Western Indian Ocean Ecosystem Guidelines and Toolkits

Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region

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Preface

Overexploitation and general degradation of mangrove forests is a common feature across the countries in the Western Indian Ocean (WIO) region. Accordingly, mangrove restoration initiatives have been increasingly proposed as mechanisms to compensate for the losses and promote sustainable use of mangrove resources. However, in many countries, more failures of mangrove restoration projects than successes are reported. This has been attributed to poor understanding of the local ecosystem requirements and misapplication of the principles of ecological mangrove restoration.

The current *Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean region* targets communities, civil society, national agencies, and practitioners involved in mangrove conservation activities. The *Guidelines* provides background information on the mangrove forests and their attributes, as well as the threats they face – both human and natural. Using experiences in mangrove restoration projects from Kenya, United Republic of Tanzania, Mozambique, Madagascar, Mauritius and Seychelles, the *Guidelines* analyzes challenges facing community-based mangrove restoration projects; and provide possible solutions to the identified problems.

During the preparation of the *Guidelines*, authors collected country specific information through expert consultations, workshops, and field visits. Additional information on mangrove restoration was accessed online and through direct contacts with ongoing projects in other regions for comparison and learning.

Many mangrove restoration projects have been implemented with specific objectives, such as production forestry, coastal protection, ecosystem preservation, and fisheries support, among others. Lessons from around the world have demonstrated that mangrove restoration is feasible as long as the questions of *why, where, when, how* and *by whom* are appropriately addressed. The *Guidelines* demonstrate the value of goal setting in restoration projects and illustrate how they can be achieved.

There are many ongoing mangrove restoration activities in the WIO region, involving different stakeholders, including local communities, government agencies, non-governmental organizations (NGOs), private sectors, and funding agencies. However, these initiatives are faced with a number of operational challenges that have led to multiple failures. The *Guidelines* comprehensively analyze prevailing circumstances, sharing local lessons for best institutional arrangements and stakeholders' engagement mechanisms that enable efficient implementation of restoration projects.

Interaction between local communities and mangroves is often not well appreciated when formulating mangrove restoration projects. Over-exploitation of mangrove resources and conversion of the area into other land uses are socio-ecologically complex issues that require deep understanding of the root causes to identify possible intervention measures. Multiple dimensions of mangrove restoration and management have been addressed in the *Guidelines*.

Many mangrove restoration initiatives in the region are small scale, largely involving one to several local communities and only a few mangrove tree species. Implementation of mangrove restoration projects at larger scale involves more species and consequently requires adaptive approaches (learning by doing) to be effective. Adaptive pathways include the use of multiple scenarios of future socio-economic and physical changes (e.g. population growth, climate change, or land-use). The *Guidelines*, which describe a step-by-step approach to ecological mangrove restoration in order to realize success, will be hosted by the WIO Mangrove Network, which will be responsible for any future revisions and dissemination in consultation with the United Nations Environment Program (UNEP) Nairobi Convention and also in collaboration with other partners in the region.

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Acronyms and abbreviations

BMU	Beach Management Unit
CBO	Community Based Organizations
DBH	Diameter at Breast Height
DW	Dry weight
CFAs	Community Forest Associations
EbA	Ecosystem based Adaptation
EMR	Ecosystem Mangrove Restoration
FAO	Food and Agricultural Organization of the United Nations
GEF	Global Environmental Facility
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeit
ha	hectare
IMS	Institute of Marine Sciences in Zanzibar
IGAs	Income Generating Activities
KFS	Kenya Forest Service
KMFRI	Kenya Marine and Fisheries Research Institute
MAP	Mangrove Action Project
MCB-FF	Mauritius Commercial Bank- Forward Foundation
MHWS	Mean High Water Springs
MICOA	Ministry for the Coordination of Environmental Affairs
MITADER	Ministry of Land, Environment and Rural Development of Mozambique
MSL	Mean Sea Level
MTL	Mean Tide Level
NGO	Non-Governmental Organization
NRMC	Natural Resource Management Committee
PES	Payments for Ecosystem Services
PSC	Project Steering Committee
SWAMP	Sustainable Wetlands Adaptation and Mitigation Program
t	tonnes
TNC	The Nature Conservancy
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
USFS	United States Forest Service
VBF	Vanga Blue Forest
WIO	Western Indian Ocean
WIOMN	Western Indian Ocean Mangrove Network
WIOMSA	Western Indian Ocean Marine Science Association
WIOSAP	Western Indian Ocean Strategic Action Program
WWF	World Wide Fund for Nature

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Photo credits: Abel Kiprono (plate 3), Ann Wanjiru (plate 4), Elvina Henriette (plate 16), GIZ (plate 12), Henriques Balidy (plate 13 - also cover photo), KMFRI archives (plates 5 and 17), Mikoko Pamoja (plate 15), Mwita M. Mangora (plates 1, 2, 6, 7, 8 and 14), MCB Forward Foundation (plate 11), Uzo Egbuche (plate 10), Z. H. Randrianasolo (plate 9).

About this Guide: Need and Use

The WIO Mangrove Network regional book *on Mangroves of the Western Indian Ocean: status and management* (Bosire *et al.*, 2016) identified commonalities in the challenges facing mangroves of the region. The book demonstrated widespread degradation and loss of mangrove forests across the region and the need for their restoration, protection and sustainable management. Accordingly, mangrove restoration initiatives through natural regeneration and actual planting are beginning to compensate for some of the degraded and lost mangrove resources.

However, experience and lessons from many restoration projects within the region pose questions on the desired impacts and sustainability of restored areas, because failures continue to be reported in many countries; mainly attributed to poor understanding of the local ecosystem requirements and poor applications of the principles of ecological restoration. While there are a number of guidelines for mangrove restoration developed based on activities in other regions around the world, mostly from South East Asia (e.g. Primavera *et al.*, 2012; Lewis and Brown 2014), their applications have not improved the success of restoration projects in the WIO region, hence the need for a specific regional guide that is relevant to local conditions and economies.

Development of these *Guidelines* has involved in-country and regional consultations and expert knowledge sharing coordinated by the WIO Mangrove Network (WIOMN), and comprehensive review of literature on past and ongoing mangrove restoration efforts to understand what works and what does not for the region. Initial drafts of the guidelines were subjected to expert reviews prior to the production of a final version. The *Guidelines* was tested in the field and used to establish demonstration projects in Kenya supported through The Nature Conservancy (TNC) and other agencies.

Many mangrove restoration projects have been implemented in the WIO region over the years. These attempts include more failures than successes (Bosire *et al.*, 2008). Kairo *et al.*, (2001), highlighted poor site selection, species suitability, unclear objectives driving restoration projects and lack of monitoring programmes as some factors that have contributed to failures of mangrove restoration projects. Information on the lessons and best practices has not been readily available for projects intending to carry out restoration activities within the region. Rather, many restoration activities have been haphazard or with techniques employed without key considerations of their workability in the region.

The purpose of preparing this *Guidelines on Mangrove Ecosystem Restoration for the WIO Region* is, therefore, to provide the information that will help ensure successful mangrove restoration projects within the WIO region. The aims are to provide step-by-step procedures to restore mangrove on areas impacted by both human and natural stressors. The objectives are to:

- i Highlight status and conditions of mangrove forests around the world, their goods and services, threats facing them, and the need to restore degraded mangroves for present and future generations;
- ii Serve as documentation of previous mangrove restoration activities and lessons learnt from across the WIO region;
- iii Outline best practices from previous mangrove restoration activities across the region thus allowing for objective site-specific assessment of restoration pathways and enhanced successes; and
- iv Help users in the region to focus on what is most likely to work for them, to assist them to better match the array of available tools to their particular situation.

Target Audience and Users

These *Guidelines* are intended for the entirety of different stakeholders concerned with mangrove conservation and management, including: resource managers, practitioners, scientists, students, and communities at large. These *Guidelines* integrate and make use of existing literature and guidelines/protocols/manuals, complemented by the practical experiences on mangrove restoration projects in the region.

Conversion Table

Value (grams	Unit	Name
10^3	Kg	Kilogram
10^6	Mg	Megagram (tonne)
10^9	Gg	Gigagram
10^{12}	Tg	Teragram
10^{15}	Pg	Petagram
10^{18}	Eg	Exagram
10^{21}	Zg	Zettagram

One Gigatonne = 1000 Tera-grams
One Hectare = 10,000 m^2

Glossary

Calyx: The outermost whorl of a flower parts, comprising the sepals, which covers and protects the petals as they develop.

Deforestation: The clearing of forests, conversion of forest land to non-forest uses.

Equinoctial: A maximum tidal event happening at or near the time of equinox.

Hypocotyl: Is the elongated section of a mangrove propagule and found below cotyledonary color.

Mangrove degradation: Biotic and abiotic processes that results in the loss of productive potential of mangrove forests.

Mangrove pole: The merchantable part of the mangrove stem used in construction.

Mangrove rehabilitation: The act of partially or, more rarely, fully recovering structural or functional characteristics of mangrove ecosystem.

Mangrove restoration: The act of bringing an ecosystem back into, as nearly as possible, its original condition.

Multiple uses: More than one use of a resource at one time. For instance, it is possible to practice fish culture (silvo-fishery) and bee farming (silvo-apiculture) in mangrove areas without necessarily affecting the functioning of mangrove ecosystem.

Natural regeneration: Is a process where propagules or seeds of mangroves are naturally recruited. This may occur in both degraded and non-degraded forest.

Propagule: The reproductive unit in mangroves. In some mangrove literature a propagule is also referred to as a seed.

Radicle: Part of plant embryo that develops into the primary root.

Reforestation: Replant (an area of land) with forest trees.

Sapling: Is a sprouted propagule, sometimes referred to as seedling.

Silviculture: An area managed for the production of timber and other forest produce or maintained under woody vegetation for such indirect benefits as protection against flood or recreation.

Sustainable forest management: Utilization of forest resources without compromising their use by present and future generations.

Tree biomass: The biomass of vegetation classified as trees including foliage, trunk, roots and branches.

Wildlings: Are naturally occurring saplings that are collected during replanting.

1. Mangrove Ecosystems

1.1 Global Mangrove Extent and Distribution

Mangroves are forests that grow in tropical and subtropical coasts between 32° N and 38° S (Saenger 2003, Figure 1). Latitudinal limits of mangroves are by temperature pattern; both sea-surface and air temperatures (Giri *et al.*, 2011). Rainfall and freshwater runoff have a strong influence over mangrove forest structure, largely through the reduction of salinity. In areas with low, irregular or limited seasonal rainfall the forest structure is reduced although the same species may be present.

Two main global centers of mangrove diversity have been identified: the eastern group includes the Indo-West Pacific that stretches from the central Pacific to the mainland coast of the Western Indian Ocean (WIO) region and the western group that includes the mangroves of Atlantic-East Pacific including those of West Africa, Americas and the Caribbean Sea. These two regions have quite different floristic compositions, with the eastern region having approximately five times the number of species found in the western region (Figure 1). Only one mangrove fern, *Acrostichum aureum* L., occurs in both the eastern and western groups. Three genera (i.e. *Acrostichum*, *Avicennia* and *Rhizophora*) occur in both groups (Duke 1992; UNEP 2014).

1.2 WIO Mangrove Extent and Distribution

The WIO region extends from latitude 12°N to 34°S and longitude 30°E to 80°E with a combined coastline exceeding 15,000 km (Figure 2; UNEP 2009), composed of five mainland states: Somalia, Kenya, Tanzania, Mozambique and South Africa, and five Island states: Mauritius, Comoros, Seychelles, Madagascar and Reunion (France). The total area of mangrove cover in the WIO region is estimated at 1.0 million hectares (Table 1; Bosire *et al.*, 2016); representing about 5.0% of global mangrove coverage. These forests occupy sheltered shorelines, deltas, creeks, bays and estuaries. The best developed mangroves in the region are found in the deltas of Rufiji River (Tanzania), Tana River (Kenya), Zambezi and Limpopo rivers (Mozambique) and along the west coast of Madagascar at Mahajanga, Nosy be and Hahavavy. Nine common mangrove species occur in the region (Table 1) growing as mixed and pure formations. The most dominant species are *Rhizophora mucronata*, *Ceriops tagal*, *Avicennia marina*, *Bruguiera gymnorrhiza* and *Sonneratia alba* (Bosire *et al.*, 2016). There is however, a continuing debate on whether *Pemphis acidula* should be regarded as a true mangrove.

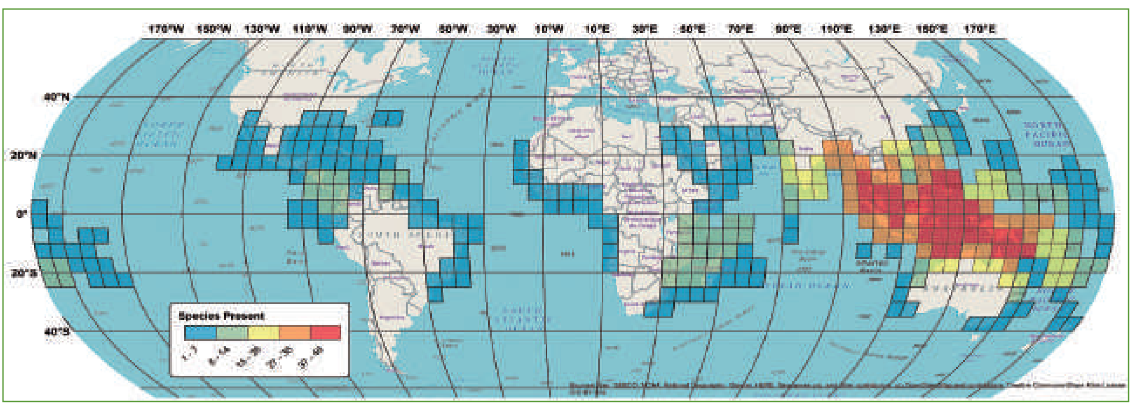


Figure 1. World map of the mangrove distribution zones and the number of mangrove species along each region (Hamilton, 2019).

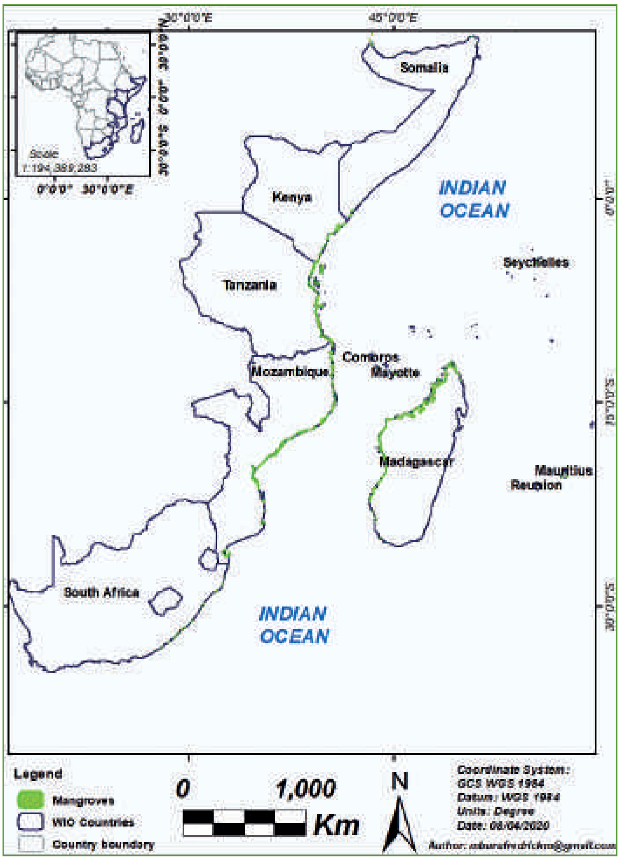


Figure 2. Map of the Western Indian Ocean region showing occurrence of mangrove forests.

Table 1. Mangrove coverage and species assemblages in WIO. (Source: Bosire *et al.,* 2016).

COUNTRY	MANGROVE AREA (ha)	AM	BG	CT	HL	LR	RM	SA	XG	XM
Somalia	3,000		x	x			x	x	x	
Kenya	61,000	x	x	x	x	x	x	x	x	x
Tanzania	181,000	x	x	x	x	x	x	x	x	x
Mozambique	390,500	x	x	x	x	x	x	x	x	x
South Africa	1,921	x		x			x		x	
Madagascar	314,000	x	x	x	x	x	x	x	x	
Seychelles	1,900	x	x	x		x	x	x	x	
Mauritius	145		x				x			
Comoros	91	x	x	x	x	x		x		

x denotes presence of mangrove species.

Am = *Avicennia marina*; Bg = *Bruguiera gymnorrhiza*; Ct = *Ceriops tagal*; Hl = *Heritiera littoralis*; Lr = *Lumnitzera racemosa;* Rm = *Rhizophora mucronata*; Sa = *Sonneratia alba*; Xg= *Xylocarpus granatum*; Xm = *Xylocarpus mollucensis*

1.3 Mangrove Forest Structure and Geomorphology

1.3.1 Mangrove forest types

Mangroves have been classified into different forest types according to their structural and functional characteristics. Hypersaline or drought-stressed areas tend to support sparse assemblages of scrubby trees that are short, brittle, and exceedingly slow growing relative to trees growing in riverine, estuarine or basin mangroves (Twilley 1995), such as those of Tana, Rufiji and Zambezi Deltas in Kenya, Tanzania and Mozambique respectively. These forests grow to different canopy heights depending on environmental conditions, substrate suitability and frequency of anthropogenic and natural disturbances. Based simply on their growth form, Lugo and Snedaker (1974) recognized six mangrove community types (Figure 3): (i) ***Fringing mangroves*** - occurs mostly in gentle coastline that are inundated by daily tides, (ii) ***Riverine mangroves*** - are influenced by freshwater input and occurs at the edge of major rivers draining into the oceans, (iii) ***Basin mangroves*** - have no direct link with the ocean; and will be found at the back of both fringing and riverine mangroves, (iv) ***Over-wash mangroves*** - are dominated by intertidal isolated stands on the seaward side, such *S. alba* stand, (v) ***Dwarf or stunted mangroves*** - scrub forests common in abnormal or equinoctial tidal reach, having tidal inundation of few days per month; and (iv) ***Hammock mangroves*** - are similar to basin mangroves but are formed over accumulated mangrove-derived peat. These different forest types may co-exist in the same area.

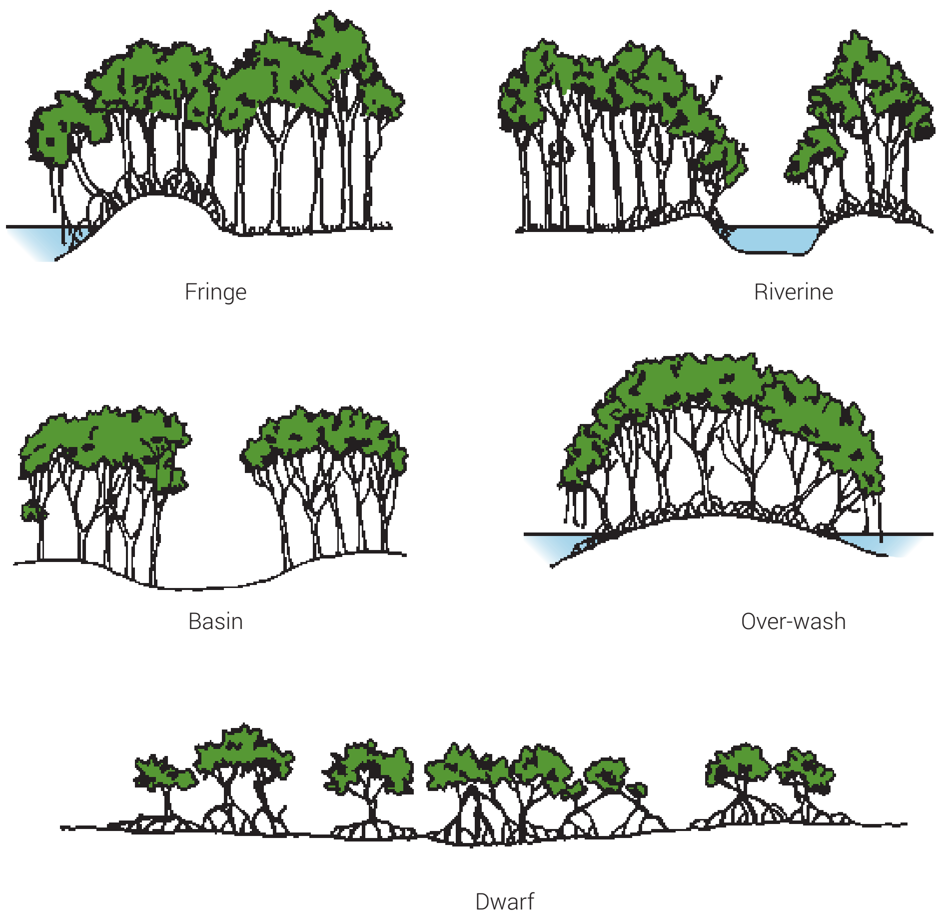


Figure 3. Mangrove forest types (redrawn from Lugo and Snedaker 1974).

1.3.2 Mangrove zonation

Zonation refers to the occurrence, often of mono-specific zones of mangroves, parallel to shorelines. This horizontal distribution of mangrove species is mainly caused by environment gradients such as salinity across the intertidal area (Johnstone and Frodin 1982). Other contributory factors include frequency of tidal inundation, tidal flow and geomorphology, nutrient availability, soil sulphide and redox levels, competition between species, tidal sorting of propagules, light availability to seedlings and predation of seedlings by crabs, among others (Saenger 2003; Ellison 2009; Friess 2016). A typical zonation pattern of mangroves in WIO is provided in Figure 4. Typically, *S. alba* is found growing at the seaward margin, followed by *R. mucronata*, *C. tagal* and *A. marina* on the landward side. Clear zonation may, however, not be observed due to disturbances that affect substrate quality, seedling dispersal, propagule stranding and development.

Knowledge of mangrove species zonation is essential in determining suitable areas for different species (Rabinowitz 1978.) For these reasons, *S. alba* should be planted in low, muddy areas closer to the sea where salinity is constant. In the marginal dry landward side with high salinity, *C. tagal* and *A. marina* may be planted (Kairo *et al.*, 2001).

1.4 Mangrove goods and services

Mangroves throughout the world connect our land and its people with the sea, providing millions with a wide range of goods and services that could be viewed at both local, national and global levels (UNEP 2014; Bosire *et al.*, 2016; Table 2). Communities along the coast depend on mangrove wood for fuel, construction, fish traps and boat building and non-wood products such as traditional medicine. Coastal communities often associate mangrove forests with sentimental and cultural values. Some communities have ventured into ecotourism and other income generating activities (IGAs) in the mangroves (Kairo *et al.*, 2008).

1.4.1 Habitat and nursery functions

Mangroves function as habitat and nursery grounds for fish and other wildlife (Huxham *et al.*, 2004, Figure 5). The habitat and nursery role of mangroves is due to their high productivity, food abundance, lower predation pressure and complex rooting system (FAO 2007; Nagelkerken 2009). The broad and towering canopies provide nesting and resting ground for migratory and sea birds and other wildlife. Stable and resilient mangrove ecosystems support the associated ecosystems such as seagrass beds and coral reefs thus maintaining their health, functioning and integrity (Kairo *et al.*, 2001; Lee *et al.*, 2014).

1.4.2 Coastal protection and erosion control

Mangroves act as buffer between land and the sea (Dahdouh-Guebas and Jayatissa, 2009), where the fringing coastline and bays surrounded by mangroves play a significant role in sediment stabilization, shoreline and coastal protection as well as water purification. In addition, mangroves stabilize shorelines, prevent coastal erosion and protect coastlines (Walters *et al.*, 2008). It has

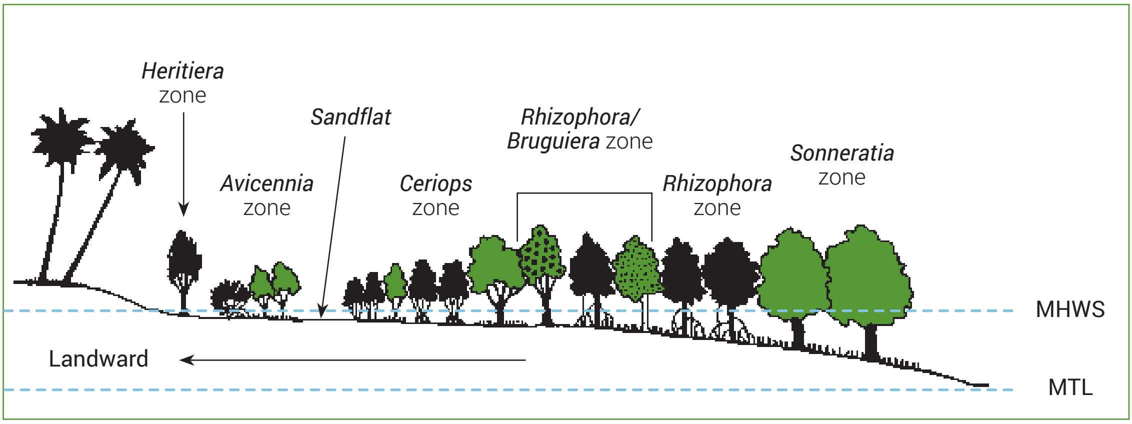


Figure 4. Typical mangrove species zonation in WIO region.

Table 2. Valuing mangrove goods and services.

COMMUNITY LEVEL	NATIONAL LEVEL	GLOBAL LEVEL
Timber and firewood	Timber production	Conservation
Fodder for animals	Charcoal production	Education
Traditional medicine	Shrimp and crab industries	Preservation of biodiversity
Food	Mangrove silviculture	Indicator of climate change
Local employment	Trade	
Recreation	Ecotourism	
Shell collection	Water quality management	
Erosion control	Education	
Protection from storm damage	Coastal and estuary protection	

been reported that mangroves can reduce the height of wind and swell waves by up to 66% over 100 m; and reduce the water level of storm surges between 5 and 50 cm per km of mangrove width (McIvor *et al.*, 2012;). Diminished energy of incoming waves also lessens the risk of flooding to communities that live behind mangroves (Spalding *et al.*, 2014).

1.4.3 Nutrient cycling and carbon sequestration

Mangroves have an estimated mean biomass of 247 t DW ha^{-1} that is virtually identical to tropical terrestrial forests (Alongi 2009), forming a base of many coastal food webs through regulating and supporting nutrient cycling. In the context of climate change, however, mangroves capture and store huge stocks of carbon – in both above and below ground components; making them one of the most carbon-rich ecosystems on the planet (Figure 6; Donato *et al.*, 2011). Estimated to cover 13.7 – 15.2 million hectares worldwide, mangroves sequester up to 31.2 – 34.4 million tonnes of carbon per year (Howard *et al.*, 2017). This carbon risks being released back into the atmosphere when mangroves are lost or their land converted for other land uses (Murray *et al.*, 2011; Pendleton *et al.*, 2012). As such, halting the current decline and restoring degraded mangroves areas may form an important part of climate change mitigation efforts.

1.5 Threats to Mangroves

1.5.1 Human pressures on mangroves

World mangrove area was estimated at 18.1 million hectares by Spalding *et al.*, (1997). However, this global coverage was revised downward to 13.7 million hectares by Giri *et al.*, (2011), and then to 8.3 million hectares by Hamilton and Casey (2016). At least 35% of mangrove forest area was lost worldwide during the 1980 to 1990s period (Valiela *et al.*, 2001), with losses of 50–80% in some regions (Wolanski *et al.*, 2000). In the WIO region, 8% of mangrove cover was lost between 1975 and 2000, translating to a decline of 3,000ha/yr (FAO 2007; UNEP 2009). Some areas in WIO have been reported to have lost as much as 88% (Bosire *et al.*, 2014). Causes of degradation and loss of mangroves in the WIO region are over-exploitation of resources (Plate 1), conversion of mangrove area to other land uses, diversions of freshwater flow, pollution, and climate change. With rapid increase in population and coastal development (Plate 2), loss of mangrove is likely to increase (Bosire *et al.*, 2016). This has consequently impacted on fisheries, shoreline stability and resources sustainability. The underlying root causes of loss and degradation of mangroves in the WIO region have been identified as population pressure, poverty and inequality, poor governance, and economic pressure (Bosire *et al.*, 2016).

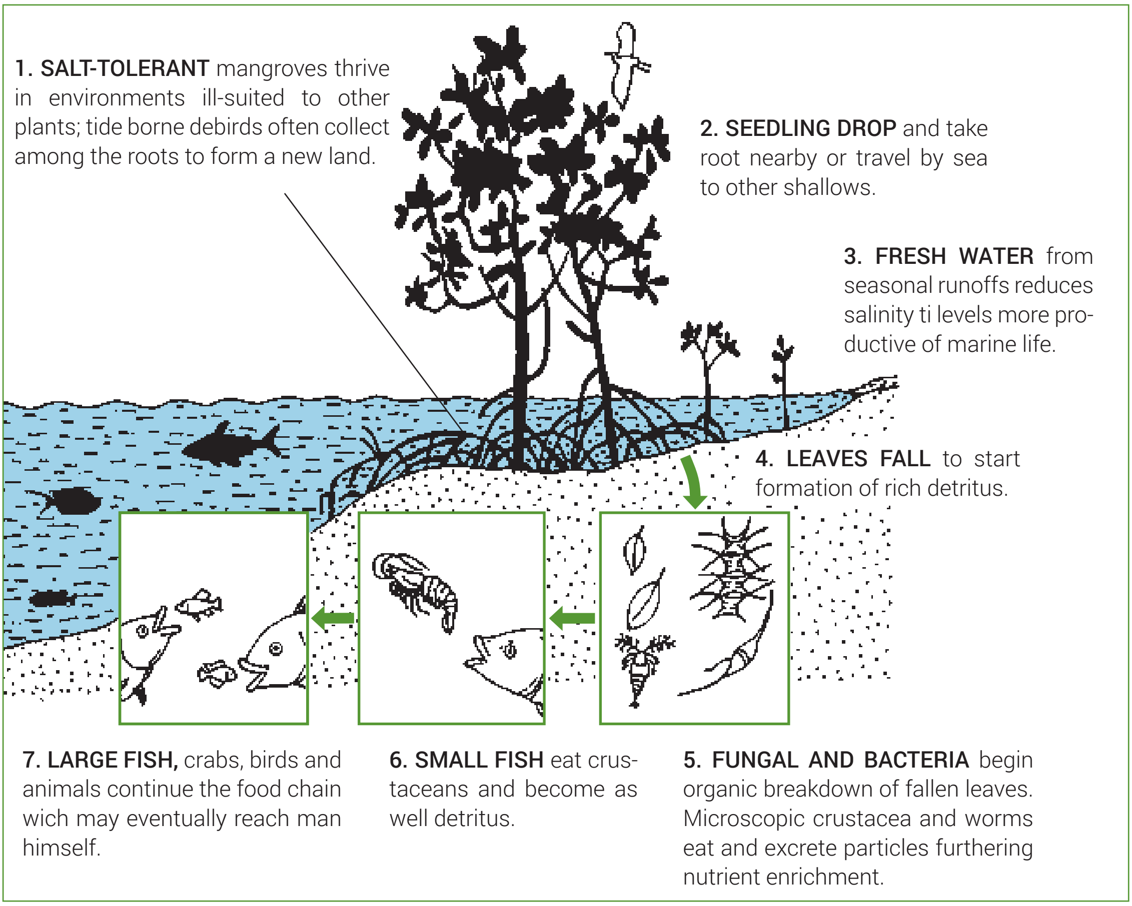


Figure 5. Ecological processes and function supported by mangrove ecosystem that are of social and economic importance.

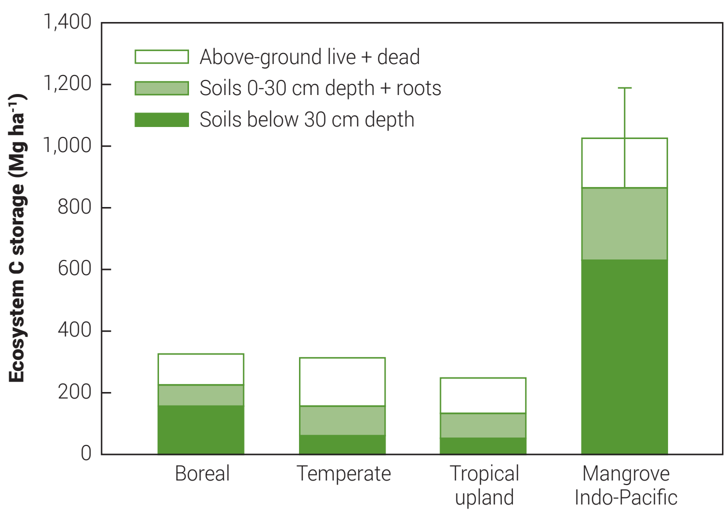


Figure 6. A global model comparing mangrove C storage (mean ±95% confidence interval) with that of other major forest domains (Donato *et al.*, 2011).

Plate 1. Charcoal production from clear felled mangroves in Ruvu Estuary, Tanzania.

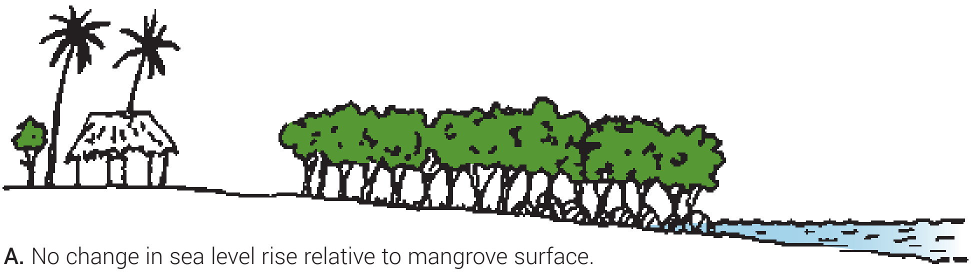
Plate 2. Peri-urban mangroves pressed with a combination of property development and salt pans at Ununio, Dar es Salaam, Tanzania.

1.5.2 Mangroves and climate change

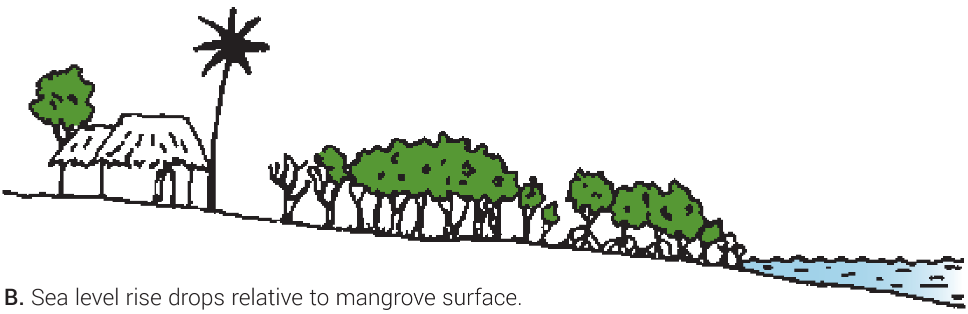
Climate change threatens the remaining mangrove areas mainly through rising sea levels and increased sedimentation caused by precipitation and shoreline change (Bosire *et al.*, 2016; Plate 3). During the 20th Century, the global mean sea level rose by about 15cm (IPCC 2019). It is currently rising more than twice as fast and the pace will further accelerate reaching up to 1.10m in 2100 if greenhouse gas emissions are not sharply reduced (IPCC 2019). There are four general scenarios for mangrove response to rising sea levels: (i) no change in mangrove position (ii) mangrove margins transgress seaward, (iii) mangrove margins transgress landward, and (iv) mangrove drown when their expansion corridor is blocked through coastal development (Figure 7). The nature of the problems produced by sea-level rise varies between and within regions due to a range of geomorphic features, socioeconomic development, institutional, and cultural factors (Gilman *et al.*, 2008)

In the WIO region, climate change effects have already devastated mangrove areas (Macamo *et al.*, 2016). In the Save delta in Mozambique, for instance, almost half of the mangroves were reported degraded and lost due to sedimentation associated with cyclones and extreme precipitation (Massuanganhe *et al.*, 2015). In other areas such as Mwache in Kenya (Kitheka *et al.*, 2002) and along the Limpopo Delta in Mozambique (Bendeira and Balidy 2016), Rufiji Delta in Tanzania (Erftemeijer and Hamerlynck 2005) and Tana River Delta in Kenya (Wieczkowski 2009), prolonged flooding has been observed to cause the death of mangroves.

Plate 3. Mangrove dieback due to increased sedimentation caused by shoreline change at Gazi Bay, Kenya.



A. No change in sea level rise relative to mangrove surface.
Therefore, no change in mangrove position.



B. Sea level rise drops relative to mangrove surface.
Therefore, mangrove transgress seaward.

C. Sea level rises relative to mangrove surface and there is no barrier.
In this case, mangroves transgress landward.

D. Sea level rises relative to mangrove surface and there is barrier on the landward side.
Therefore, mangroves on the seaward margin erodes and drowns.

Figure 7. Scenarios for generalized mangrove responses to changes in relative sea level.

2. Concept and Principles of Mangrove Restoration

2.1 Mangrove Restoration: When is it necessary?

Mangrove restoration is a management strategy to compensate for degraded and lost ecosystem goods and services. It has the potential to increase the mangrove resource base, provide employment to local populations, protect fragile tropical coastlines and enhance biodiversity and fisheries productivity. Mangrove restoration projects are already proceeding at a large scale in other countries such as Bangladesh, India, Vietnam and Malaysia principally to provide protection in typhoon-prone areas as well as to generate direct economic benefits to the people (Mclvor *et al.*, 2012; Spalding *et al.*, 2014; Sandilyan and Kathiresan, 2015). Though plantation productivity has been shown to decline with age (Kairo *et al.*, 2008), given the chance, restored mangroves may develop into mature forests with many of the structural and functional characteristics of mature mangrove systems. In Kenya, for example, low diversity planting has given way to higher diversity forests, provided the reforested area is not harvested (Kairo *et al.*, 2008). Mangrove restoration can thus be used as a tool to return the lost forest in order to achieve the objectives of sustainable mangrove management.

Restoration is recommended when an ecosystem has been altered to such an extent that it can no longer self-correct and/or self-renew. Depending on the level of human pressures, in many sites, natural regeneration is practically impossible without human intervention to restore the physical and biological characteristics. Accordingly, mangrove restoration has entailed direct planting of propagules, transplanting wildlings/saplings or nursery raised seedlings to the designated sites. Mangrove reforestation projects in most parts of the WIO region have used propagules or saplings/wildings of the family Rhizophoraceae (*R. mucronata*, *C. tagal* and *B. gymnorhiza*) and *A. marina*. In some limited cases, *S. alba* has been planted, e.g. in Gazi Bay, Kenya (Kairo *et al.*, 2003; 2008).

When a need exists for mangrove restoration it implies that degradation, losses, or habitat alteration have occurred in the past due to either human or natural factors. Given time, however, mangrove forests can self-repair if: (i) the tidal regime has not been disrupted and (ii) seedling availability is not limited or blocked (Lewis 1982; Cintron-Molero 1992; Kairo *et al.*, 2001; Saenger 2003). Nonetheless, in many places around the world, mangrove ecosystems have been degraded and lost to an extent that they cannot recover naturally (Valiela *et al.*, 2001). In such cases restoration is necessary. While artificial planting can be used to return the lost mangrove forests (Thivakaran 2017), non-mangrove areas, including; seagrass beds, mudflats and sandflats should be avoided. Restoration through planting of mangrove propagules and saplings is recommended when:

i. There is limited waterborne propagules due to lack of nearby parent trees or hydrological connection which inhibit dispersal;
ii. There is need to introduce valuable specific species which have been lost in the area (enrichment planting);
iii. Research is being carried out for educational and cultural purposes; and
iv. Planting for production forestry.

2.2 Typology of Mangrove Restoration

2.2.1 Natural regeneration

This approach uses natural occurring mangrove propagules (or seeds) to restock degraded sites. In this case, regeneration is from direct, freely falling and dispersed mangrove propagules, where species composition of the regenerated forest depends on the species types and combinations of the adjacent forest from where propagules are dispersed. In the family Rhizophoraceae for example, propagules furnished with pointed hypocotyls fall freely from the parent and can plant themselves into the mud (Kairo *et al.*, 2001), or they may be stranded and planted away from

Plate 4. Caring of planted *S. alba* in Gazi Bay, Kenya.

the parent plant (Rabinowitz 1978; Van Speybroeck 1992). The major problem of the natural regeneration method is that the recruits may not necessarily be of the same species removed (Table 3; Kairo *et al.*, 2001).

Important biological and physical factors that determine success for natural regeneration include forest conditions, tides and soil stability. Where natural regeneration is an option to restore a degraded mangrove area, and availability of propagules and seeds is ensured, restoration planning should first examine and validate the potential existence of primary stresses such as blocked tidal inundation that might prevent natural succession from occurring, and remove those stressors to enhance natural recovery. This can be achieved through **hydrological restoration**, that is re-modification and re-establishment of original conditions of the ecosystem including tidal regimes (Turner and Lewis 1996; Kamali and Hashim 2011). Where signs of natural recovery are not observed within 6 to 12 months after adjustments of the physical conditions, consideration for undertaking actual mangrove reforestation either through direct planting of propagules collected from the forest or nursery-raised seedlings should be considered and evaluated (see also Chapter 6).

2.2.2 Artificial regeneration

Artificial regeneration entails direct planting of desired propagules and saplings (of less than 1.2 m high), and rarely the use of small trees (of up to 6

Table 3. Advantages and disadvantages of natural mangrove restoration.

ADVANTAGES	DISADVANTAGES
- Cheaper to establish	- Replacement may not be of the same species removed
- Less subsidy is needed in terms of labour and machinery	- Absence of mother trees may result in low/ or no propagule supply
- Less soil disturbance	- Genetically improved stock may not be easily introduced
- Saplings establish more vigorously	- Excessive wave action may cause poor establishment
- Origin of seed sources usually known	- Predation of propagules by macrobenthos (e.g. crabs, snails etc.)
- A naturally restored stand acquires site characteristics that are almost similar to the original forests	- Less control over spacing, initial stocking and composition of seedlings
	- May lead to loss of community employment

m high) of chosen species at the designated restoration site. Use of propagules and nursery-raised saplings is the most common method of mangrove restoration. The techniques of mangrove planting have not been perfected for many species. Most mangrove restoration projects have used families, Rhizophoraceae and Avicenniaceae. This has led to poor site and species selections (Plate 5).

There are several advantages of using artificial regeneration (Table 4): the species composition and distribution can be controlled, genetically improved stocks can be introduced and, pest infestation can be controlled (Kairo *et al.*, 2001). Although artificial regeneration provides a tool of returning life into the degraded mangrove ecosystems, many problems befall this option. Artificial regeneration can be expensive particularly in areas where hydrological regime has been modified. Another disadvantage of artificial regeneration is the long-term loss of ecological productivity as evidenced by simplification of the systems from mixed to monoculture plantations (Saenger, 2003).

Plate 5. An example of a wasted effort from direct planting of propagules on a sand flat in Vanga, Kenya. Here is a case of poor site matching.

Table 4. Advantages and disadvantages of artificial mangrove restoration.

ADVANTAGES	DISADVANTAGES
- Promotes community employment during nursery establishment and out-planting	- Direct planting of mangroves can be expensive particularly in areas where hydrological regime has been modified.
- Species composition and distribution can be controlled	- May lead to introduction of wrong species
- Genetically improved stocks can be introduced	- Long-term loss of ecological productivity as evidenced by simplification of the systems from mixed to monoculture plantations.
- Pest infestation can be controlled	- Monoculture plantations may promote pest infestation
- The established nurseries can be used for training	- Nurseries may be affected by diseases and stress due to poor management
- Enhances community ownership	- Mangrove planting may lead to community conflicts particularly when not fully involved

2.2.3 Integrating mangrove restoration with alternative livelihoods

Support to livelihood activities enhances community buy-in and sustainability of mangrove restoration initiatives. Integrating restoration activities with IGAs to surrounding communities, reduces human overdependence and subsequent pressure on mangrove ecosystem and their resources. Beekeeping (Plate 6), aquaculture (fish farming and crab fattening), mangrove eco-tourism (Plate 7), and use of energy efficient stoves should be promoted where appropriate to relieve pressures and safeguard mangroves.

Plate 6. Traditional beekeeping in the mangrove forest in Makoba Bay, Zanzibar inspires communities to restore and protect mangroves.

Plate 7. Gazi Women Mangrove Boardwalk in Kenya.

3. Step by Step Procedures for Mangrove Restoration

Despite several mangrove restoration initiatives in WIO countries, only a few success stories can be cited (e.g. Kairo *et al.*, 2001, 2008). In many of these initiatives, mangrove reforestation has simply meant direct planting of propagules, wild saplings, and in few cases use of nursery raised saplings without adequate site assessment and considerations of the site quality. Neither have there been plans for long-term monitoring of mangrove restoration projects. Based on the authors' knowledge as well as practical reforestation experiences, factors that have contributed to failures in mangrove reforestation projects can be summarized as follows:

- **Extreme changes in site conditions** – e.g. soil factors (especially salinity), hydrology (relating to water movement), and sedimentation,
- **Inappropriate restoration techniques** – species-site mismatch, poor quality seeds/propagules, poor nursery establishment and management, poor site preparation, inappropriate transplantation,
- **Failure to involve all stakeholders,** especially local communities and relevant government institutions.

In this Chapter, three different **phases** for ensuring successful mangrove restoration initiatives are described, including; Project Planning, Implementation, and Monitoring and Evaluation phases (Figure 8). Each of these phases has several activities described in nine steps that are not necessarily linear. Local variations due to diverse landscapes of biophysical settings (hydrology and tidal regimes, geomorphology and types of mangroves, natural dispersal, as well as socio-economic and governance factors (tenure and legislations, awareness, gender) may require deviations and/or skipping of one or more of the nine steps. Later in Chapter 6, a question of *planting or not planting* of mangroves in degraded areas is revisited using a decision support tool that includes 10 key steps (Figure 17).

3.1 Project Planning Phase

STEP 1: PROBLEM REALIZATION

Restoration campaigns should be initiated by starting with identification of the problem. Realizing and appreciating that there is mangrove degradation that has led to loss of mangrove goods and services; and that there is need and willingness to take action is crucial for the ultimate success of restoration initiatives.

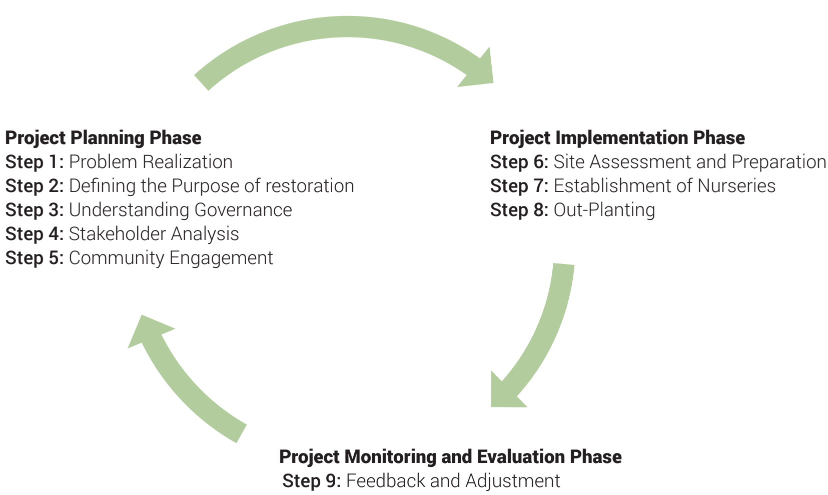


Figure 8. Steps of adaptive mangrove restoration cycle to ensure success in the WIO region (drawn by M.M. Mangora).

Questions to consider during project planning for mangrove restoration

- What caused the loss and degradation of mangroves?
- What is preventing natural regeneration to occur in the area?
- Why should we plant mangroves in the degraded site?
- Who has ownership of where planting is intended?
- Who should be involved in the restoration initiatives?

Understanding the problem associated with degradation and loss of mangrove forest may require rapid consultative field surveys with key actors, including communities. This exercise is important for rapid understanding of the values and benefits of mangroves, priorities, preferences, willingness and support to their restoration. In many cases, external actors tend to overlook this important step.

Realizing that there is a problem, leads to determining whether there is need to take any action to resolve the problem, which is critical for subsequent steps. This is followed by the need to make a decision on the type of action to take, such as to plant or not to plant, safeguarding natural regeneration, identifying the main stakeholders as well as the range of resources and expertise needed for the action.

STEP 2: DEFINING THE PURPOSE

In many places where restoration has been undertaken, there is lack of explicit stakeholders' consensus on the definition and formulation of the purpose of implementing a restoration project. Where a purpose has been formulated, experiences indicate that it is often not explicitly understood to all stakeholders, particularly on how they fit with the national or local conservation objectives and priorities. This contributes to difficulties in evaluating the performance and outcomes of the restoration projects. Experiences and lessons from the field demonstrate that restoration of degraded mangrove areas is feasible as long as the questions of **why, where, when, how** and **by who** are appropriately addressed.

Objective formulation of restoration goals to answer the first question of "why" is integral to subsequent operations. Mangrove restoration often has multiple goals that include timber production, coastal protection, biodiversity conservation, fishery support, ecotourism, and education. These should be carefully aligned when assessing and preparing a restoration site (Step 6) to ensure that it supports the defined aims. Accordingly, mangrove restoration initiatives are undertaken with at least one of the following objectives, which must be defined at the planning and inception phase of the project:

i. Enhancement of natural regeneration, biodiversity and ecological restoration;
ii. Sustained yield of both wood and non-wood forest products – poles, timber and charcoal;
iii. Coastal protection, erosion control and channel stabilization of lagoons and estuaries;
iv. Support to fisheries resilience and enhancement;
v. Establishment of new mangrove locations and adapting to climate change;
vi. Coastal landscaping and ecotourism;
vii. Social enrichment; and
viii. Legislative compliance.

STEP 3: UNDERSTANDING GOVERNANCE: INSTITUTIONAL AND LEGAL CONTEXTS

Land and resource tenure rights (access and user) is fundamental to successful mangrove restoration. In most countries where mangroves occur, there are laws and legislations for their management. Any activities within mangroves (including restoration) might, therefore, require permission from the responsible regulatory agencies. In addition, many countries also have laws that call for compensatory measures (nowadays commonly referred to as "biodiversity offsets") in case of projected environmental impacts from development projects where there is loss of biodiversity, for example known areas of certain habitats, such as coral reefs or mangroves. Therefore, restoration of mangroves in a site might be mandatory as an off-setting measure by a developer. However, based on the governance frameworks in the respective countries, many mangrove restoration projects tend to forego this important process of defining the governance arrangements to ensure and secure commitments and manage expectations.

It is important to clarify land ownership for the restoration site from the beginning of the project because unclear land tenure can hinder success of a restoration project, threatening the long-term conservation of the site and project investment. This problem can be avoided by making clearly understood written long-term agreements with the landowners and users to ensure they are all committed to the project. While mangroves in many countries of the WIO are legally designated as state forest reserves, there is still little awareness of the true value of the ecosystem at various levels, coupled with weak governance and inadequate resources among management agencies, resulting in poor mangrove management.

STEP 4: STAKEHOLDERS ANALYSIS

Mangroves are multiple use systems, providing multiple resources to multiple users. This often leads to multiple conflicts (Beymer-Farris and Bassett, 2012), that warrants adequate stakeholder identification, consultations and engagements to ensure that the interests of each group are collaboratively and consensually taken into consideration. Appropriate engagements of particularly local stakeholders are important in ascertaining stakeholder's interests and expectations, and hence determine where restoration intervention(s) is most practical, useful and acceptable.

STEP 5: COMMUNITY ENGAGEMENT

Engagement should extend along the entire restoration process to ensure that interests of local communities are recognized, appreciated and safeguarded. The process should also be iterative so that unforeseen issues, the interests of stakeholders absent from initial meetings, or new information can be considered and adjustments made. Important issues that must be considered in bringing in and addressing community interests are such as:

i. Community perceptions and understanding on the comparative benefits of conversion to other uses versus maintenance of intact mangrove forest ecosystems;
ii. Legal recognition of the mangrove resources in terms of rights to access and use; and
iii. Land use governance defined by the institutional, economic, socio-cultural and property rights dynamics.

3.2 Project Implementation Phase

Implementation of mangrove restoration projects requires adaptive approaches (learning by doing) to be effective. This includes the use of multiple scenarios on future socio-economic and physical changes (e.g. land use and/or climate change). Each potential restoration site requires field investigation to identify areas of stressed, dead or lost mangroves, and to determine whether the site requires management to support recovery or it is capable to recover by itself over time.

STEP 6: SITE ASSESSMENT AND PREPARATION

Site selection is more conceptual than practical in the WIO region, particularly where restoration is participatory as communities specifically go out to

Questions to consider during implementation phase of a restoration project

- Is there a need to gather information on biophysical features, including; soil depth and hydrology etc.?
- Is a species inventory of the designated site required?
- Which species should be planted?
- What are the best approaches to return the lost mangroves?
- Which approach is best to use: direct planting, nursery raised or natural regeneration?

only restore local areas that are degraded in their localities. Normally, the site to be restored should be accessible and devoid of strong waves. Planting should be restricted to vegetated areas where the forest has been degraded and lost. Once an area is marked for a restoration exercise, the *Golden Rules* proposed by Enright and Wodehouse (2019) should apply:

- **Understand why natural regeneration is not** occurring or is not sufficient and then make adjustments to the site or find solutions to social issues.
- **Plant close to where** that species is naturally occurring as this follows nature. Try planting two or three propagules or seedlings close together in clumps or groups.
- **Do not plant mangroves too densely** covering the entire area as this will restrict the opportunity for natural regeneration and higher biodiversity. Plant as many species as are naturally occurring on your site, if possible.
- **Small-scale test planting is a wise** way to assess your site, as mass planting could be setting you up for a big failure.
- **Do not plant in any water channels,** seagrass beds, mudflats, or on the raised sand flats (Plate 4)
- **Make sure the local community members are fully involved** from the planning stage and it is best if they take on the ownership of the project.
- **Ensure the site is protected from people,** boats and livestock, fenced if necessary. Signboard the site with a phone number so outsiders know it is a restoration site.
- **Plant seedlings, propagules, or wildlings collected as close as possible** to the restoration site. If wildings are used, replant them immediately, preferably in the late afternoon
- **Monitor your site long-term** (usually 5 years) and learn from both successes and failures and make necessary corrections and adjustments.

STEP 7: NURSERY ESTABLISHMENT

Mangrove nursery establishment involves a series of activities and the supervisor should see to it that all workers are informed of their daily activities. The site for nursery should be selected in the inter-tidal area, in close proximity to creeks with drainage channels. Water quality should be good and the area should be fenced, to prevent disturbance by human or animals. It should be easily accessible to reduce the cost of transportation of seedlings from the nursery to the restoration site.

(i) NURSERY LAYOUT

A typical sketch of a mangrove nursery, with basic compartments, is given in Figure 9. For ease of construction, the design should be square or rectangular in shape. The following are the compartments for an ideal mangrove nursery.

Seed germination bed

To protect the soil from movement, sunken beds should be constructed by making dug out troughs where the seed pots (typically plastic potting bags) will be arranged, to help preserving soil moisture and preventing the pots from toppling over. Alternatively, where the soil is rocky, wooden supports and planks can be used, pegged into the soil, to secure the pots. Depending on the pot sizes, the troughs should be at least ¾ depth of the height of the pots. Where the selected site is open, the germination beds may require shade, created by using thatch material and branches over a simple frame. The resulting sheds, for easy operations, have two sunken beds, 10 m x 1 m each, with at least 1 m path in between.

Potting shed

This is a covered shed designed for workers protection during rainy as well as on hot days while filling potting bags/ polybags with soil. The shade can be made from 4 to 6 pieces of mangrove poles and should not be smaller than 3 m x 4 m in size. To further reduce direct sun-light, it is better to construct the potting shed under a big mangrove tree.

Hardening off beds

Germination beds can be used also as hardening beds provided that the seedlings are not moved from one place to another until they are ready for out-planting. Artificial shedding needs to be removed one month prior to out-planting in order to acclimatize the seedlings to greater sunlight exposure.

Soil media
Only muddy soil that is clayey should be used for filling the potting bags. The soft clayey mud available in the mud flats during low tide should be collected and all debris removed before filling the bags with mud.

(ii) FILLING POTS

For most species, raising seedlings in polybags is most appropriate. Different species require different pot sizes: 12.5 x 20 cm polybags are suitable for small sized seedlings, e.g. for *A. marina;* while large seedlings of *R. mucronata* require large bags of 15 x 30 cm or more. To ensure maximum germination percentage and survival of potted seedlings, the following should be taken into account:

- Fill potting bags with soft clayey mud from the mangrove forest
- Avoid water stagnating on the top of the pot by filling the soil firmly to the bream
- Allow the pots to harden
- The pots should be arranged in a dug-trough such that at least ¾ of the height of the bags is below the ground level. This ensures that moisture is preserved (see Plate 8)
- Proper drainage to ensure no water stagnation within the nursery bed

(iii) COLLECTION, TRANSPORTATION AND SORTING PROPAGULES

Most mangrove species have specific fruiting peak seasons; hence, propagule/seed production may not be available throughout the year. It is,

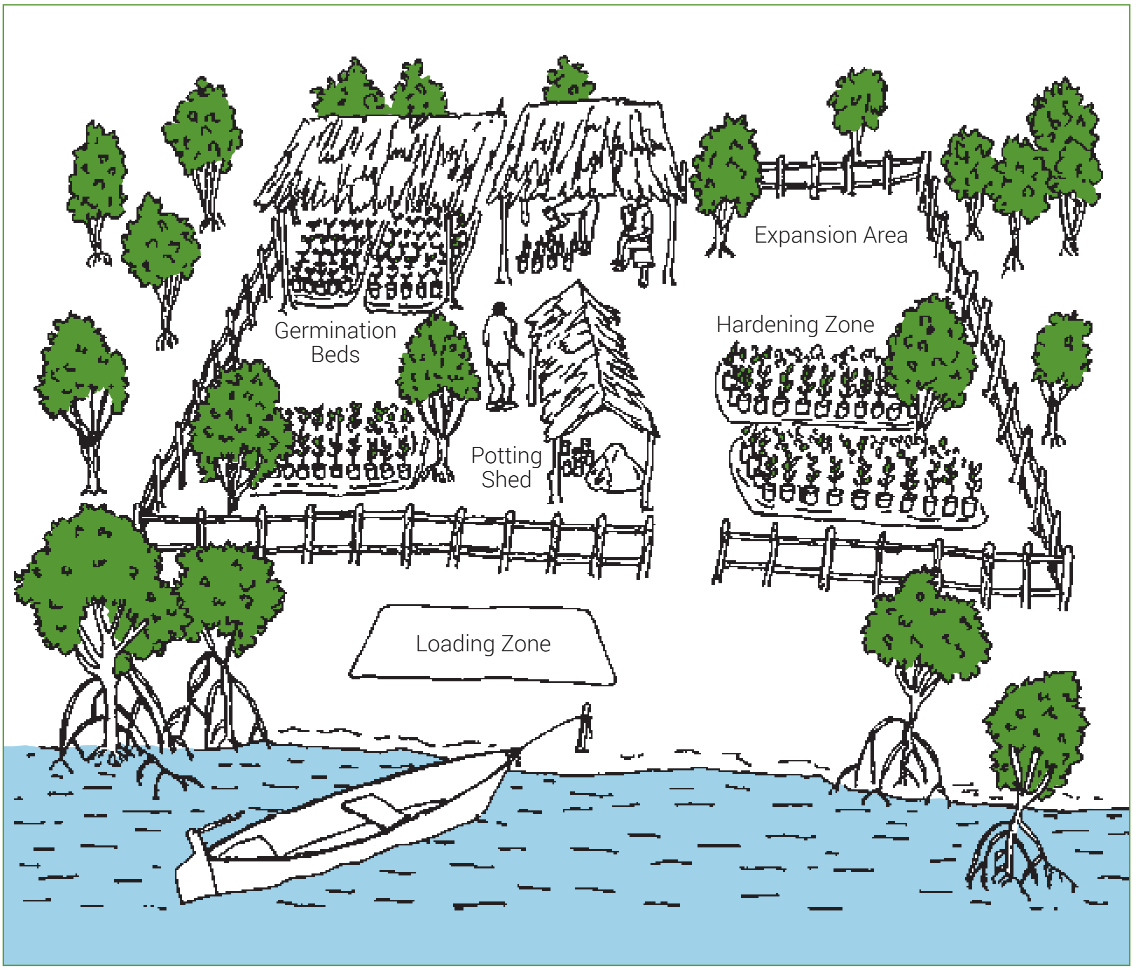


Figure 9. A typical mangrove nursery layout showing different compartments.

Plate 8. A local community mangrove nursery with *A. marina* and *C. tagal* at Kilimani, Zanzibar.

therefore, necessary to know the propagule/seed peak production seasons for each of the mangrove species selected for replanting in a particular site. In the WIO region, peak fall for mangrove propagules tend to coincide with the wet period from April-June (Table 7). Propagules and seedlings of common mangrove species in WIO are shown in Figure 10.

Mature propagules should be collected from a forest that is close to the selected planting site to ease transport. After collection, propagules should be sorted to ensure good quality planting materials. A distinct cotyledon colour in the hypocotyls of *R. mucronata* and *C. tagal* is a good indicator of the maturity of propagules. In *A. marina* mature propagules have a dark-blue seed coat and will dislocate from the parent plant without the calyx with a slight twist. Direct planting of propagules should be planned to coincide with their peak fall (Table 5). Many species flower frequently, producing propagules throughout the year, though with peak periods, however, *A. marina* has a single flowering period, producing propagules only once during the year.

(iv) SOWING OF PROPAGULES

Seeds and propagules require different sowing methods depending on the species. For large propagules, the hypocotyl should be inserted to a depth of ~ 4-5 cm (*Ceriops* and *Bruguiera*) and 7-8 cm (*Rhizophora*). For *Avicennia* and *Xylocarpus* seeds, the radicle part must be pushed gently (1/3 of the seed) into the soft mud. Where necessary a fine netting screen house can be used to raise the seedlings in order to avoid incidences of insect pests attack. *Sonneratia alba* and *A. marina* seeds should be soaked overnight with water to hasten the opening of fruits and

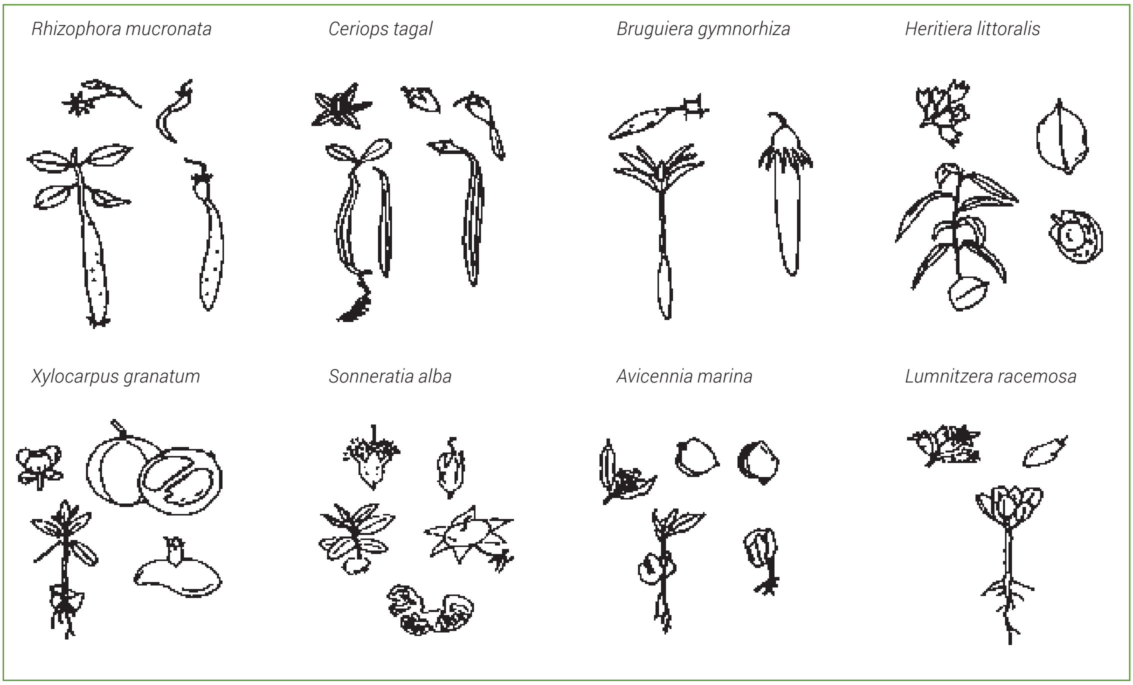


Figure 10. Propagules and seedlings of common mangrove species in the WIO region.

the splitting of their seed coat respectively. *H. littoralis* fruits should be soaked in fresh water for 1-2 weeks after which the husk can be split by hand prior to planting. Morphology of propagules and seedlings of mangroves, *R. mucronata* and *A. marina*, are shown in Figure 11 and Figure 12 respectively.

STEP 8: OUT PLANTING

Direct planting of propagules is commonly undertaken for mangroves belonging to Rhizophoraceae family (*Rhizophora*, *Ceriops* and *Bruguiera*). Species in this family produce large and pointed propagules that can be planted directly into the mud (Figure 10). Experience has shown that mature propagules picked from mother trees or those recently fallen have a higher survival rate than transplanting of saplings. Further, transplanting of saplings is three times more expensive than use of propagules (Kairo *et al.*, 2001). Propagation method for different mangrove species in WIO is summarized in Table 6.

When using nursery-raised saplings as well as wildings in mangrove restoration projects, protection of the roots during collection and planting of saplings is an important handling technique to ensure survival after planting. If scooping wildlings from the field, it is important to ensure that the root-ball diameter is half the height of the sapling (Kairo 1995; Kairo *et al.*, 2001). Previous experiences in Kenya have recorded 80-100% survival for nursery-raised saplings compared to use of wildlings in mangrove reforestation (Kairo *et al.*, 2001).

3.3 Project Monitoring and Evaluation Phase

Monitoring is important in any restoration initiative. For this to be practically realized, achievable and measurable, success criteria must be defined and incorporated into a monitoring program prior to initiation of restoration activities. Adoption of experiences and lessons from past initiatives are relevant in determining the best and effective monitoring plan. Long-term monitoring of restoration projects is important since it can detect both negative trends, due to on-going pressures on the resources, as well as positive trends, due to effective interventions (Plate 9). For proper monitoring, a plan must be in place to provide guidance of what will be monitored, the methodology, who will be involved in that process and the monitoring schedule. Gen-

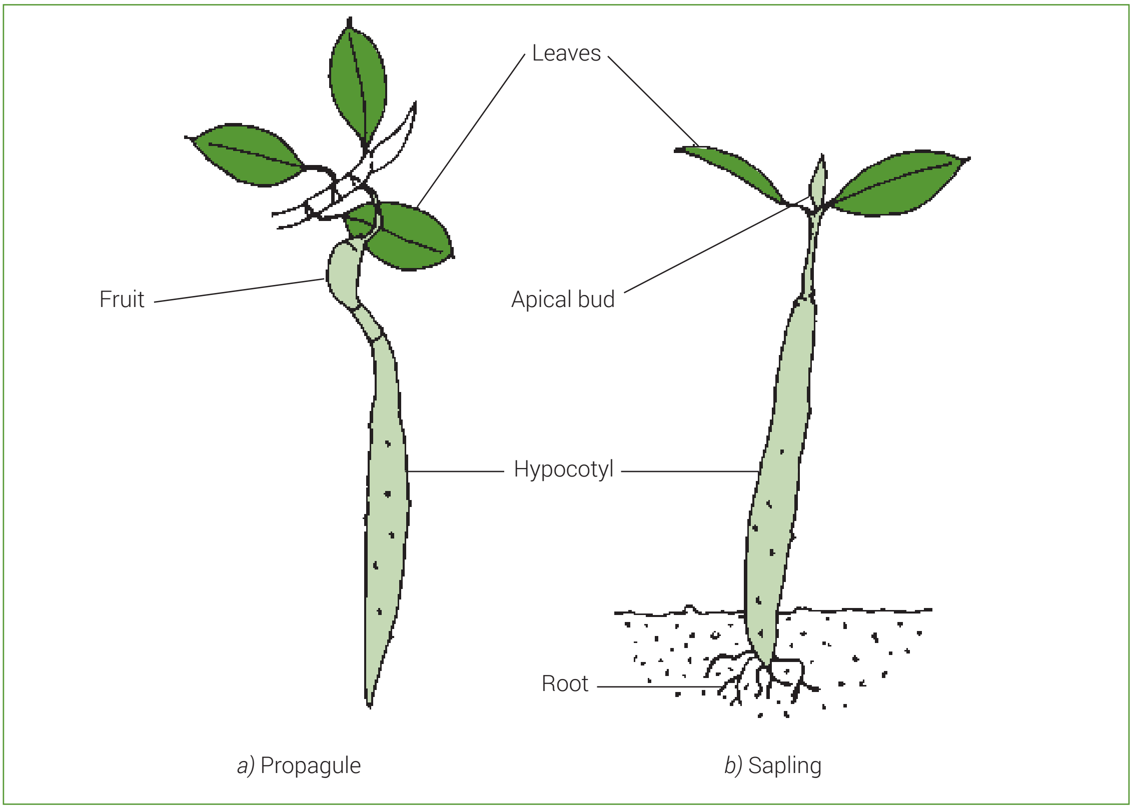


Figure 11. Morphology of *R. mucronata* propagule and sapling.

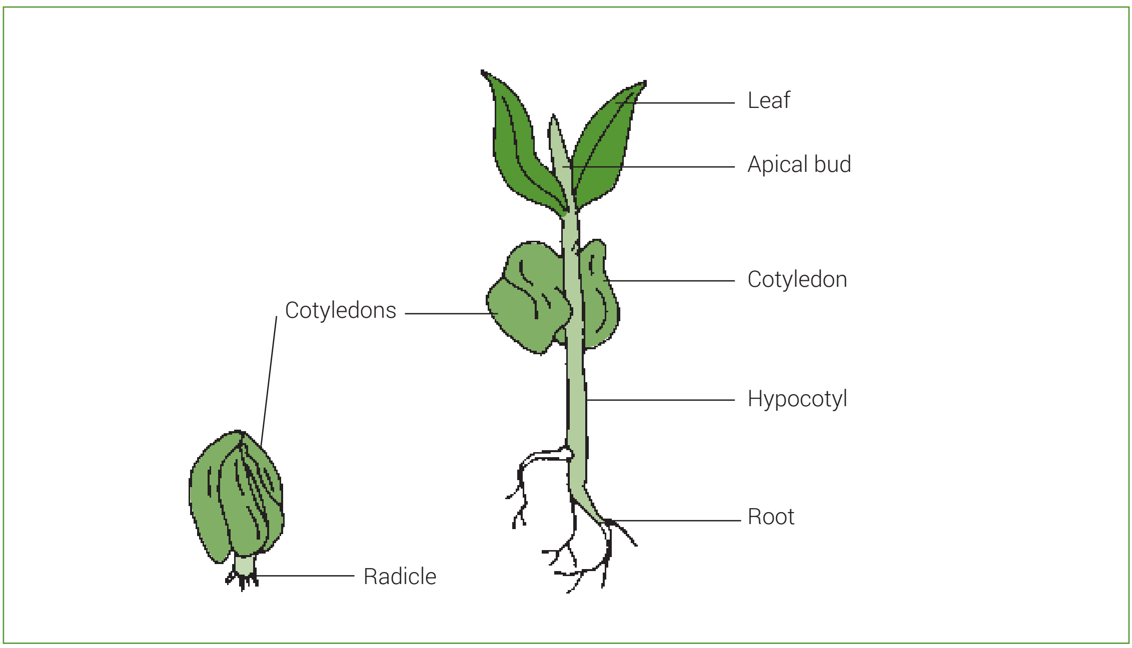


Figure 12. Morphology of *A. marina* seed and seedling.

Table 5. Propagules/seedlings availability for mangroves in the WIO region.

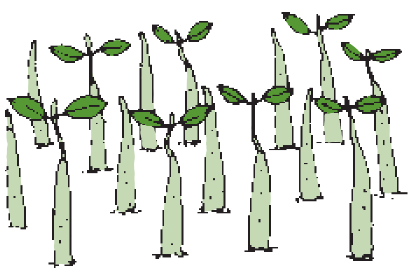
SPECIES	PLANTING MATERIAL	PEAK AVAILABILITY OF PROPAGULES*	INDICATOR OF MATURITY	SIZE OF MATURITY	STORAGE (MAX DAYS)	TREATMENT
Avicennia marina	Seedling	April-May	Seed-coat turns light yellow, wrinkly	Weight of 100 seeds >150g	5	Soak in fresh water (>12 hrs)
Bruguiera gymnorrhiza	Propagule	April-July	Reddish brown body	Propagule length >15 cm	10	Cool wet conditions
Ceriops tagal	Propagule	February-March	Light yellow collar, brown/green body	Propagule length >20cm	15	Cool wet conditions
Rhizophora mucronata	Propagule	March-June	Yellow collar, green body	Propagule length >40 cm	30	Cool wet conditions
Sonneratia alba	Fruit	September-November	Dark green, float in water	Fruit diameter >4cm	5	Soak in freshwater or sea water >12 hrs
Xylocarpus granatum	Fruit	May-July	Dark brown, float in water	Weight of individual seed inside fruit >30g	30	Store in dry cool conditions until it open
Xylocarpus moluccensis	Fruit	May-July	Dark green	Weight of individual seed inside fruit >10g	20	Store in dry cool condition until it opens
Lumnitzera racemosa	Seed	May-July	Dark green dry style	Dark green, dry style	20	Store in moist conditions
Heritiera littoralis	Fruit	May-July	Dark brown	Seed intact inside the fruit, no sign of insect attack	>30	Soak in fresh water (1-2weeks)

* Peak fruiting period given here may vary from site to site. Project developers must understand seasonality of the trees in their locality prior to initiating reforestation project in any particular area

erally, most restoration projects have not prepared systematic plans for monitoring restoration. Where present, monitoring has been conducted to understand only the survival rate of the planted seedlings, ignoring other ecosystem services.

STEP 9: FEEDBACK AND ADJUSTMENT

In most restoration projects, the perception has been that once mangroves are replanted, they will grow without further monitoring. This is likely to fail because mangroves are dynamic ecosystems impacted by stressors within and outside the system. Table 7 summarizes reasons associated with failures of many mangrove restoration efforts and lessons that can be gauged from monitoring to inform adjustments in the planning and implementation phases. Elaborative steps and procedures for implementing a restoration plan are provided in detail in Chapter 4. A rather rare case in the region that may need specialized expert monitoring is the rehabilitation of oil spill impacted mangrove sites (Box 1).



Issues to consider during the monitoring and evaluation phase:

- Revisit restoration site to assess performance
- Identify who will implement the monitoring plan
- Assess secondary succession (flora and fauna)
- Evaluate the cost of restoration projects

Table 6. Propagation methods for different mangrove species.

SPECIES	MODE OF PROPAGATION	SOWING DEPTH	SHADE	GERMINATION PERIOD*	COMMON PESTS	HEIGHT/AGE FOR OUT PLANTING
Avicennia marina	Nursery	On surface of potted soil	30%, whole sides	Within 10 days	Crabs, insects caterpillars	Ht ~ 50 cm No. of leaves 12 Age 6-8 months
Bruguiera gymnorrhiza	Direct planting/ nursery	Push ~ 5 cm in	30%, 2/3 sides	10-20 days	Crabs	Ht ~ 50 cm No. of leaves ≥6 Age 8 months
Ceriops tagal	Direct planting/ nursery	Push ~ 5 cm in	50%, 2/3 sides	10-20 days	Crabs	Ht ~ 30 cm No. of leaves ≥6 Age 8 months
Rhizophora mucronata	Direct planting/ nursery	Push ~ 7 cm in	50%, 2/3 sides	10-20 days	Crabs	Ht ≥ 80 cm No. of leaves ≥8 Age 8 months
Sonneratia alba	Nursery/wildings	Scatter seed on nursery bed Push gently radicle	30%, whole sides	5-7 days	Crabs	Ht ~ 50 cm No. of leaves ≥10 Age 6-8 months
Xylocarpus granatum	Direct planting/ nursery	Lay on surface with radicle downward	30%, whole sides	3 weeks to 3 months	Crabs	Ht ~ 80 cm No. of leaves 12-14 Age 8 months
Xylocarpus moluccensis	Direct planting/ nursery	Lay on surface with radical downward		20 days	Crabs	Ht ~ 50 cm No. of leaves 12-14 Age 8 months
Lumnitzera racemosa	Nursery/wildings			1 week to 2 months		Ht ~ 30 cm No. of leaves ≥10 Age 8 months
Heritiera littoralis	Direct planting/ nursery	Lay on surface with radicle downward			Crabs	

*Germination period may vary with the maturity and quality of seed.

Plate 9. A six years old stand of replanted mangroves, *R. mucronata* by HonkoReef Doctor Project, Madagascar.

Table 7. Summary of common reasons for failure of mangrove restoration projects and lesson learnt

REASONS AS TO WHY RESTORATION EFFORTS FAIL	LESSON LEARNT
- Use of inappropriate methods - Insufficient information - Failure to involve communities - Inadequate monitoring of seedlings after planting - Poor habitat selection without adequate site assessment - Faulty selection of mangrove species for replanting. - Improper planting of mangrove seedlings at a substrate depth beyond the natural range for mangroves in the area - Poor coordination among the institutions involved - Poor understanding of the ecological role of mangrove forests among policy and decision makers at different levels of government that result in weak support of restoration initiatives	- Diagnostic studies on socio-ecological aspects of mangroves - Embracing a more holistic approach - Engaging multiple experts and stakeholders - Linking local language to expertise of the scientific community - Monitoring and assessing success - Early identification of problems and taking corrective actions - Sharing knowledge and experience - Importance of mangrove valuation studies - Continued awareness and advocacy on mangrove conservation

Box 1. Rehabilitation of oil spill impacted mangrove sites

Oil spills have the potential to cause severe and long-lasting impacts on mangrove ecosystems. The type of oil and the extent of contamination will dictate the appropriate mitigation actions. Although oil spills is not a big challenge in the WIO region, the situation is subject to change as increased explorations of hydrocarbon are being witnessed in the coastal areas some of which have mangroves. In assessing remediation and rehabilitation approaches, the overriding consideration is the need to apply the safest, cost-effective and sustainable approach that will improve the situation and bring about measurable changes in the shortest possible timeframe. In some cases though it is appropriate to do nothing when natural oil removal is rapid, when mangroves are inaccessible, or where cleanup will cause more harm than good. In cases where mangrove planting is necessary to recover from oil spills, bioremediation must be implemented to reduce toxicity before replanting takes place. Bioremediation options appropriate for the WIO region include the following,

(i). Land farming: This process involves stimulation of microbes to increase biological activity using nutrients (nitrogen, phosphorus, potassium), tilling or air sparging for better aeration and microbial activities (Plate 10). The most challenging aspect of land farming is oxygenation because anaerobic conditions can occur frequently during land farming, reducing aerobic activity (Liu *et al.*, 2012). The success rate of land farming varies widely depending on a variety of physico-chemical and anthropogenic factors (Maier and Gentry 2015).

(ii) Hydrogen peroxide treatment: Peroxidation may be used in special applications where contaminants require oxidation to reduce toxicity and enhance degradation. Peroxide use is cost-effective for treatment of both soil and groundwater aquifers treatment. The use of peroxides (e.g. hydrogen peroxide, manganese peroxide or sodium peroxide) could be complemented by other methods in order to accelerate degradation.

Plate 10. Land farming of petroleum contaminated soils.

(iii) Phytoremediation: This technique refers to the use of plants and associated microorganisms for the in-situ treatment of contaminated soils (White *et al.*, 2005; Agbogidi *et al.*, 2011; Kathi and Khan 2011; Njoku *et al.*, 2012). Grasses, herbs, shrubs, and trees are the general types of plants that have been considered in phytoremediation. Grasses that have been known to do well in bioremediation include wheat grass, rye grass, and vetiver among others (Kathi and Khan 2011).

(iv) Rhizoremediation: This aspect deals with the application of filamentous fungi such as white rot, which uses the process of mineralization to degrade pollutants. White rot contains enzymes that can breakdown and mineralize hydrocarbons and many other pollutants into non-toxic forms. (Adenipekun and Fasidi 2005; Obire *et al.*, 2008).

(v) Phycoremediation: This technique uses algae to enhance the degradation of contaminants. Algae are photosynthetic organisms that possess chlorophyll and very simple reproductive structure but have no roots, stem or leaves. They need carbon for photosynthesis and during this process oxygen is released that enhances bacterial activity and promotes degradation of hydrocarbons and releases carbon dioxide which is then used by the algae for photosynthesis.

(vi) Bioaugmentation: Bioaugmentation is the application of microbes and/or biosurfactants to enhance the degradation of hydrocarbon contamination in soil and water. The major advantage of the use of biosurfactants in bio-remediation is that it greatly increases the bioavailability of contaminants, enabling better access to microbes.

Re-establishment of mangrove vegetation in oil spill impacted areas

Oil contamination in highly organic mangrove soils can persist and be toxic to species for several years. Accordingly, baseline studies of the extent of contamination, rate of natural breakdown of oil in the sediment, degree of sediment toxicity to mangrove fauna should be conducted in order to determine when the site is ready for ecosystem restoration and which remediation option should be employed.

Where tidal regime of the affected sites have been disrupted, hydrological restoration through digging of canals that mimic natural water flow must be re-established to support regeneration of a dying forest. Canals should be dug at an angle of 45° to the natural creek while the side canals should be dug at an angle of 30° to the main canal (Figure 13). The canal dimensions are determined by contour levels and by the tidal amplitude of the impacted sites. Canals should be dug in a trapezoidal shape in order to plant the saplings at the mid-level of the canal. This is to ensure that the plants receive tidal water, but at the same time they are not submerged. Nevertheless, the nine steps described in Chapter 3 and the implementation plan in Chapter 4 should be adhered to.

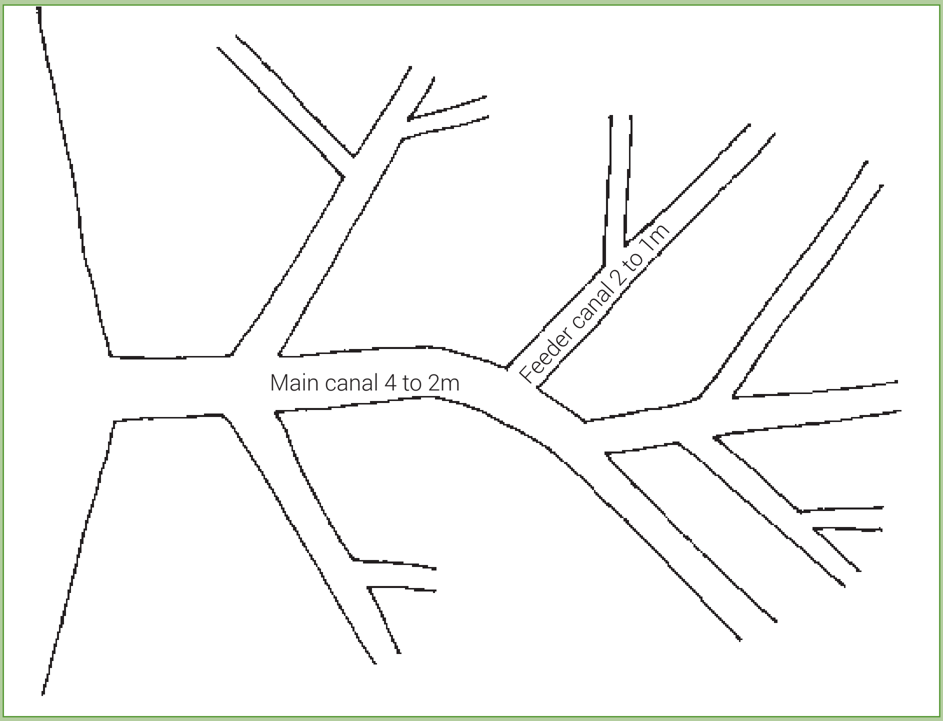


Figure 13. Canals appropriate for hydrological restoration

4. Implementing a Mangrove Restoration Plan

The failures of most restoration projects have been associated with lack of a monitoring plan. It is essential to monitor mangrove restoration projects for several reasons:

- It facilitates assessment of survival and growth performance of seedlings, thus dead seedlings and those with poor growth can be replaced over time.
- It enables one to timely determine the possibility of a project achieving its restoration goals and objectives
- One can document challenges and successes encountered and where possible identify ways of addressing them. This could also provide lessons for future restoration programs
- Pest/ disease attack can be noted in time and controlled
- Removal of debris (algal growth, solid debris brought by tides) can be done during monitoring
- Surveillance in need to assess damages e.g. by waves, crabs, vandalism

The success of restoration initiatives is determined through assessment of forest health, productivity, regeneration recruitment and faunal succession relative to the objective of the program. Performance of a plantation is compared to an adjacent natural system to establish success thresholds based on biomass increment, species diversity and faunal colonization. Therefore, data on productivity and succession proxies is needed to determine the success of restoration. Collection of data on vegetation attributes (tree height, diameter at breast height (DBH) and juvenile densities) and secondary succession (benthic species, fisheries) and soil conditions is essential.

4.1 Vegetation Assessment

Vegetation assessment should be carried out both in the nursery and restoration site. The following parameters should be monitored using the schedule shown in Table 8.

i. Mortality/survival and germination percentage (for the whole sample)
ii. Average height increment (in cm), number of internodes, number of leaves, number of lateral branches (for a sample size of 20 – 30; Figure 14)
iii. Diameter of stem (in cm) at 2nd internode. For *A. marina*, stem diameter is taken at **50%** of total plant height (for 20 to 30 samples).
iv. Measure the length and width of leaves (for 20 to 30 samples)
v. Determine the recruitment of non-planted species (wildings)

4.2 Secondary Succession

A complete and meaningful monitoring program should include an assessment of the return of biodiversity and ecosystem services by comparing rehabilitated sites to reference sites (non-degraded forest). This is because mangrove associated biodiversity have an intricate association with the mangrove trees. Indicators of restoration success can thus be assessed based on **total sum of the faunal species** and **densities present** in a forest. Nevertheless, most mangrove restoration projects in the WIO are small, and may not necessarily be able to undertake such a comprehensive monitoring program due to budgetary limitations. Hence, this should only be fully considered where resources are guaranteed; otherwise only general features can be evaluated.

Mangroves benefit from the mutual interaction with associated faunal biodiversity that serve the following purposes:

- Influence vegetation structure through selective predation on seedlings;
- Play a role in nutrient cycling by quick utilization of fallen mangrove leaves;
- Alter mangrove sediments by the numerous burrows they dig;

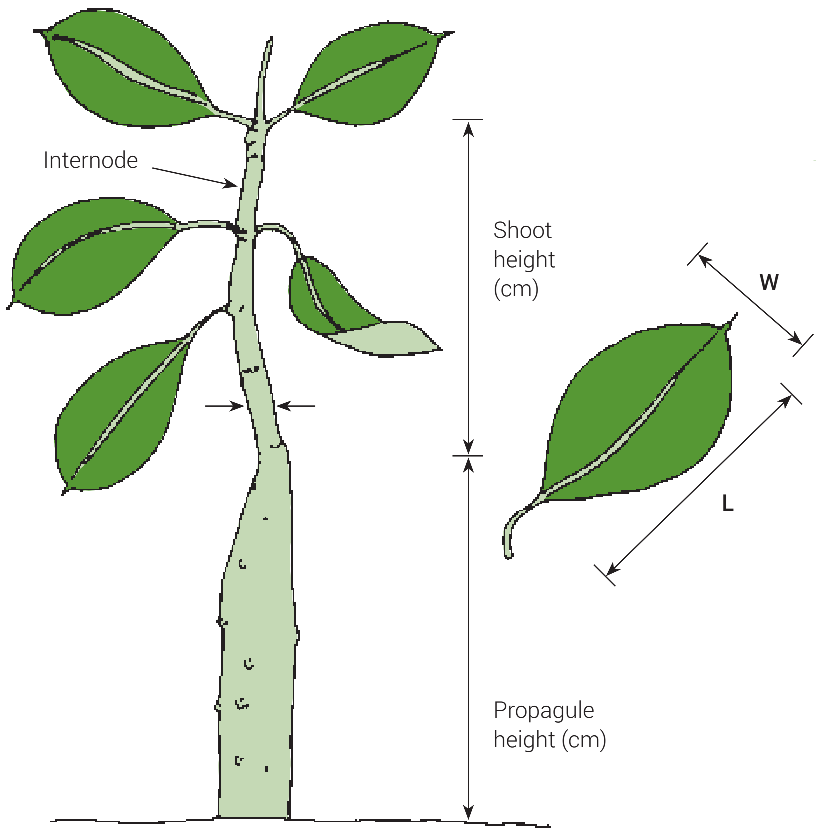


Figure 14. Biometry of a mangrove sapling.

- Reducing pore water salinity by allowing flushing of the sediments via their burrows;
- Maintain the organic matter within the system by burying and eating fallen mangrove leaves;
- Insects play a vital role in mangrove pollination; and may also be pests on different tree species thus influencing the mangrove forest structure;
- Bats are also pollinators of *S. alba*, and birds may also contribute to controlling insect pests;
- Large mammals are also important in dispersal and maintaining the food web in the forest. They contribute in nutrient cycling and influence forest structure through predation of the mature mangrove trees and young sapling and propagules.

Extensive dieback and/or over-harvesting of mangrove trees is likely to affect faunal species composition and density, constrict species range due to loss of habitats, and eventually affect even the population size of some species. It is essential to assess recovery of mangrove-associated biodiversity in a restoration project. Macrobenthic species like crabs and molluscs have varying capacity to adapt to environmental changes as such they are regarded as important indicators of the return of ecosystem functions. These groups appear in large numbers and they have a quick and varied response to slight perturbation of the system.

4.2.1 Faunal re-colonization protocol

Within the 10m x 10m permanent plots set for vegetation monitoring above, two 2m × 2m subquadrats should be randomly placed for actual monitoring of crabs and molluscs at least a day

Table 8. Vegetation monitoring schedule for mangrove restoration project.

	ACTIVITY	REMARKS/PARAMETERS TO MEASURE
0+3 months	a) Preparing report of nursery and out planting phases b) Survival assessment c) Gap filling d) Pest control e) Debris removal	- Survival % - If survival is low attempt to identify cause of problem - Note source of debris - Note any form of disturbance, or damages
6	a) Assessment – seedling survival and growth performance b) Surveillance	- Survival % - Height (from the ground to the base of top-most leaves), number of leaves for randomly selected individuals (tag them for subsequent monitoring) - Note any form of disturbance, or damages
9	a) Assessment – seedling survival and growth performance, recruitment of wildlings b) Surveillance	- Survival (%) - Height, diameter (between 1st& 2nd internode for *Rhizophora*, *Bruguiera* and *Ceriops*; at 30 cm from ground for other species), number of leaves for tagged individuals - Note number and species of natural recruitments - Note any disturbance
12	a) Assessment – seedling survival and growth performance, recruitment of wildlings b) Assessment - animal types and abundance c) Surveillance d) Annual report	- Survival (%) - Height, diameter, no. of leaves for tagged individuals - Note number and species of natural recruitments - Note emerging challenges and propose appropriate plan of action to address them - Make a report of all activities done during the first year
18	a) Assessment – growth performance, recruitment of wildlings b) Assessment -animal types and abundance c) Surveillance	- Height, diameter, number of leaves for tagged individuals - Note number and species of natural recruitments - Note any form of disturbance, damages
24	a) Growth performance, wildings, animals b) Environmental factors c) Annual report d) Surveillance	- Same growth parameters as in previous measurements (but may need to revise point of diameter measurements as seedlings grow older, if internodes are no longer visible, take measurements at ~ ½ the tree height) - Note also survival of wildings - Note changes in soils
36	a) Growth performance, wildings b) Surveillance c) Annual report	
48	a) Growth performance b) Surveillance c) Annual report	
60	a) Growth performance - general forest assessment, including natural regeneration b) Pruning/or thinning c) Detailed report – baseline for subsequent assessment (e.g. every 5 years) d) Detailed financial report – documenting the cost of planting and other operations	- Forest assessment using standard techniques – measure DBH at 130 cm above the ground - Natural regeneration – seedlings/saplings grouped into three regeneration classes – Class 1: < 40 cm height, Class 2: 40-150 cm and Class 3: >150 cm - Pruning & thinning depend on the objective of planting i.e. preferably for replanting for wood production. Determine appropriate spacing – usually between 1 to 2 m

before each real sampling episode. Monitoring should strictly be done during early morning low spring tides. An observer or two should stand at least 10 meters from the quadrat and observe the crab species using a pair of binoculars. Depending on the mangrove species where the restoration has taken place, the observers will stand still for a period of 10 - 20 minutes before starting observation. When the crabs have started their normal feeding activities, the observers should begin recording the following information in a template datasheet (Table 9).

- All the crab species present,
- The number of all crabs per species present within the quadrat.
- The sex of all the crab species present in the field (Plate 11)

In order to avoid under-estimating of those species not active during the direct binocular counts, three sub-quadrats (0.5 m × 0.5 m) should be randomly placed in the 2m × 2m quadrat after the binocular counts in order to count the crab burrows. The burrows should be categorized according to sizes (i.e. <1cm, = 1cm, >1cm). Within the sampling quadrat, molluscs species found at 1 m height on trees should also be identified and counted. Common crabs and molluscs likely to be encountered in mangroves of the WIO are provided in Table 10.

4.2.2 Sampling of fish community in mangroves

The fish community dependent on mangroves may also be affected when mangroves are lost or degraded. With pneumatophores that extend dozens of meters away from the trees, mangroves form unique habitats for fish (Plate 12). The following steps can be used to sample the fish community within the restoration site and compare it with results from a non-degraded mangrove area:

- Install stake nets made of 2 mm fine mesh netting, 10 m long by 2.5 m wide, within the replanted areas;
- The use of a centipede net is encouraged particularly in the vegetated areas with dense pneumatophores which may make it difficult to set stake nets. This would increase the chance of catching rare species and therefore provide a better representation of fish community structure;
- Nets should be installed during low spring tide, by burying the lead line in the sediment and securing it to the ground using wooden pegs;
- During high tide, the top of the net is lifted onto wooden stakes firmly hammered into the sediment at 2.5 m intervals and tied so that the top of the net is above the water level;
- Fish should be identified and counted at low tide once the water in the net enclosure drains out;
- Seasonal rhythms of the monsoons should be taken into consideration during sampling.

Table 9. Template for collecting data on faunal colonization.

SPECIES	SEX		BURROWS		
	MALE	FEMALE	< 1CM	= 1CM,	>1CM

Table 10. Common species of crabs and molluscs likely to be encountered in mangroves of the WIO region.

CRAB/MOLLUSC SPECIES	MANGROVE ZONE	WAITING TIME (MINUTES)	REMARKS
Uca annulipes	Desert and *Ceriops*	15-20	Found where sediments are sandy
Uca inversa	Desert zone	15-20	Found where sediments are sandy
Uca chloropthalmus	*Rhizophora* and *Sonneratia*	15-20	Found mainly in clay sediments and daily inundated
Uca urvillei	*Rhizophora* and *Sonneratia*	15-20	Found mainly in clay sediments and daily inundated
Uca vocans	*Rhizophora* and *Sonneratia*	15-20	Found mainly in clay sediments and daily inundated
Uca tetragonon	*Rhizophora* zone	15-20	Found on seaward fringe associated with sand
Perisesarma guttatum	All the zones	15-20	They get bigger in the *Rhizophora* zone
Parasesarma leptosoma	*Rhizophora*	15-20	They are mainly seen climbing up *Rhizophora* trees. They resemble *P. guttatum*
Neosarmatium meinerti	*Rhizophora* and landward zone	30 - 45	Make big burrows and quickly pick up leaves when they fall
Chiromantesort manni	*Rhizophora* and *Sonneratia*	15-20	They have green yellowish chelae and a dark body
Neosarmatium smithii	*Rhizophora* and landward sides	30 -45	Are medium in size easily identified by their very red chelae
Metopograspus thukuhar	*Rhizophora* zone	20 - 30	
Metopograspus messor		20 - 30	Found on muddy shores, roots and tree trunks
Pachygraspus minutus		20 - 30	Found mainly among dead corals fragments and rubble
Cardisoma carnifex	*Rhizophora* and landward side	30 - 45	Very big crabs that make larger burrows. They inhabit landward *A. marina* and terrestrial trees, and are active at night
Cerithidea decollata	All the zones	No time needed	They climb mangroves and drop following the tides
Littoraria scabra	All the zones	No time needed	Can be found on leave surfaces
Terrebralia palustris	*Rhizophora* and seaward zone	No time needed	The largest mangrove true snail
Crassostrea culcullata oyster	*Rhizophora* zone	No time needed	Sessile, attached to trunks and branches

Figure 15. Common crabs and molluscs found in mangroves of the WIO region (from Richmond, 2011).

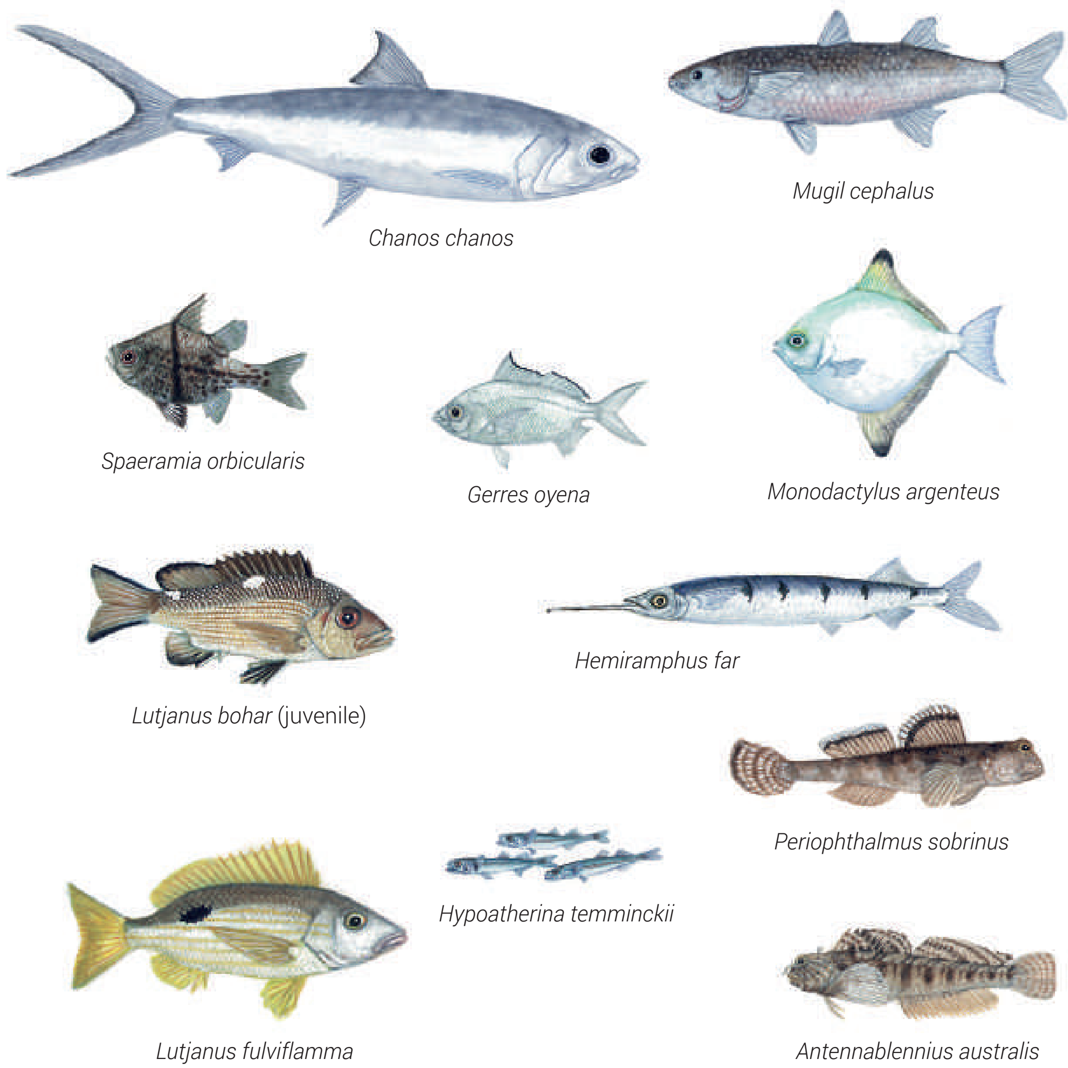


Figure 16. Some of the fish species commonly found within the mangrove forests (from Richmond, 2011).

5. Case Studies on how it has Worked and Lessons Learnt

Mangrove restoration campaigns in the WIO are mostly supported by aid agencies through either at the initiatives of government, non-government organizations (NGOs), community, or a mixture of all.

5.1 Government Driven Initiatives: a case of Mauritius

The best example of this initiative is Mauritius where the government has played an active role in the restoration and management of mangroves since 1990's (Plate 11). The initiative involved setting up of a mangrove nursery at the Mahebourg Fish Farm in the south east part of Mauritius. In the first phase of the project (June 1995 - 1996), over 12,000 seedlings were planted at nine sites around the island covering a total lagoonal area of 22,750 m², much of this in and adjacent to the MPAs including Black River in the west, Poudre d'Or in the north and Grand Port Fishing Reserves in the south east. An average survival rate of 65% was recorded. The second phase (June 1997 - December 1998), involved four sites along the west coast, covering an area of 23,750 m² where 47,500 seedlings were planted. The third phase (February 2000 - 2001), included five sites along the north shore planted with 40,000 seedlings covering 20,000 m². In the subsequent fourth and fifth phases, each of one year, three sites in the east with an area of 29,000 m² witnessed 58,000 seedlings planted; and a mud flat of 23,000 m² on the western part of the island, received about 41,000 propagules. A year later (in 2002), over 95% of the planted mangroves had developed into healthy plants reaching four to six leaf stage, eventually recording survival rate exceeding 80%. This has increased the area of mangroves countrywide from a 45 ha to 120 ha by 2005. Based on this success, NGOs and local stakeholders were subsequently encouraged to continue the task, and increase public awareness. By 2014, the mangrove cover in Mauritius had increased to 179 ha. To safeguard this achievement, the laws of the country have placed emphasis and are stringent on mangrove protection.

5.2 NGOs Driven Initiatives: a case of Madagascar

Madagascar is known for the NGO-driven approach where local and international NGOs have directed restoration activities for many years, notably along the south-western and north-eastern coasts of Madagascar, with involvement of multiple stakeholders including regional and local authorities, community-based organizations (CBOs), research institutes and the private sector. Apart from initiating restoration, the NGOs have taken to the coordination of the restoration programme nationwide, providing financial and technical support to restoration projects. In engaging communities in Madagascar (Plate 12) and stakeholders, NGOs have used two approaches:

i. Voluntary participation in mangrove restoration through education and awareness campaigns undertaken prior to the initiation of planting activities. Due to the labour-intensive nature of mangrove planting there is need for awareness creation and motivation of the local communities towards such initiatives. The common practice is that no financial remuneration is given, although the NGO may organize food for work as an incentive. This approach has proved to be more effective and sustainable in mangrove restoration and management.

ii. Financial compensation, following mobilization and awareness creation, is provided for local community labour. This remuneration is made for the collection of propagules, actual planting, and the post-plantation surveillance. Here, other stakeholders such as CBOs also contribute financially. The financial compensation varies depending on the financial capacity of the financiers.

Plate 11. Planted mangroves at Le Morne, Mauritius. Top: before planting May 2011 and Bottom: after planting September 2011.

5.3 Community Driven Initiatives: a case of Mozambique

This approach is characteristic in Mozambique where communities embark on mangrove rehabilitation with no external assistance when the larger population directly feels obvious ecological impact of mangrove degradation. On realizing the problem, communities decide to restore degraded areas within their localities using their own resources (Plate 13).

An example of a community project is that of Nhangau in central Mozambique where the community, on a voluntary basis, engaged in mangrove restoration and conservation from the mid-1990s. They created a Natural Resources Management Committee (NRMC), responsible for mangrove planting and oversight of planted and natural areas, enforcement of law and local regulations, promotion of alternative income generating activities (IGAs) such as production of energy-efficient stoves, beekeeping, medicinal gardens and aquaculture, as well as continuous awareness creation. Government representatives, students and members of the civil society were also regularly invited to join in the voluntary planting campaigns at Nhangau, only incentivized through monthly groceries, capacity building, and the creation of a community trust fund. The positive results from this initiative triggered its transformation into a programme for which the government decided to allocate an annual budget through the respective ministry from 2001.

Plate 12. NGO sponsored mangrove planting at Ambanja, Madagascar.

The community has subsequently reported several benefits from the initiative including, an increase in fish and crab catches, habitat enhancement, and shoreline protection. However, a number of challenges still persist including inadequacy in law enforcement, need for more innovative IGAs and financial insecurity.

5.4 Mixed approach: a case of Kenya, Tanzania and Seychelles

This is characteristic in Kenya, Tanzania and Seychelles where government agencies, NGO's, funding agencies, and communities work together in mangrove restoration and management. In this approach, community awareness creation of the importance of mangroves has been key and has improved over the years. Integration of local knowledge in the restoration of mangroves is widely utilized in the initiative. In Rufiji Delta (Tanzania) for instance, through both government and NGO sponsored campaigns, communities plant mangroves during rain seasons because of their accumulated experience that seedlings and saplings grow much better in less saline soils (Plate 14). Local knowledge has also been used to select areas suitable for restoration based on local experience of hydrological processes such as tidal regime and frequency of water flushing in the proposed restored areas. In Kenya, increased awareness creation and interactions within stakeholder groups has empowered local communities to eventually restore and protect mangroves at Gazi Bay through sale of carbon credits (Plate 15). In such cases, communities plan, implement and manage the replanted mangrove areas with minimal dependence on the external partners.

Plate 13. Effective community participation is key to success in mangrove restoration at Limpopo Estuary, Mozambique.

Mozambique: legal framework to support community empowerment

Community involvement in all sorts of mangrove management issues is recommended and safeguarded by the Mozambican law (Law No 19/97 from October 1st; Law No 10/99 from July 7th) and by several other regulatory instruments including the National Environmental Policy (Resolution 5/95 from August 3rd), based on the principle that the communities are the most impacted by any decision made regarding the management of the resources. Community participation in the design of local management measures also promotes community empowerment, increases compliance and legitimates self-policing (Agrawal 2003). However, involving the communities is not always an easy process (Frank *et al.,* 2017). It involves thorough consultations, inclusive participatory mechanisms, incentives and fair distribution of benefits, among other aspects (Frank *et al.,* 2017; Damastuti and Groot 2017). In most of the mangrove rehabilitation projects conducted by MICOA/MITADER the community participation was one of the greatest weakness due to:

- Low awareness of the importance of mangroves and restoration purposes;
- Inadequate incentives system;
- Lack of transparency in the selection of community-members directly involved in restoration activities;
- Lack of inclusion of vulnerable groups (such as the non-influential groups or illegal users)

5.5 Lesson Learnt

There are several lessons that can be drawn from the above mangrove restoration approaches:

- **Continued awareness creation** gives self-drive and a high sense of responsibility, reflected in the voluntarism and continued replanting and management of mangroves in some areas.
- **Mangrove rehabilitation works better as a programme** and not a short-term project, as it takes time for the communities to engage, build capacity and empower. Additionally, awareness and monitoring should be a continuous process.
- **The existence of dedicated and well-trained staff is** key to the success of a community-based management system.
- **Partnerships are crucial** particularly, in the promotion of community engagement and capacity building in mangrove management and community access and user rights to forest resources. The legalization of the NRMC in Mozambique was aided by an NGO and was a crucial step in community empowerment. The community is entitled to 50% of the fees charged from illegal cutters of mangroves reported by the community.
- **Mangrove restoration must be complemented by other measures** for effective management.
- **There is need for documentation of such community-based management systems** to provide lessons and opportunities for studies and improvement.
- **Long-term monitoring of mangrove reforestation activities** is essential to ensure success
- **There is need to develop alternative income generating activities** (IGAs) aimed at all mangrove users including mangrove cutters. Ecotourism and payment for ecosystem services (PES) programs may also be exploited. For instance, the success of mangrove conservation at Gazi bay, Kenya, has mostly been due to direct income to participating community from sale of carbon credits.

Rufiji Delta - Tanzania

Community-based mangrove restoration is commonly used in the Rufiji Delta, with the support of donor agencies and civil society. A recent example is the government sanctioned project "Developing Core Capacity to Address Adaptation to Climate Change in Productive Coastal Zones of Tanzania" through the Vice President's Office – Division of Environment which had a mangrove restoration component. The project engaged local community groups of 8-10 men and women, assigned areas of mangrove forest to restore and paid for each day they spend replanting or weeding. In such arrangements, village leaders facilitate selection of mangrove planting groups and women are given a priority, local contracts are agreed between communities and the project management prior to the exercise. In most cases, the contracts include collection of seedlings or seeds of the required mangrove species from the nearby forests that are then planted in an agreed area depending on the accessibility of the area and weather. Through this arrangement, between 2014 - 2016 about 1000 ha of mangroves were replanted in the delta. The major risk of this approach is that the restoration campaign may be exposed more to the motives of financial gain than conservation such that some villagers complained to this approach, citing targeted exclusions.

Plate 14. Contract mangrove planting with rice farming has been tried in Rufiji Delta, but effectiveness and sustainability is not guaranteed.

Kenya: Restoration and protection of mangroves through carbon incentive schemes

Mangrove restoration projects in Kenya have embraced a participatory approach as enshrined in Forest Act (2005) that led to the establishment of Community Forest Associations (CFAs). Through CFAs communities are engaged in benefit sharing and management of designated forest reserves. Building on this provision, several CFA's have been established along the coast in coordination with Kenya Forest Service (KFS) and other agencies. Through the Kenya Marine and Fisheries Research Institute (KMFRI) for example, a small-scale carbon offset facility involving mangroves was launched at Gazi bay in 2013. Dubbed Mikoko Pamoja – this was the world's first community-type project to restore and protect mangroves through sale of carbon credits. International demand for carbon credits from Mikoko Pamoja now exceeds supply, and the project is achieving its climate, community and conservation objectives. Hence it has established a model that could be replicated elsewhere in Kenya and internationally, and has already influenced national level policy, for example the Kenyan National Mangrove Ecosystem Management Plan. So far activities of Mikoko Pamoja have been replicated in the Vanga Blue Forest (VBF) project, located in the transboundary mangroves of Kenya and Tanzania, and involving larger mangrove area than *Mikoko Pamoja*. VBF will offset 5500t CO_2-eq. per annum in a contracting period of 20-years (from 2019), generating an income of ca. US$3000/annum to the local community. Similar to Mikoko Pamoja, the generated income under VBF will support local development projects in water and sanitation, education and environmental conservation. In this case, the community has taken full control of mangrove conservation and is well trained in nursery establishment, planting, surveillance and monitoring thus enhancing success rate of mangrove restoration projects. Such transfer of rights and skills has bolstered community support, cooperation, participation and ownership.

Plate 15. Income through sale of carbon credits by Mikoko Pamoja is used to support local development projects such as education in Gazi bay, Kenya.

Seychelles: Investing in future generations – Our future is now

Mangrove restoration activities in the Seychelles include projects on habitat restoration and biodiversity protection that are implemented by NGOs and schools (Plate 16). Nature Seychelles and the Seychelles National Park Authority are lead organisations in mangrove restoration projects that have aimed to enhance the habitat for wildlife amongst other environmental benefits. In 2016, the Seychelles implemented the GEF Ecosystem-based Adaptation-South project (EbA-South) "Enhancing Capacity, Knowledge and Technology Support to Build Climate Resilience of Vulnerable Developing Countries". The project aimed to address the vulnerabilities of local communities to climate change by using ecosystem-based approaches to adapt to climate change through on-the-ground interventions, increasing institutional capacity, mobilising knowledge and transferring appropriate best-practice adaptation technologies. This EbA educational and awareness demonstration project included the construction of culverts to improve hydrological flow through a 300 hectare area of artificially fragmented mangroves; channel desilting, mangrove planting and removal of invasive species impacting on the wetlands.

Plate 16. Use of school children in the Seychelles to plant mangroves ensures long term community commitment, while building a community of mangrove practitioners.

6. But still, to plant or not to plant?

The preceding Chapters have demonstrated the increasing support that mangrove restoration received from state and non-state actors around the world (Plate 17). This is due to an enhanced understanding of the true value of mangrove ecosystem and the need to protect them for climate change regulation, community livelihood, and biodiversity conservation (see Section 1.4). Most mangrove restoration efforts, however, have emphasized on planting as the primary tool for managing degraded areas (Chapter 3), rather than first assessing causes for the degradation, then assessing the natural recovery opportunities, and how to facilitate such efforts. In addition, few projects have integrated mangrove restoration with the broad objectives of sustainable mangrove management, in terms of stand structure and regeneration, return of biodiversity and other ecosystem processes (Bosire *et al.*, 2008; Kairo *et al.*, 2008).

As a dynamic ecosystem, degraded mangrove areas may recover naturally without actual planting of propagules (Kairo *et al.*, 2001; Bosire *et al.*, 2008). As discussed in Chapter 3, before initiating any mangrove planting activities to first consider promoting natural recovery, by adequately assessing the potential existence of stressors such as disruptions of tidal regimes that might be preventing natural recruitments of propagules to occur (Kairo *et al.*, 2001).

In the present Chapter, 10 simple steps to be followed by prospective project managers in deciding whether *to plant or not plant* mangroves in

Plate 17. Government support. Mangrove planting in Kenya involving key government agencies.

degraded areas are discussed (Figure 17). When natural regeneration fails and the process needs human intervention, an understanding of the autoecology and community ecology of the targeted mangrove species is necessary, i.e. its reproductive patterns, propagule dispersal, seedling establishment, zonation and hydrology **(steps 1 and 2).** With this understanding, an assessment of factors hindering secondary succession can be done **(step 3),** involving the local knowledge of communities depending on the mangroves **(step 4),** which will be relevant throughout the subsequent steps. The socio-ecological information gathered from steps 3 and 4 is then used to select appropriate restoration sites **(step 5),** and the obstacles to successful natural regeneration removed **(step 6).** If conditions are favorable, this should allow natural recruitment of propagules, which is more cost-effective than replanting. If natural regeneration fails despite all these interventions then appropriate mangrove species for planting **(step 7)** must be selected in view of genetic diversity, faunistic impacts, and individual performance of the species (Kairo *et al.*, 2001; Bosire *et al.*, 2008) and mangrove replanting **(step 8)** becomes necessary to restore the degraded site. At regular intervals the replanting effort should be monitored for both biological and physical parameters **(step 9).** When the assessment has a negative outcome, recommendations should be given for improved site management **(step 10),** which may have to be accompanied by extra planting. When the assessment has a positive outcome the site has restored, although further monitoring of the restored site can be undertaken using the procedure outlined in Table 8 [this volume]. Mangrove planting should embrace capacity building on ecological mangrove restoration principles which puts into consideration the common factors attributed to failure thus restoration success may be enhanced.

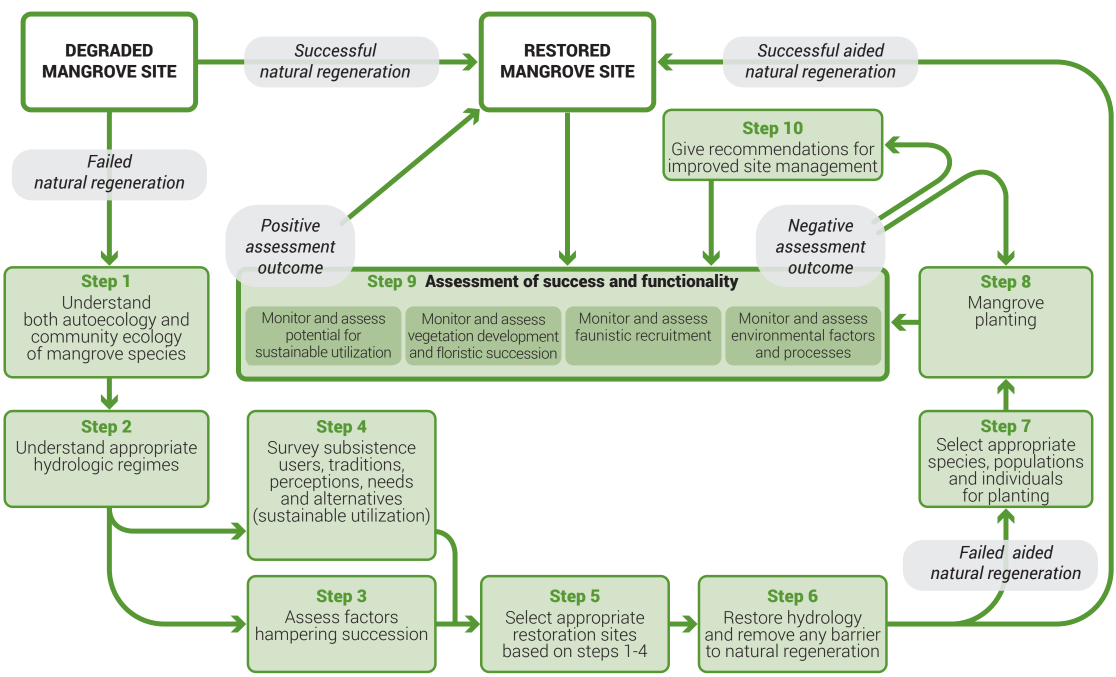


Figure 17. A 10 steps scheme depicting decision support tool for ecological mangrove restoration (Bosire *et al.*, 2008).

In summary, therefore, mangrove planting is only recommended where:

- **Natural supply of seeds or propagules are limited** as a result of blockage of hydrological connection or lack of nearby mother trees
- There is need to **re-introduce valuable species** that have been lost from an area, the so called ‘enrichment planting’
- **Severe erosion of the intertidal area** has occurred necessitating planting mangrove to curb shoreline change
- **Mangroves are being managed for silvicultural** purpose (i.e. to provide the desired wood products). Also, mangroves are often planted in combination with aquaculture system (silvo-aquaculture) to introduce additional benefits in the system such as shade and dykes stabilization,
- **Community may generate income** from mangrove planting activities including establishing of nurseries and out-planting.
- **Planting can be used for educational or cultural purposes.** Mangrove growing can create lasting commitments and ownerships amongst all those involved.

7. References

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The Nairobi Convention through the GEF-funded project, Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP), in collaboration with WIOMSA, are facilitating the production of a series of regional guidelines. The first three volumes are on Seagrass Ecosystem Restoration, Mangrove Ecosystem Restoration and Assessment of Environmental Flows in the WIO Region.

The participating countries in the WIOSAP include Comoros, Madagascar, Mauritius, Seychelles, Mozambique, Kenya, Tanzania, France (not a beneficiary of GEF funds), Somalia and South Africa. The Goal of the WIOSAP is to: 'Improve and maintain the environmental health of the region's coastal and marine ecosystems through improved management of land-based stresses'. The specific objective of the WIOSAP is 'To reduce impacts from land-based sources and activities and sustainably manage critical coastal-riverine ecosystems through the implementation of the WIOSAP priorities with the support of partnerships at national and regional levels.'