occurrence crosses an economic threshold level and calls for intervention to minimize financial and environmental consequences. If further monitoring, identifications and action thresholds indicate that less risky controls are not working, additional pest control methods would be employed, such as targeted spraying of safe pesticides. Broadcast spraying of non-specific but environmentally safe pesticides is seen as a last resort

Routine management of nursery health

- Conduct daily inspections for insects and pests that may harm the seedlings. Remove insects and possible weeds.
- Polluted water sources should not be used to water the nursery.

5.4 Nursery Protection

Protecting a mangrove nursery is critical to safeguarding it from threats like human interference, wildlife, and browsers/stray animals. In addition to fencing, frequent surveillance is necessary to keep potential threats at bay.

5.5 Grading and Sorting

Grading is the selection of quality seedlings and sorting is the systematic separation of quality seedlings from dead, weak and dwarfed seedlings. seedlings are sorted based on size and quality. The sorting criteria may include ‘premium’, ‘standard’ and ‘reject.’

Sorting and grading seedlings is important in maintaining a high quality of seedlings in the nursery. All undesirable and malformed seedlings, as well as dead seedlings, should be removed. During sorting and grading, seedlings should be shifted regularly to prevent the roots from anchoring into external soil if on bare ground. The grouping assists in uniform care and monitoring.

During grading and sorting, the following should be considered;

- Species separation: all raised species are separated into groups to address their growth requirements.
- Consistent height of seedlings within production batches will ensure even growth and reduce competition for light.
- Shoot/stem diameter (girth) where thicker stems indicate robust seedlings
- Seedling leaves (count and size) as an indicator of seedling vigor.
- The leaves should be pest and disease-free.
- Healthy and well-developed root system.
- Seedling health status: those exhibiting symptoms of infection are separated for treatment or disposal to prevent the spread to healthy seedlings.

5.6 Root Pruning

Conventional root pruning practices should not be encouraged in mangroves as they expose sensitive root tissues to a highly saline environment, resulting in mass seedlings' mortality. Seedlings should not be allowed to stay in the nurseries beyond the required period to avoid roots penetrating and anchoring deep into the soil. Therefore, the seedlings should be regularly lifted every four weeks to prevent seedlings from establishing deep roots into the nursery floor and hence reduce transplanting shock. Polythene sheets may also be spread on the floor of the nursery bed, on which the potting tubes are arranged to prevent root penetration.

5.7 Monitoring and Record Keeping

The nursery requires regular monitoring and record keeping to ensure that the seedlings remain healthy and in good condition throughout the production period before they are taken out to the mangrove restoration site. Various nursery operations occur at different times during the production period and it is necessary to keep record of each activity. As per the nursery calendar there are those activities that are carried out once, occasionally and daily like watering. Therefore at any given time, the nursery has to be attended on daily basis.

The following records are necessary to maintain in a nursery.

- Seeds/propagule records to capture the seed collection information for reference
- Nursery daily diary to document the daily activities or operations undertaken
- Monthly nursery seedlings production, which captures the seedlings' production performance and stock balances at the close of every month
- Nursery tools, equipment and materials inventory
- Monthly nursery incidences and seedling mortality occurrence
- Nursery audit checklist for use by tree nursery inspectors from relevant government agencies

Effective monitoring and record-keeping not only improve the success rates of mangrove nurseries but also contribute to broader conservation goals by providing valuable data for research and restoration efforts.

Detailed sample record forms for use by the respective nursery practitioners are in Annex II

6.0 SEEDLINGS PREPARATION FOR OUT-PLANTING

6.1 Hardening Off

Preparing mangrove seedlings for field planting is essential for acclimatizing them to the outside environment. This is often an overlooked process, known as hardening off, which involves gradually reducing nursery practices like watering and shading to enable seedlings adapt to harsh field conditions. Hardening off should be done on the fourth or fifth month of seedling growth, a month before outplanting

- **Watering:** Managing watering levels for hardening off can be challenging in flooded nurseries and, in most cases, not feasible. In floating nurseries, watering frequency should be gradually decreased until planting time. In cases where freshwater is used in watering nurseries, hardening off entails progressive replacement with saline water.
- **Shade management:** During hardening off, exposure to sunlight should be increased one month before planting to acclimatise the plants to more sunlight. Remove the shade progressively through the last month, a layer each week.

6.2 Criteria for Selecting Seedlings for Out-planting

Mangrove seedling selection is an essential step that determines the success of restoration. It involves selecting vigorous seedlings that have been hardened off for outplanting. Selection of the seedlings will also require consideration of the period the seedlings have taken to grow in the nursery. Assessment of mangrove nursery seedlings performance in Lamu found that *C. tagal, R. mucronata, B. gymnorhiza,* and *A. marina* typically produced 6 to 8 leaves between 4 and 5 months under flooded nursery conditions. However, *C. tagal and R. mucronata* had four leaves in the floating nursery. *B. gymnorhiza* had the highest number of leaves (8) in both nursery types. At this age, the root system is also entirely developed (Plate 14).. Beyond this period, the roots may penetrate the potting tube into the ground and establish. However, this depends on the size of the potting tube and species type. Based on these observations, mangrove seedlings could be prepared for outplanting in approximately 4 to 5 months, depending on the specific nursery conditions and dynamics

Plate 14: Ready seedlings of various mangrove species with the respective root system (A- *Avicennia marina,* B-*Ceriops tagal,* C-*Bruguiera gymnorhiza* and D-*Rhizophora mucronata*)

6.3 Seedling Handling and Transportation

Proper handling of selected mangrove seedlings during collection and transportation is essential for seedling survival. Care must be taken to avoid breaking the soil ball and protect roots. Collect seedlings after the high tide or after watering to minimize root disturbance. Avoid picking seedlings at the tip to prevent injuring seedlings. While transporting the seedlings ensure they are not exposed to strong wind. The wind could cause seedlings to dry out and become burnt. Potting bags should be carefully removed only when planting to prevent soil loosening during transportation.

7.0 BEST PRACTICES AND COMMON MISTAKES

7.1 General Recommendations

i. Nursery establishment

A restoration plan should inform the establishment of mangrove nurseries for a specific site or area. The plan will guide the type of nursery, the mangrove species, and quantity of seedlings required. Mangrove nurseries should mimic natural mangrove habitats, align with restoration goals, and actively contribute to the restoration of mangrove ecosystems.

ii. Species selection

Mangrove nurseries must promote native species that are well adapted to local environmental conditions and facilitate production of healthy, disease-free germplasm to enhance mangrove ecosystem resilience and biodiversity. Species diversity is encouraged to promote biodiversity and ecosystem resilience.

iii. Sustainable Nursery Practices

Nursery practitioners should employ efficient water use and integrated pest management approaches, which entail using chemicals and non-chemical practices that do not harm seedlings or contaminate the environment.

iv. Training

Restoration campaigns should enhance the capacity of stakeholders in community-based ecological mangrove restoration (CBEMR) and awareness of when mangrove nurseries are essential. Efforts should engage local communities, which, in the long run, fosters stewardship and a sense of ownership and integrates Indigenous traditional knowledge into the management and establishment of the mangrove nurseries.

7.2 Common Mistakes in Mangrove Nursery Establishment and Management

i. Inappropriate site selection and set-up

Avoid choosing sites without adequate tidal flows, improper salinity levels, or unsuitable soil conditions, which can hinder seedling growth.

Plate 15: Dried-up *Ceriops tagal* propagules not frequently flooded by tidal waters

ii. Exclusion of local stakeholders

Local communities, environmental groups, and government agencies are key stakeholders in the planning and implementing mangrove restoration initiatives. Their involvement and understanding are vital for success of the mangrove nurseries.

Plate 16: *Ceriops tagal* seedlings cut down by unknown people

iii. Over-harvesting of planting materials

Avoid overharvesting planting materials, as this can deter natural regeneration and affect ecosystem balance. Always collect or harvest only mature and healthy planting materials. Training seed collectors to identify mature and quality germplasm for propagation can minimize the malpractice.

Plate 17: : Bulk collection of *Rhizophora mucronata* propagules

iv. Promoting mangrove nurseries as a livelihood activity, disregarding long-term restoration objectives

Nursery establishment and seedling production should be objective, focusing on long-term sustainability, which integrates its operations into the restoration and productivity of the broader ecosystem. This will avoid scenarios of overgrown mangrove seedlings in nurseries due to a lack of potential buyers or users. Chances of such seedlings surviving in the field are minimal due to shock and injuries in the root system.

Plate 18: Overgrown *Rhizophora mucronata* seedlings in a nursery

Plate 19: Overgrown *Rhizophora mucronata* seedlings in a nursery

v. Use of inappropriate propagation methods

When establishing flooded nurseries, avoid propagation methods interfering with the normal tidal flow. Ensure tidal waters drain during low tides to avoid waterlogging conditions within the nursery. Such practices include using; non-perforated potting bags, Swaziland beds, deeply made nursery beds. The seedlings will not survive in waterlogged conditions.

Plate 20: Unfilled non-perforated potting tubes

Plate 21: Swaziland beds in a flooded nursery

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ANNEX I: MANGROVE NURSERY PESTS AND MANAGEMENT

Name of pest or threat	Mangrove species attacked	Type of damage	Severity	Control Methods	Source
Littoraria sp.	*Rhizophora mucronata* *Avecinia marina*	Feeding on seedling leaves and biofouling.	Moderate	Manual removal using forceps.	Ong *et al.* (2010); Harmonis *et al.,* 2024; Citizen Science
Rhizophora Whiteflies	*Rhizophora mucronata*	Feeding on sap, causing leaf yellowing and defoliation.	Moderate to severe	Have an extensive number of natural enemies such as birds, ladybird beetles. Alternatively, oil emulsion sprays, made from a mix of oil, water, and soap, are effective, affordable, and ecofriendly for controlling softbodied insects like Rhizophora Whiteflies.	Ong *et al.* (2010); Citizen Science
Balanus sp.	*Avecinia marina*	Biofouling	Moderate to severe	Select suitable nursery sites on the upper shores to avoid barnacle infestation. Alternatively, use a soft brush to remove soft young shells.	Ong *et al.* (2010); Harmonis *et al.,* 2024; Citizen Science
Bag worms	*Rhizophora mucronata*	Seedling defoliation.	Moderate to severe	Use forceps to manually remove visible worms.	Ong *et al.* (2010); Citizen Science
Caterpillars *(Streblote sp.)*	*Avecinia marina*	Feeding on leaves, causing defoliation and stunted growth.	Moderate to severe	Manual removal by forceps.	Ong *et al.* (2010); Moslehi *et al.* (2024); Citizen Science.

Name of pest or threat	Mangrove species attacked	Type of damage	Severity	Control Methods	Source
Cattle / Livestock	*Avecinia marina* *Rhizophora mucronata* *Ceriops tagal*	Browsing on leaves, destroying the apical growth.	Moderate to severe.	Enhanced barriers around the mangrove nursery. Alternatively, physically, chase the cattle away.	Ong *et al.* (2010); Citizen Science.
Leaf Miners	*Ceriops tagal* *Avecinia marina*	Larvae tunnelling within leaves, leading to leaf necrosis.	Moderate	Direct control is unnecessary for leaf miners, as natural biological control keeps their population at manageable levels; maintaining optimal nursery conditions ensures healthy seedlings.	Ong *et al.* (2010); Chen *et al.* (2016); Citizen Science
Scale Insects (Crawlers)	*Avecinia marina* *Rhizophora mucronata*	Feeding on sap, causing leaf yellowing and reduced vigor.	Moderate	Manual removal by forceps.	Ong *et al.* (2010); Gawas & Yogamoorthi (2016); Citizen Science
Barnacle (Whither's barnacle)	*Rhizophora mucronata* *Avecinia marina*	Biofouling hence growth retardation.	Moderate to severe	Select suitable nursery sites on the upper shores to avoid barnacle infestation. Alternatively, use a soft brush to remove soft young shells.	Ong *et al.* (2010); Xiang *et al.* (2006); Citizen Science

Name of pest or threat	Mangrove species attacked	Type of damage	Severity	Control Methods	Source
Mealybug	*Rhizophora mucronata* *Ceriops tagal*	Sap sucking.	Moderate to Severe	Have an extensive number of natural enemies such as birds, ladybird beetles. Alternatively, oil emulsion sprays, made from a mix of oil,water, and soap, are effective, affordable, and ecofriendly for controlling soft bodied insects like mealybugs	Ong *et al.* (2010); Citizen Science

ANNEX II a:

MANGROVE TREE NURSERY SEED/PROPAGULE RECORD FORM

County: ……..

Name of CFA: ……..……..

Name of Nursery/Group/ …… **Location (Village)**……....

Name of Nursery: …….

S/No	Date Received	Species	Quantity Received		Date collected	Provenance (Source)	Batch no/ID	Remarks
			Seeds (kgs)	Propagules (number)				
1	27.04.2024	C.tagal	N/A	600	26.04.2024	Mokowe	M/2024/4/1	Collected and delivered by Rukia Abdi

ANNEX II b:

NURSERY DAILY DIARY[1]

County: ……..

Name of CFA: ……..……..

Name of Nursery/Group/ …… **Location (Village)**……....

Name of Species: …….

Date	Activity	Remarks	Recorded by
16.8.24	Received 200 propagules	Fresh and healthy	Bakari Hassan
16.8.24	Monitoring of pests and disease attacks	20 seedlings of *R.mucronata* were destroyed by crabs	Bakari Hassan
17.8.24	Germination of *A. marina* seedlings	About 50 seedlings germinated	Fatuma Ali

Guiding notes in filling:

Capture respective activity and details as follows:

1. Quantity of seeds/ propagules received
2. Pre-treatment method (where applicable)
3. Quantity sown/propagate (kg/pcs)
4. Date of Germination/Rooting
5. Number of seedlings pricked out
6. Number of seedlings died
7. Number of seedlings sold
8. Number of seedlings issued free
9. Number of seedlings affected by pests and diseases
10. Number of potting materials filled
11. Labour (Potting, watering, cleaning, pest control, weeding, protection)
12. Remarks

ANNEX II c:

MANGROVE MONTHLY TREE NURSERY SEEDLING PRODUCTION FORM

County: ……..

Name of CFA: ……..……..

Name of Nursery/Group/ …… **Location (Village)**…….....

Date of propagation/ sowing	Batch No/ID	Mangrove species	Pre-treatment method (where applicable)	Quantity sown/ propagated (Kg/pcs)		Date of Germination/ Rooting	Total pricked out	No. of seedlings died	No. of seedlings sold	No. of seedlings issued free	Balance	Cummulative	No. Plantable	Remarks
				Seeds (Kg)	Propagules (No)									
2.2.24	K/2024/1	Ct	N/A	N/A	500	16.2.24	500	0	0	0	500	500	200	Healthy

Germination/rooting percentage ……

ANNEX II d:

MANGROVE TREE NURSERY EQUIPMENT AND MATERIAL RECORD FORM

County: ……..

Name of CFA: ……..……..

Name of Nursery/Group/ …… **Location (Village)**…….....

Equipment/Material	Date of acquisition	Quantity	Cost	Condition	Remarks

ANNEX II e:

MANGROVE MONTHLY NURSERY INCIDENCE & SEEDLINGS MORTALITY OCCURRENCE FORM

County: ……..

Name of CFA: ……..……..

Name of Nursery/Group/ …… **Location (Village)**…….....

(Incidence/ Mortality)	Species affected	Severity (%) / No affected	Causative Agent / Organisms	Source of Agent / Organism	Date and Response applied	Remarks
On 10.05.2024 *A. marina* seedlings were destroyed	*A. marina*	50	Livestock	Nearby homesteads	Reported to CFA leadership and area chief on 11.05.2024	Plan to reinforce the fence

ANNEX II f:

MANGROVE TREE NURSERY AUDIT CHECKLIST FOR USE BY TREE NURSERY INSPECTORS (KEFRI & KFS)

County: ……..

Name of CFA: ……..……..

Name of Nursery/Group/ …… **Location (Village)**…….....

No	Heading	Standard	Mark	Remarks
1	Category	Commercial Floating nursery (Set above tidal range)	Pass mark - 75%	
		Commercial Flooded nursery (Set in tidal/mangrove areas)	Pass Mark - 65%	
2	Production capacity	Large scale commercial tree nursery with an output of over 1 million seedlings	Class 3	
		Medium scale commercial tree nursery with an output of over 501000-1000,000 seedlings	Class 2	
		Small scale commercial and individual tree nursery with an output of 5000-500,000 seedlings	Class 1	
3	Location of nursery and source of germplasm	Indicate verified source of planting materials and provenance areas		
4	Accessibility	Is the road/path leading to the nursery trafficable?	0.5	
		Is there a water channel leading to the nursery?	0.5	
		Is there a nursery signpost/ID marker?	0.5	
		Score	**1.5**	

No	Heading	Standard	Mark	Remarks
5	Propagule, seed and seedling quality	Does the nursery have seed/propagule storage facility or area?	1	
		Are seedlings well positioned/ well centered in the pot relative to the root ball?	1	
		Is there one plant per pot? Is there a single, straight, sturdy and well-centered seedling in the pot?	1	
		Absence of overgrown seedlings in the nursery/seedling carried over from the previous season	1	
		Is there any sign of root distortions? Are the roots well balanced and developed with no coiling in the pots? Is there satisfactory root plug development?	1	
		Are the seedlings sorted?	1	
		Is there a good Root: Shoot ratio (1:2)? Are ready seedlings having the shoot twice the root in height?	1	
		Are the seed or transplant beds constructed at the recommended height (at least 30cm high) to facilitate proper root development?	1	
		Is the nursery weeded? Free from weeds	1	
		Are there symptoms of nutrient deficiencies (Coloration)	1	
		For nurseries raising, Sonneratia alba,: Is transplanting of the germinated seedlings (pricking out) to the growing beds/pots done with great care to prevent deformation of the root system?	1	
		Score	**11**	

No	Heading	Standard	Mark	Remarks	
6	Seedling health	Are there incidences of plant pests of commercial species	10-15 seedlings affected	5-9 seedlings affected	Less than 5 seedlings affected
		Species 1	0.5	1	2
		Species 2	0.5	1	2
		Species 3	0.5	1	2
		Species 4	0.5	1	2
		Species 5	0.5	1	2
		Species 6	0.5	1	2
		Species 7	0.5	1	2
		Species 8	0.5	1	2
		Species 9	0.5	1	2
		Score	**4.5**	**9**	**18**
		Are there incidences of plant diseases of commercial species	10-15 seedlings affected	5-9 seedlings affected	Less than 5 seedlings affected
		Species 1	0.5	1	2
		Species 2	0.5	1	2
		Species 3	0.5	1	2
		Species 4	0.5	1	2
		Species 5	0.5	1	2
		Species 6	0.5	1	2
		Species 7	0.5	1	2

No	Heading	Standard	Mark	Remarks	
		Species 8	0.5	1	2
		Species 9	0.5	1	2
		Score	**4.5**	1	2
		For any pests were they reported to relevant authorities (KEFRI) and appropriate preventive and control measures taken?	2	1	2
		For any diseases, were they reported to relevant authorities (KEFRI) and appropriate preventive and control measures taken?	2	9	18
		Is there isolation of infected seedlings from other plants?	1		
		Are there any management system, knowledge or effort to control pest and diseases	1		
		Score	**6**		
7	Seedling care and maintenance	Are young seedlings put under shade after pricking out?	1		
		Are the seedling well watered	1		
		Is root pruning done frequently?	1		
		Is hardening up properly done	1		
		Score	**4**		
8	Nursery beds	Are the beds well aligned in the East-West direction?	0.5		
		Are the beds constructed at the recommended height and width?	0.5		
		Is each bed clearly labelled with species and sowing details?	0.5		
		Are the beds partitioned for easy stock taking as well as maintenance?	0.5		
		Is shade provided to the seedlings?	0.5		
		Are the beds free of weeds?	0.5		
		Score	**3**		

No	Heading	Standard	Mark	Remarks
9	Growing media and potting	Are pots used of the recommended sizes	0.5	
		Do the tubes have perforations to allow for excess drainage?	0.5	
		Is the media freely draining?	0.5	
		Is the media cohesive for transport?	0.5	
		Is the soil ball around the roots stable?	0.5	
		Score	**2.5**	
10	General Nursery hygiene/ neatness and Environmental care	Is the nursery and its surrounding clean and tidy?	1	
		Is there a rubbish pit? Is Waste/Refuse disposed of in an appropriate manner?	1	
		Is the nursery well drained?	1	
		Are there no signs of erosion in the nursery?	1	
		Are there alternative /innovative potting materials used in the nursery	0.5	
		Are the potting materials disposed off in an appropriate manner? Does the nursery recycle, re-use or bury old polythene pots?	1	
		Score	**6**	
11	Water Quality and Quantity	Is the water used clean and clear of suspensions?	0.5	
		Are there adequate water storage facilities?	0.5	
		Does the nursery have a reliable water source?	0.5	
		Do they use the right watering equipments/tools?	0.5	
		Score	**2**	
12	Nursery protection	Is there a fence to protect the nursery from animals and other intruders?	1	
		Is the nursery protected from wind damage?	1	
		Score	**2**	

No	Heading	Standard	Mark	Remarks
13	Nursery staff Welfare	Are workers provided with appropriate clothing and Personal Protective Equipment (PPE)?	0.5	
		Is drinking water provided?	0.5	
		Are workers provided with a shade to carry out some operations?	0.5	
		Is ergonomics taken into consideration in the working environment?	0.5	
		For a floating nursery Is there a toilet for workers and other nursery visitors?	0.5	
		Is there a complete(well-stocked) First Aid kit available for the nursery	0.5	
		Is there a trained First Aider with valid training certificates?	0.5	
		Score	**3.5**	
14	Stores and record keeping	General appearance and cleanliness of storage area: Is the store well organized?	2	
		Is the tools register kept up to date?	2	
		Are seed and seedling purchase records kept up to date? E.g. (date of receipt, supplier, species, Lot No. etc.)	2	
		Are seed sowing and germination records/data recorded?	2	
		Are financial transactions recorded? Payment vouchers, receipts, invoices etc?	2	
		Are activity records kept to date?	2	
		Are fertilizers, pesticides and fungicides used recorded?	2	
		Are pest and diseases incidence records made	2	
		Are there records of the nursery stock	1	

No	Heading	Standard	Mark	Remarks
		Do they have an up to date visitors book	1	
		Score	**20**	
15	Skills of nursery workers	Evidence of having attended a training in nursery management/CBEMR from a recognized session	3	
		Score	**3**	
		TOTAL	**100**	

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