MANGROVES IN THE NIGER DELTA- RESTORATION MANUAL

HYDROCARBON POLLUTION REMEDIATION PROJECT
(HYPREP)

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FEDERAL MINISTRY OF ENVIRONMENT
HYDROCARBON POLLUTION REMEDIATION PROJECT (HYPREP)

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List of Acronyms

BMI	Bodo Mediation Initiative
CEER	Center of Excellence for Environmental Restoration
CEHRD	Centre for Environment, Human Rights and Development
CSO	Civil society organization
CSR	Corporate Social Responsibility
HAT	Highest astronomical tide level
HYPREP	Hydrocarbon Pollution Remediation Project
MCA	Mangrove conservation area
MPA	Mangrove protected area
NEBA	Net environmental benefit analysis
NGO	Non-governmental organization
NOSDRA	National Oil Spill Detection and Response Agency
NUPRC	Nigerian Upstream Petroleum Regulatory Commission
SCAT	Shoreline Cleanup and Assessment Technique
UNEP	United Nations Environment Programme

Purpose of this Document

Attempts are now made in many countries to rehabilitate and restore mangrove areas which have been destroyed, damaged or degraded. The present manual is intended to be used as a handbook for mangrove rehabilitation in the Niger Delta.

The manual describes the strategies and methods for mangrove rehabilitation with a focus on areas where oil contamination has caused destruction to the mangroves and areas invaded by nipa palm.

A parallel document, *'Ogoniland and the Niger Delta: Mangrove Restoration and Conservation Strategy'*, provides a roadmap for mangrove conservation and rehabilitation in the Niger River Delta.

1. Introduction

Mangrove is the term used for a highly specialized environment which only occurs in the tropics and subtropics. The mangrove vegetation is adapted to grow and survive in the intertidal zone along more or less sheltered shallow water (less than 20 – 30 cm depth at mean low water) and soft-muddy bottom coasts and in river deltas. Mangroves also grow less luxuriantly on sand, peat, limestone, coral reef and rock.
Mangroves are highly productive trees, shrubs, herb, palm and ferns which are hosts to a rich and diverse association of plants and animals which interact with and depend on the mangroves for their lifecycle. Hence the mangroves are often referred to as mangrove forests or mangrove ecosystems comprising of a community of plants and animals.

Through a number of adaptations mangroves are able to survive and grow in the difficult environment between land and sea. Such adaptations include a multitude of roots and trunks which enable the trees and bushes to remain in place when the tides are rising and falling.

The complex root architecture provides protection to young stages of fish and shellfish, many of which are fished as adults in waters within and outside the mangrove covered coastlines. Other services of mangrove forests include carbon sequestration, shoreline protection, water purification and cultural and educational support (Fentiman and Zabbey 2015).

Globally it is estimated that mangrove forests cover between 135,000 and 150,000 km2 (Spalding et al. 2010, Global Mangrove Alliance 2022) (See Figures 1-5 and Table 1) which makes the mangrove environment a relatively rare type of forest compared to other forest types.

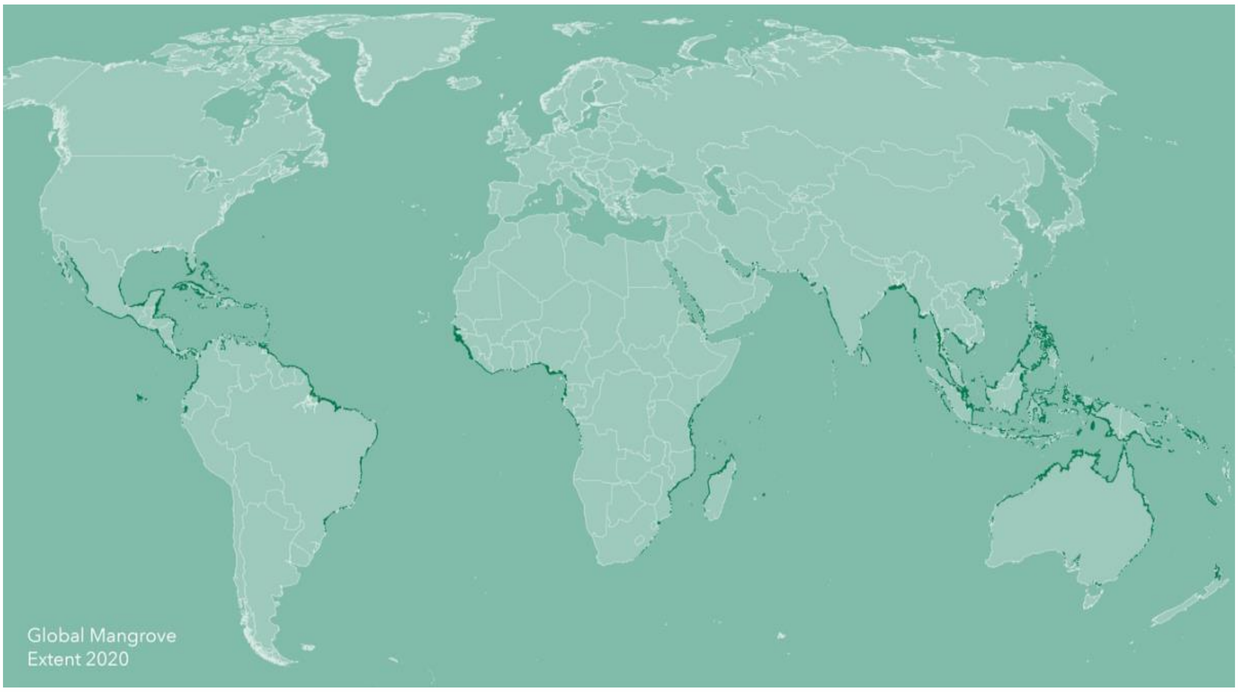


Figure 1: Global mangrove distribution.

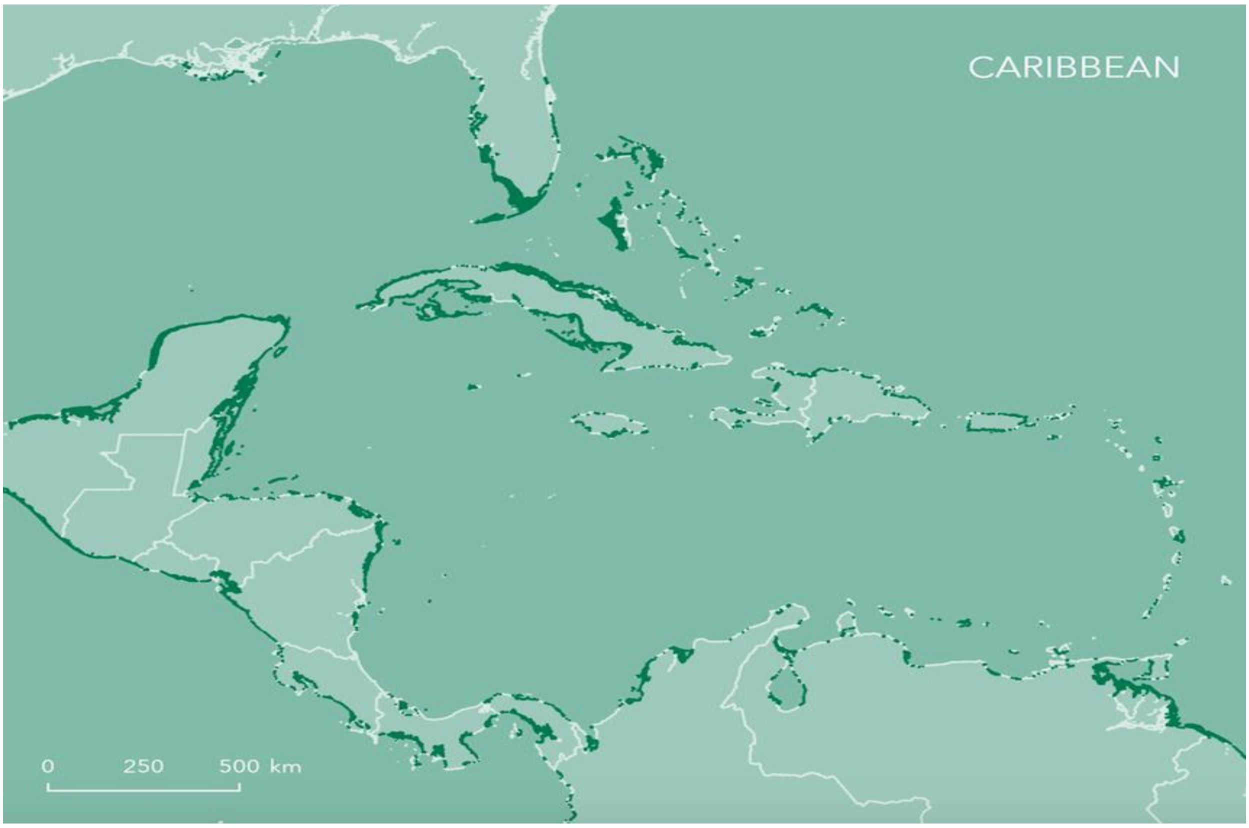


Figure 2: Mangrove distribution within the Caribbean.

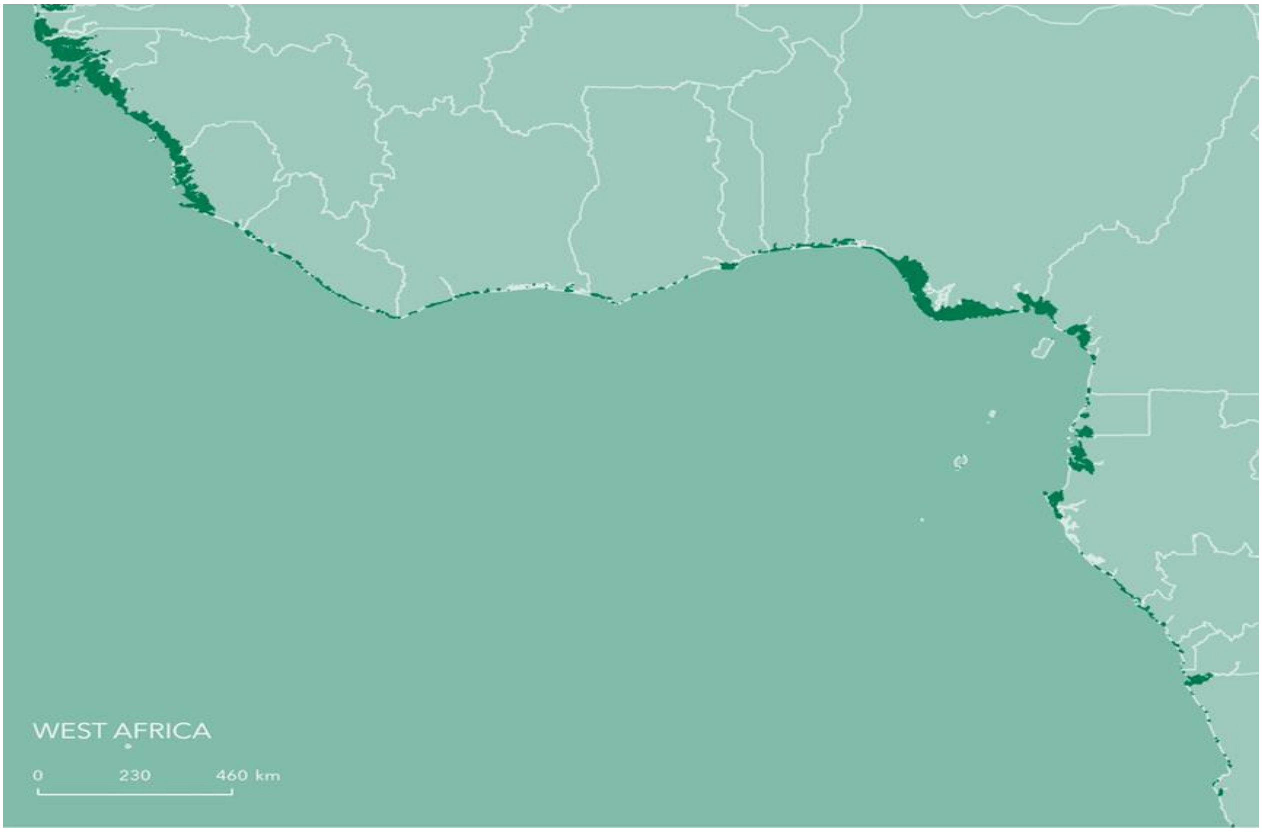


Figure 3: Mangrove distribution on the coast of West Africa.

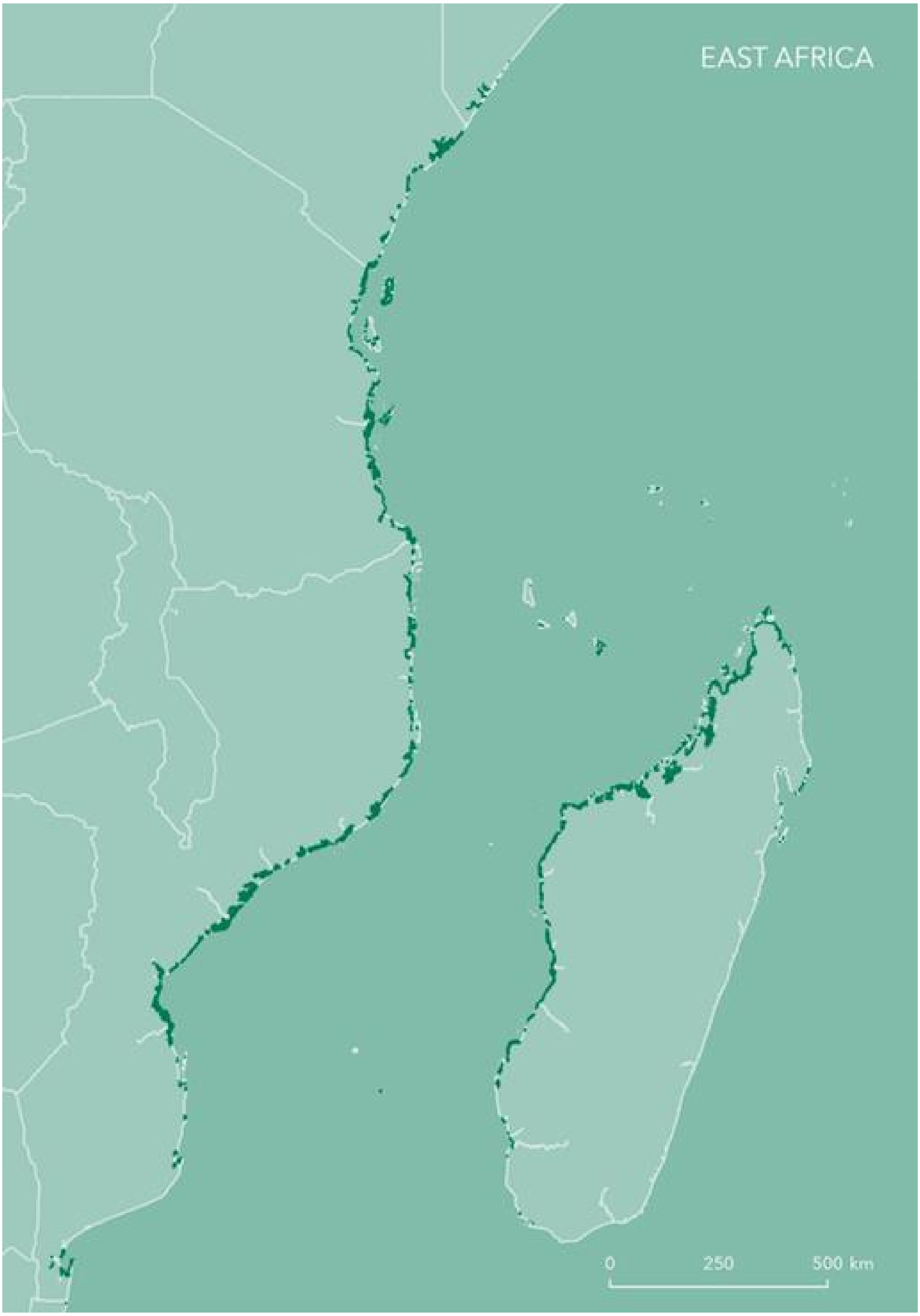
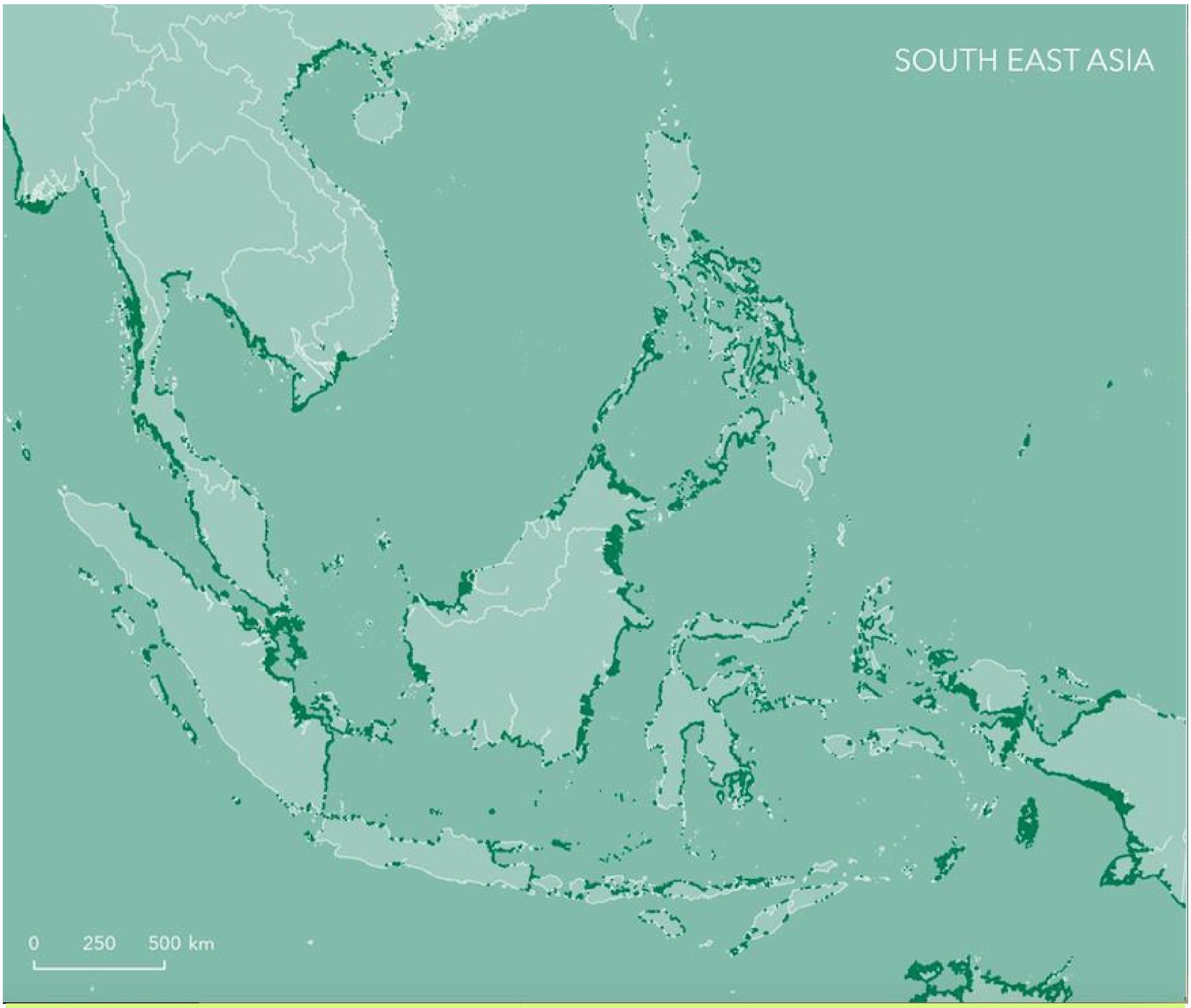


Figure 4: Mangrove distribution throughout East Africa.



Figures 5: Mangrove distribution within South East Asia. In addition to what these maps (Figures 1 - 5) illustrate, mangroves are found in the Red Sea and the Middle East, and along the coasts of South America (Colombia, Ecuador, Guyana, Brazil, Uruguay and northern Argentina as well as in northern Australia).

Mangroves have been lost throughout the world due to a number of human activities. According to FAO (2007) some 41,000 km2 were lost between 1980 and 2020, and 25% of the original mangrove covered area have been lost as a consequence of human actions.

The annual global loss of mangroves from 1980-1990 and 1990 - 2000 was 2% and 1%, respectively, which reduced to 0.69% annually in 2010 (Lewis et al., 2019). The relatively lower rates of mangrove loss on the global level are partly due to conservation efforts. However, in the Niger Delta the loss of mangrove forests is still very significant and increasing (see below under chapter 2). The dominant causes for mangrove loss globally are due to transformation of the mangroves into aquaculture (mainly prawn) farms.

Table 1: The extent of mangrove forests in 2020 in different regions of the world. The total figure of approximately 147,000 km^2 shall be compared with a figure of approximately 188,000 km^2 in 1980s (Source: State of the World's Mangroves Report 2022).

North & Central America and the Caribbean	South America	West & Central Africa	East & Southern Africa	Middle East	South Asia	South East Asia	East Asia	Australia & New Zealand	Pacific Ocean	Total
22,827	20,378	21,715	7,630	285	9,549	48,222	228	10,467	6,058	147,000

Figures 6 and 7: Mangrove forests have been lost for a number of reasons, such as for giving space to saltpans (above in Sri Lanka) and aquacultures for fish and shrimp (below Vietnam) (Photo: Olof Linden).

Also, mangroves are threatened by expansion of urban areas, road construction and overharvesting for timber and fuel. In a few areas of the world (such as the Niger Delta) mangroves over large areas have been destroyed as a result of oil spills. It is estimated that the Niger Delta accounts for 27% of the global oil releases that had impacted mangroves (Duke, 2016). More so, the continuous spread of nipa palm (*Nypa fruticans*), an introduced invasive mangrove palm, is another major threat to the native mangroves of the Niger Delta (see Chapter 4 for text box on Nipa palm).

Attempts are now made in many countries to rehabilitate and restore mangrove areas which have been destroyed, damaged or degraded. The present manual is intended to be used as a handbook for mangrove rehabilitation in the Niger Delta. It incorporates the ten principles for ecosystem restoration to guide the United Nations Decade 2021- 2030 (FAO et al., 2021).

Figure 8: Mangrove replantation in Sri Lanka (Photo: Olof Linden).

Figure 9: BMI mangrove reforestation in Bodo Creek (Photo: Nenibarini Zabbey).

The manual describes the strategies and methods for mangrove rehabilitation with a focus on areas where oil contamination has caused destruction to the mangroves and areas invaded by nipa palm.

Restoration of a degraded or destroyed ecosystem is desirable and possible, but difficult to be achieved. The term restoration refers to returning a degraded, damaged, or destroyed ecosystem to its pre-existing conditions.

On the other hand, **rehabilitation** entails a broad range of remedial actions undertaken to recover the structure and functions of a degraded ecosystem without necessarily returning it to the pristine (pre-disturbance) state (Dale et al., 2014; Bosire et al., 2014; López-Portillo et al., 2017).

Hence rehabilitation is the process of restoration, which would be achieved without necessarily returning the degraded ecosystem to its pristine or pre-degraded conditions. In other words, rehabilitation is the process of achieving restoration (the goal).

Thus, rehabilitation is relatively more achievable and is technically gaining currency and ascendency (López-Portillo et al., 2017). However, the term restoration is popular in the public domain and more entrenched in literature than rehabilitation. Hence, in this manual both terms (restoration and rehabilitation) are used interchangeably, whereby restoration contextually takes on rehabilitation meaning.

2. The Mangrove Forests of the Niger Delta

2.1. Area covered by mangroves

The mangrove forests of the Niger Delta cover an area of approximately 8,240 km2 in 2020, down from about 10,500 in 2010. Although the mangroves are disappearing rapidly, Nigeria is still the country in Africa with the largest area covered with mangrove forests (see Table 2 and map of tropical Africa). Africa as a whole is estimated to have about 27,000 km2 of mangrove forest, which is about 20% of the total mangrove forests of the world.

2.2. Species of mangroves

The true mangrove vegetation in the Niger Delta consists of six species of trees/shrubs, one palm and two ferns (Table 2), various shrubs and ferns that occupy the aquatic parts of the Delta influenced by marine water.

The distinct identification features of the Delta's red, black, and white mangroves have been compiled by Jackson and Lewis (2000) and are reproduced in Appendix 1. In many places in the Delta there is a gradual transition from true mangrove environments into freshwater swamp forests. The figure below shows the distribution of mangroves in the Delta.

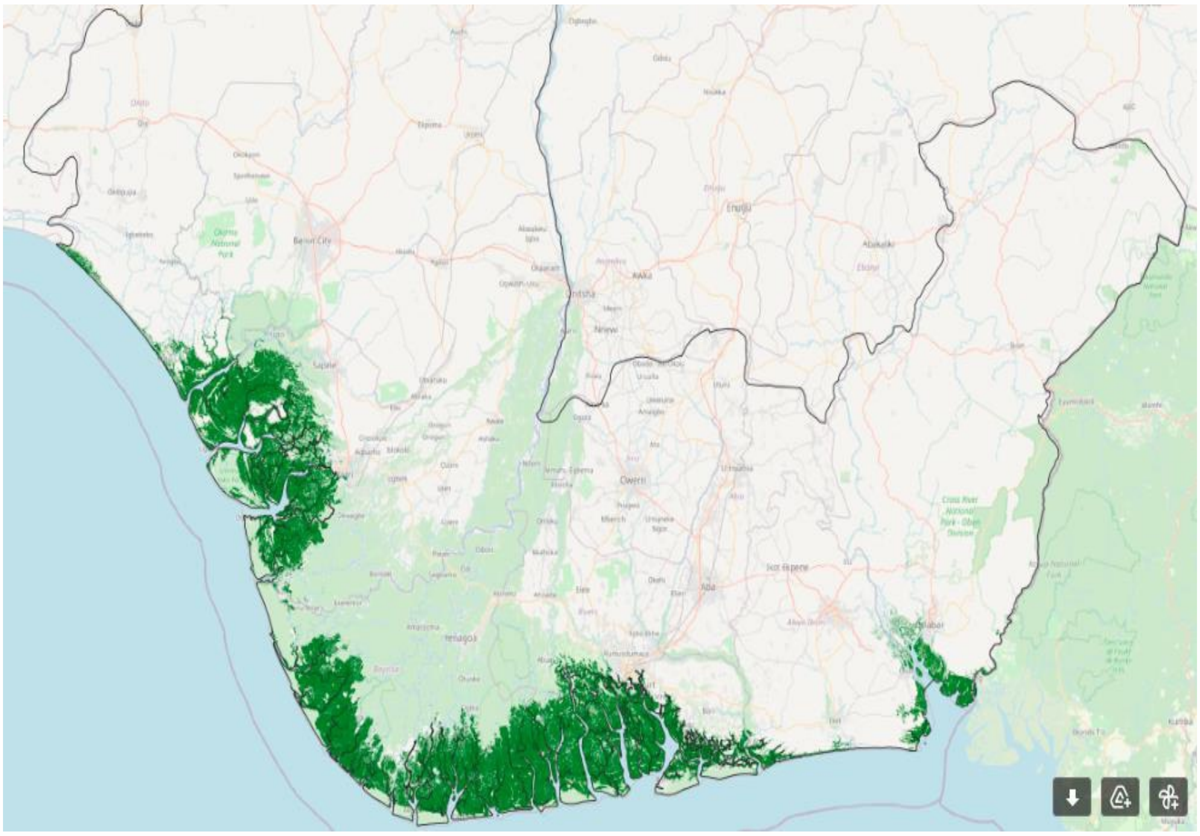


Figure 10: The extent of mangrove vegetation (8,240 km^2) including nipa palm (about 10%) in 2020 based on GMW Dataset and NASA Satellite images.

Table 2: The nine true mangrove plants and associated species in Nigeria with information about their relative abundance.

Family	Common Names	Species	Relative abundance
		True mangroves	
Rhizophoraceae	Red mangrove	*Rhizophora racemosa* *Rhizophora mangle* *Rhizophora harrisonii*	Dominant Very Common Very common
Avicenniaceae	Black mangrove	*Avicennia germinans*	Very common
Combretaceae	White mangrove	*Laguncularia racemosa* *Conocarpus erectus*	Common Rare
Arecaceae	Mangrove palm	*Nypa fruticans*	Very common
Pteridaceae	Mangrove fern	*Acrostichum aureum* *A. danaeilfolium*	Common Common
		Mangrove associates	
Poaceae	Silt grass or Seashore paspalum	*Paspalum vaginatum*	Common
Palmeae	Date palm	*Phoenix reclinata*	Common
	Screw pine	*Pandanus candelabrum*	
Malvaceae	Sea hibiscus	*Hibiscus tiliaceus*	Common
		Drepanocarpus lanatus	Common
Chrysobalanaceae	Coco plum	*Chrysobalanus ellipticus*	Common
		C. orbicularis	Common
Cyperaceae	Jointed flatsedge	*Cyperus articulatus*	Common

2.3. Productivity and benefits

The mangroves of Niger Delta are highly productive in the sense that the primary productivity is very high in this type of ecosystem. Almost all the primary production in the form of leaves, fruits, etc. are directly or indirectly consumed within the mangrove forests by numerous organisms such as the larvae and young stages of fish and shellfish including prawns, crabs, oysters and mussels (Table 2).

The environment in the mangrove forests is ideal for young stages of fish and shellfish not only because of the high concentrations of feed for these organisms but also for the protection from larger predators that the many trunks and roots provide.

Table 3: Some commercially important fish and shellfishes that depend on mangroves in the Niger Delta.

Family of fin fishes	Species	Common name
Lutjanidae	*Lutjanus gonensis*	Red snapper
Lutjanidae	*Lutjanus agennes*	African red snapper
Serranidae	*Epinephelus spp*	Groupers
Sciaenidae	*Pseudotolithus senegalensis*	Croaker
Sciaenidae	*P. Typus*	Longneck croaker
Sciaenidae	*P. Elongatus*	Bobo croaker
Clupeidae	*Ethmalosa fimbriata*	Bonda shad/bonga fish
Mugilidae	*Liza grandisquamis*	Large scaled mullet
Mugilidae	*L. Falcipinis*	Grey mullet
Cichlidae	*Sarotherodon melanotheron*	Blackchin tilapia
Cichlidae	*Tilapia guineensis*	Guinean tilapia
Eleoctridae	*Eleotris seneganensis*	Silver fish
Butidae	*Bostrychus africanus*	
Sphyraenidae	*Sphyraena baracuda*	Great barracuda
Cynoglossidae	*Cynoglossus senegalens*	Tongue fish
Oxudercidae	*Periopthalmus papilio*	Mudskipper
Shellfish		
Portunidae	*Callinectes amnicola*	Bigfisted swimcrab
Graspidae	*Goniopsis pelli*	Purple mangrove crab
Gecarcinidae	*Cardisoma armatum*	Lagoon land crab
Ocypodidae	*Uca tangeri*	West African fiddler crab
Penaeidae	*Farfantepenaeus notialis*	Southern prink shrimp
Penaeidae	*Penaeus kerathurus*	Caramote prawn
Palaemonidae	*Nematopalaemon hastatus*	Estuarine prawn
Ostreidae	*Crassostrea gasar*	African mangrove oyster
Potamididae	*Tympanotonus fuscatus fuscatus*	West African mud creeper
Potamididae	*T. Fuscatus var radula*	West African mud creeper
Thiaridae	*Pachymelania aurita*	Freshwater snail
Thiaridae	*P. Fusca*	Freshwater snail
	Semifusus morio	Sea snail (Giant hairy Melongena)
Muricidae	*Thais coronata*	Murex snails or rock snails

In addition to the benefits of well-preserved mangroves to local human societies in the form of securing stocks of fish and shellfish in nearby river and marine areas, there are a number of other direct and indirect positive aspects of such environments. One such benefit comes from the fact that well-developed mangroves like other forests can sustain a certain level of harvesting for fuelwood and timber.

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The illustration below shows how mangroves can be harvested in a sustainable way 'enlightened harvesting'. This includes avoiding fruiting stems as much as possible, and cutting the trunk at least 30 cm above the root base (Figure 2). The stumps in turn regrow and produce multi-stem, whereas the current unsustainable harvesting method of cutting the prop roots to fell the trunk causes the plant to die.

Figure 11: Current unsustainable method of harvesting mangrove wood and the recommended sustainable harvesting method that promotes regrowth.

Well-developed mangroves along a coastline have a number of other indirect benefits to local communities. For example, the presence of the trees with many trunks and roots protects the coast from erosion from extreme waves, spring tides, storms, etc. The protective properties of mangroves were clearly illustrated during the 2004 Indian Ocean Tsunami. Coastlines where mangroves had been destroyed were much more affected by the tsunami waves than coastlines behind belts of mangrove forest.

Because of the dense curtain of roots and trunks in a mangrove forest the environment functions as a filter for sediment-rich water from land. Silt and detritus are trapped in the mangroves and the water reaching the ocean is consequently cleaner with less particles and nutrients reaching the sea.

As mentioned above mangroves forests are highly productive with carbon fixation rates well above forests on land. Mangroves allocate proportionally more carbon belowground and hence the sediment in mangrove forests contains high concentrations of organic carbon. As a consequence, mangroves are among the most carbon-rich ecosystems and play an important role in the global carbon cycle.

3. Threats to the Mangrove Forests of the Niger Delta

The major causes of the degradation and disappearance of mangrove forests in the Niger Delta are oil pollution, unregulated and destructive harvesting, conversion of mangrove covered areas into agricultural land or built-up zones, such as for housing or industrialization.

Figure 12: Former mangrove area reclaimed for housing, Bundu waterfront, Port Harcourt (Photo: Nenibarini Zabbey).

There are also losses of mangrove areas due to illegal dredging for sand in creeks and rivers which leads to erosion of sediments in mangrove areas. Another cause of native mangrove loss is the displacement that is occurring due to the spreading of the invasive nipa palm.
In addition, the construction of roads may alter the hydrology and thereby the ecology of the mangrove forests and as a consequence, much of the benefits of the mangroves are lost.

3.1. Loss due to oil spills

The problem of oil spills in the Niger Delta has been described in a number of reports (see for example the United Nations Environment Programme (UNEP) report of 2011 (UNEP 2011). Spills happen due to a variety of reasons, for example due to corrosion of pipelines and operational mishaps. For example, in the Bodo Creek area, more than 1,000 ha of mangrove forest were degraded by two major operational oil spills in 2008 and 2009, and subsequently reinforced by several spills due to pipeline breakage (Figure 13).

However, a significant portion of the spills during the last decade were caused by criminal activities (sabotage), such as in connection with the theft of oil from oil

infrastructure (manifolds, pipelines), and in connection with artisanal refining of stolen oil.
Oil spills in mangrove forests are destructive mainly due to the physical properties of the oil, which leads to clogging and prevents the mangrove plants from breathing. In addition, crude oil consists of more or less harmful hydrocarbon molecules which result in various toxic effects on the mangrove vegetation.

Heavy oiling may also lead to accumulation of high concentrations of oil in the sediment which will become a long-term problem as the natural degradation of petroleum hydrocarbons in sediment is a very slow process.

3.2. Cutting

Another major threat to mangroves in the Niger Delta is over-exploitation in connection with the gathering of fuel wood and wood to be used for other purposes such as for building, production of fence poles, charcoal, etc. (Table 4).

Mangroves can tolerate a certain degree of harvesting, but a part of the main trunk of the tree with its supportive prop roots must be left for regeneration and its harvestable capacity should not be exceeded (see Figure 11).

Table 4: Uses of processed and unprocessed parts of mangrove plants in the Niger Delta (modified from Zabbey 2020).

S/No	Broad types	Examples	Comments
1	Processed or unprocessed mangrove woods	Mangrove leaves and sticks	Mixed with thick mud (*ke kel* in Gokana) to create a fire platform in canoes.
		Heavy-knob mangrove stumps	Tied with rope to the canoe as an improvised anchor.
		Two-pronged mangrove sticks	Erected and used to hang fishing nets.
		Tiny peelings of the woody trunk (below the bark)	Temporary sealing of minor leak-holes in wooden canoes.
		Mangrove wood (flesh or dry)	Produces top choice charcoal
		Debarked tall and straight mangrove sticks	Used to form the internal frame of mud houses, and as roof trusses.
		Scaffolds	Scaffolds made of mangrove woods are durable
		Cultivation sticks	Climbers for yam and vegetable, and use to fence farmlands and homesteads.
		Mangrove fern	Used to invoke deity punishment for stolen properties

2	Processed mangrove woods yield a lot of domestic and livelihood support products	Chewing stick, net mending sticks, axe handles, mortar and pestles	Mortar and pestles are used to pound yam, cassava, plantain, and soup thickening condiments.
		Walking sticks, paddles, masquerade masks, drums and ancillary tightening pieces	Carved from mangrove wood
		Fish smoking racks and indoor screens.	Weaved with slices and strands of fleshy hanging prop roots
		Sail pole, bed, tables and wooden plate and for constructing kitchen shelf	Processed from mangrove sticks/wood
		Liquid (sap) extract	Has blood-clotting function.
		Dye	To maximize fish catch, red mangrove sap is used to dye new nets

3.3. Transformation of the landscape

Changing land use is also a major cause of the disappearance of mangroves in the Niger Delta. A large portion of the original mangroves that existed some decades ago have been transformed into built up residential and industrial areas. Some mangrove areas have been converted into fishponds. Network of roads, pipeline right-of-way, seismic lines and electric power lines that cut through directly lead to loss of mangroves, and the fragmented mangroves impact on the animal community.
The direct effects of filling and cutting are visibly obvious, but what may be less apparent is the change in the hydrology that is caused by, for example, the road embankment. If the tidal flow pattern is lost the mangrove area will be transformed and the valuable properties of the mangroves will disappear.

3.4. Nipa palm

The invasive nipa palm is spreading rapidly in the Niger Delta from east to west. Fossil records show that during the Paleocene (63-58 million years ago), nipa palm had dominated the estuarine swamp vegetation of the Niger Delta and later became extinct (Saenger and Bellan, 1995).

The extant stock of nipa palm was introduced to the shores of Nigeria in 1906, became invasive and has now naturalized. A recent estimate indicates a 600% spread of nipa palm in the Niger Delta in the past ten years (Nwobi et al. 2019). In spite of the invasive trait of nipa palm and the invasibility (vulnerability to invasion) of the Niger Delta mangrove swamps due to human disturbances, the little or non-utilization of the palm contribute greatly to its continuous spread in the region.

While native mangrove plants are shrinking due to oil pollution, urbanization, unregulated harvesting, etc. (see detailed causal factors in Chapter 3), nipa palm is almost locally untouchable. The native mangrove plants (e.g., red mangroves) are heavily exploited as preferred sources of energy for cooking and charcoal production, among other uses (see Chapter 2 for ecosystem goods and services of mangroves). By contrast, nipa palm is barely harvested in the Delta. This enhances its competitive advantage. It has been illustrated that intact native mangrove plants preclude nipa invasion (Zabbey et al., 2021). Nipa competes for space, usually at the edge of the native mangrove forest. However, soon it is also spreading into the native mangroves when access is created by human activity, and at some stage it may become the dominant plant. In order to protect the native mangroves of the Niger Delta it is necessary to prevent the spread of nipa palm, utilize the palm for various local needs and restore the native mangroves in some areas colonized by nipa palm.

3.5. Ownership

Mangrove ownership in the Niger Delta is somewhat complex. In most cases natural mangrove swamps are under communal ownership, considered common property. At least, all downslope mangroves (that is, those that do not have a direct interface with residential land) are customarily communal.

However, there are some subsisting pseudo-systems of individual ownership. For example, the owner of terrestrial land that fringes mangrove wetland overlooks or potentially exercises "custodial" ownership of the abutting mangrove swamp. A similar temporary ownership applies to areas leased for pond aquaculture.

Ownership of the mangrove wetland where ponds are dug may be complex (Primavera and Esteban, 2008). Sometimes, the fishpond lease agreement is poorly documented or merely granted by the verbal pronouncement of the community leadership with no defined tenure. The fishpond owner may exercise control over a disused pond area even though the area was a common property prior to pond development. Therefore, reversion of the disused ponds to mangroves through restoring hydrology or planting will require the buy-in of the pond owner. It is important that tenurial agreement precedes the lease of communal mangrove areas to pond developers to forestall ownership conflicts over time.

Figure 13: Extensive mangrove loss caused by oil spills in Bodo Creek, Niger Delta (Photo: Nenibarini Zabbey).

4. Prerequisites for Mangrove Rehabilitation/Restoration to be Successful

4.1. Defining the objective(s)

One of the foremost preconditions to achieving a "successful" mangrove restoration is to clearly define the goal and objectives of the project. These should be achievable and measurable, and should form the basis of the criteria and method for monitoring the performance of the project over time (see section 6 for monitoring).

There is no "one-size-fits-all" mangrove restoration goal or objective. However, in developing the project goals and objectives, some fundamental questions need to be addressed by the project proponent in conjunction with the local communities where the project will be sited. It is important to integrate the community's expected outcomes into the planning and implementation stages of the project. Large-scale mangrove restoration projects should be led by a chief restoration officer who will incorporate the expectations of key stakeholders as well as biodiversity protection elements into project design and implementation.

The questions that would inform developing the goal and objectives include: is the goal to restore vegetative cover (afforestation/reforestation/silviculture) or community (structural and functional) diversity (ecosystem restoration)? The latter goal is broader than the former, as it involves restoring both flora and faunal diversity to achieve the return of ecosystem goods and services.

In the context of the Niger Delta, the recovery of ecological and economic functions of the rehabilitated mangroves is crucial because the local communities depend largely on the mangrove ecosystem for livelihoods. In sum, the objectives of mangrove restoration would include emphasis on the ecological values, livelihoods of the local population, coastal stabilization, provisioning of fuelwood, habitat for animals, support of fisheries, stable employment for the local communities, and contribution to sustainable development.

4.2. Support from local communities

Once a restoration site is identified, the local community needs to be consulted to understand and resolve issues of landownership and secure the buy-in of the local population. Consultation would foster the incorporation of community use expectations into the restoration goal so that the project would benefit from local support.

The buy-in and active involvement of the local people have long-term advantages. Community folks learn the science and art of mangrove restoration by participating in the process.

The skill legacy of the project would engender future voluntary rehabilitation and sustainable management efforts of some of the locals. It would aid a seamless co-management model. The pool of volunteers (community scientists) can be leveraged by research institutions that would be assigned the role of long-term research and monitoring of the restoration site (see recommendation in section 6).

4.3. Oil spills have ceased

As discussed in section 3, oil pollution is one of the major stressors/threats to mangrove in the Niger Delta. Many potential restoration sites in the Delta are degraded by oil (UNEP, 2011; Duke, 2016). Next in the ranking of potential mangrove restoration sites are nipa palm colonized areas that would require replacing the exotic palm with native mangrove plants. Some mangrove sites impacted by urbanization (abandoned reclaimed areas) and road construction in the region.

Broadly, understanding the cause of mangrove loss is a necessary prerequisite before starting mangrove restoration. The factors that cause the mangrove vegetation to be degraded, should also have ceased. UNEP (2011) recommended the prevention of further oil contamination by stopping oil theft and artisanal refining operations as well as improving the maintenance of oil infrastructure, before starting cleanup and restoration of Ogoniland. The contrary would amount to 'leaving the tap on while mopping the floor'.

4.4. Keeping track of tides and elevations

An essential prerequisite for success is good knowledge of the tidal conditions and the elevation in the areas to be cleaned and revegetated. The window during which it is possible to reach to and be able to carry out work in the mangrove is rather limited, possibly a few hours when the tidal flats are exposed at low tide. At high tides it is difficult to do any meaningful work, and during low tides it may not be possible to reach the sites with the workboats. Therefore, careful planning is key to success. Personnel and equipment must be on site at the right time to be able to make use of the conditions.

For efficient cleanup of mangrove tidal flats and to prevent re-pollution from flushing operations, a tide-cooperative strategy is required (Figures 14 and 15). Failures of booms typically re-pollute previously cleaned and certified areas. If re-pollution is not prevented, it will be a waste of both manpower and resources. Multiple booming backstops oil lost from the inner boom. Rapid currents, which characterize concave meanders during spring tides, can, however, overwhelm multiple booms. As a result, for efficient cleanup of mangrove tidal flats and prevention of re-pollution, a response strategy that prioritizes convex meanders during periods of swift current is required. In addition, given the network of oil pipelines that traverse the mangroves of the Niger Delta and the complex interconnectivity of the mangrove belt by tidal creeks, it is important to have in place a robust and effective oil spill contingency plan. Oil facility owners in mangrove areas should develop an emergency response plan that would be reviewed, approved, and its compliance enforced by the National Oil Spill Detection and Response Agency (NOSDRA).

Better still, NOSDRA can develop a national mangrove protection contingency template and train the staffers of the oil facility owners that are responsible for its implementation. Such fit-for-purpose response strategy will protect the restoration sites and natural mangrove forests in the wake of any oil spills from operational reasons or due to sabotage/theft. Restoring mangroves in oil degraded areas would hinge on a reduction of oil concentration in the environment (free phase and sediment- buried oil) to tolerable levels for seeds/propagules and established seedlings, as well as prevention of re-oiling. It is vital to understand and include in restoration planning the fact that the same stressors that degrade the mangrove can also pose a threat to the restoration (Dale et al., 2014).

For mangrove areas that have been degraded due to altered hydrology as a result of road construction, restoring tidal connectivity is required before restoration starts. It is also important to identify and mitigate at the planning stage potential stressors and disturbances such as pests, weeds, animal tramping, etc. (Zimmer et al., 2022).

Figures 14 and 15: Flushing operation in a mangrove environment, Bodo Creek (Photo: Nick Story).

4.5. SCAT-survey in order to establish that the degree of contamination is low enough

The Shoreline Cleanup and Assessment Technique (SCAT) is a rapid tool for assessing the quantities of oil on shorelines and in mangrove swamps. It is a method of documenting oil pollution levels, recommending management strategies and approving 'satisfactorily' cleaned grids carried out by multi-stakeholder teams (Owens and Sergy, 2000; NOAA, 2013) (Figure 16).

The SCAT process reduces stakeholder disputes and facilitates collaborative learning and decision-making. The SCAT process has evolved based on the different scenarios where the framework has been applied since it was first used in 1990 to manage the Exxon Valdez spill of 1989.

Figure 16: SCAT team assessing the level of contamination (Photo: Nenibarini Zabbey).

SCAT was only recently adopted in the cleanup of an oil spills in Nigeria, starting with the 2017 pre-cleanup SCAT surveys of the BMI project and restoration of the Bodo Creek (Bonte et al., 2019). The SCAT process is gaining traction in Nigeria and is now being mainstreamed in the Hydrocarbon Pollution Remediation Project (HYPREP) cleanup of Ogoniland.

In addition to assessing the levels of oiling by visual observations, SCAT surveys also map areas that have natural growth of mangrove seedlings (so called "wildlings") in oil degraded areas (see discussion below). Net environmental benefit analysis (NEBA) is a guiding principle of remediation and restoration. Therefore, SCAT or the project leaders should determine whether cleanup efforts would cause more harm to the sites ("ecological disservice").

By carefully using low-pressure flushing and the removal of dead stumps of mangrove covered with tar and oil it may be possible to clean the sites without damaging the naturally recruited mangroves (the "wildlings"). However, if such actions are likely to cause damage to the existing mangroves, the area should be left for natural recovery.

4.6. Presence of volunteer seedlings (setting up of nursery if necessary)

Deforested mangroves could naturally be reforested with tidally-borne seeds and seedlings if some basic conditions exist: i) the factors that caused the degradation of the mangroves is no longer present or reduced to tolerable levels, ii) seedlings are available to be dispersed naturally by tide to the affected area, iii) the hydrology is sufficient to facilitate transport of seeds/seedlings to the restoration area, and iv) for disused dugout ponds, sufficient sediment siltation has taken place to prevent perennial flooding of newly settled recruits (Figure 17).

Figure 17: Abandoned pond with natural recruit seedlings growing on an elevated sediment deposit in the pond. In the background are mature mangrove stands on the dyke and the sluice gate (Photo: Nenibarini Zabbey).

Other influencing factors include trapping of the seedling in the high and mid-intertidal zones where mangrove plants thrive. However, seedlings stuck in the low intertidal zone (mud/sand flat) might sprout but would perish overtime due to inundation more than the 30% limit of physiological flooding of mangrove plants (Elllison, 2000; Lewis, 2005). The natural recruits (volunteers/wildings) can potentially restore a degraded mangrove area with or without human intervention when the above conditions are met.

Within oil-killed mangrove areas in the Delta, the presence of volunteer seedlings indicates a reduced (at least, tolerable to the seedlings) level of contamination in the immediate subsurface sediment. This implies that such an area is being naturally colonized by volunteer seedlings and may not necessarily require intensive cleanup. The oil level can be double-checked with the results of chemical samples taken from random spots within the designated area.

The rate of natural seedling recruitment may determine whether or not planting is required. Other factors that will drive the decision on the restoration approach include the availability of waterborne seedlings, the potential duration it would take to attain natural colonization of the site, and having the right hydrology in place.

4.7. Mapping in order to establish suitable propagules/seedlings to be planted

About 90% of mangrove plants in the Niger Delta are red mangroves, the family Rhizophoracae represented by *R. racemosa*, *R. mangle* and *R. harrisonii. R. racemosa* constitute more than 70% of the mangrove plants. Generally, the zonation pattern of the mangrove swamps in the Niger Delta has the red mangrove in the front, followed landward by the black mangrove (*A. germinas*), then white mangrove (*L. racemosa*). The buttonwood (*Conocarpus erectus*) occupies the highest astronomical tide level (HAT) (Figure 18).

The invasive nipa palm is mostly confined to the creek (mangrove) fringes but also thrives landward in the high intertidal zone where black mangrove dominates. The mangrove ferns (*A. aureum* and *A. danaeifolium*) exist mainly in the high intertidal zone, but their distribution may extend to the mid intertidal zone forest fringes (Figure 19). However, there are limited distribution patterns that deviate from the ideal zonation described above. For example, white mangroves may occupy the creek fringe with red mangroves behind (Figure 20) and there are also swamps with nearly homogenous species.

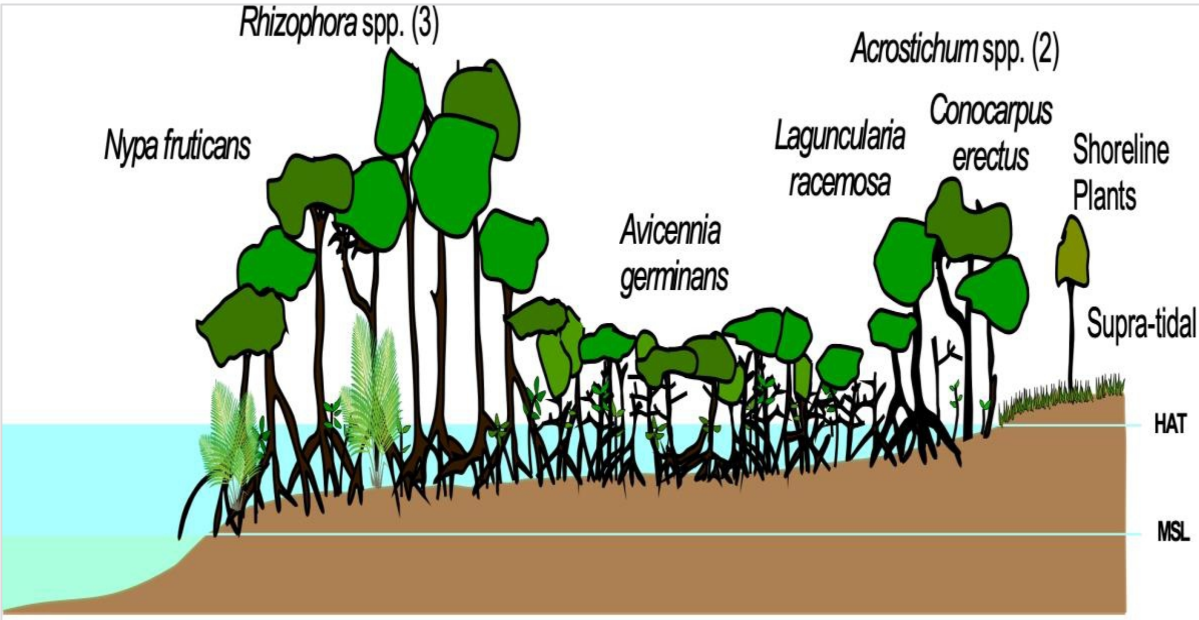

Figure 18: Shows a typical zonation pattern of mangrove plants in the Niger Delta (Illustration by Norman Duke).

Figure 19: A swamp with frontal mangrove fern having the red mangroves behind (Photo: Nenibarini Zabbey).

Figure 20: Mangrove forest with L. racemosa in front and red mangrove behind (Photo: Izuchukwu Uche).

There is a global preference of planting Rhizophora species (planting by convenience; Primavera and Esteban, 2008) because they are easier to plant and maintain than other species or polycultures (Ellison, 2000). As noted above, the primary aim of mangrove restoration in the Niger Delta is to restore the ecosystem structure and functions to support to the local communities (e.g., seafood, livelihoods, coastal protection). Monospecific reforestation in areas with hydrological challenges (Alexandra et al., 2022) and in the Niger Delta, where naturally floating propagules are becoming increasingly scarce, would fail to re-establish a functionally diverse mangrove ecosystem. Thus, restoration efforts should mimic and preserve the natural species diversity, complexity and trophic integrity of the region's mangrove ecosystem.

As much as possible, seedlings of the different species should be sourced from the wild and planted according to the natural zonation pattern of the reference mangroves. That is, monospecific reforestation of Rhizophora should be avoided. Aside compromising diversity of the ecosystem, pest infestation has been associated with monocultural plantation (Saenger and Siddigi, 1993).

However, seedling limitation can be a challenge, especially for the non-Rhizophora taxa given their relatively low density and the difficulty of raising the seedlings in the nursery. White mangrove seedlings can be accessed by transplanting wildlings (seedlings) around the base of a mother plant at a reference (natural) site. Newly dropped and unestablished black mangrove propagules can be entrapped by setting nets round the parent plants or by hand-picking stranded seedlings from the highwater tide mark.

4.8. Site preparation

This takes on different dimensions depending on the restoration approach. Assisted natural restoration might simply require enhancing the local hydrology by removing blockages along tidal sinuous creeks of the area to enable seamless flow and dispersal of naturally waterborne or broadcast seedlings (propagules). If normal tidal hydrology is not disrupted and waterborne seedlings are available, and there is absence of contaminants or a tolerable level of contaminants in the environment, damaged mangroves can self-repair in 15-30 years (Stevenson et al., 1999). The following section describes the different approaches to site preparation applicable to the Niger Delta where natural restoration is impeded (Gundlach et al., 2022).

4.9. Removal of nipa palm colonized unoiled areas

In order to encourage the re-establishment of native species, restoration activities should incorporate competitive control strategies and the eradication of alien plant species (Chen et al., 2013; Ren et al., 2014). Thus, to restore native mangroves at sites colonized or newly invaded by nipa palm in the Delta, removing the palms will be unavoidable. The palm fronds, fruits, bole, and rhizomes should be physically removed. However, where the palm occurrence extends to the mangrove front (as in Figure 21) or the outer gradient of the swamp is steep and vulnerable to erosion, the palm stumps at the creek fringes should not be uprooted to maintain the sediment stability and prevent erosion.

Figure 21: Nipa palm occurrence extends to the swamp fringes, Kono Creek (Photo: Nenibarini Zabbey).

Though removing the palms can be done faster by mechanical means with swamp excavators, manual removal, however slow it would be, is recommended. First, it will create jobs for the local communities. Second, it will minimize alteration of the sediment integrity.

Sustainable management of the palm waste stream is important. This includes careful packing ashore for local energy use. Alternatively, the palm trunk and fronds can be chopped and retained as downed wood at the site to aid in the trapping of waterborne propagules. However, the palm fruits must not be allowed to disperse and colonize new areas. They should be taken ashore, dried, and used as wood for energy. Effective planting of the native mangrove seedlings should follow the careful removal of nypa palms.

4.10. Removing oiled dead stumps

Free phase oil removal discussed under section 4.4 is intended to remove coated oil on dead wood (main stem or the roots), on downed wood, as well as the sedimentary surface and oil buried in shallow subsurface sediment.
If the free phase flushing does not remove the coated oil on dead wood, the clogged oil will cause re-oiling of the site, which may hinder natural mangrove recruitment and planting success. On the other hand, the presence of nurse plants (e.g., Paspalum vaginatum) and uncontaminated dead wood (vertical stumps or down woods) traps propagules for natural recruitment and enhances mangrove re-establishment. They

also stabilize the temperature of the site by shading, at least, some parts of the exposed mangrove floor from direct sun-heating. Solar heating of exposed sediments at low tide causes elevated temperatures of the tidal flats (Gray and Elliot 2009) Removing the dead wood would hamper and cause higher mortality of natural recruits (Duke et al., 1999). Therefore, dead woods should be removed as a last resort when they are heavily oil-clogged even after flushing.

4.11. Retaining cleaned or less oiled dead stumps (depending on hydrological conditions)

Retained cleaned dead wood at the restoration site has a lot of benefits, namely, trapping waterborne propagules for natural recruitment, habitat provisioning (e.g., for crabs), reducing boating wave shocks, and preventing foreshore erosion, evaporation, and desiccation that would increase salinity. Thus, only dead wood that is heavily oil- clogged and recalcitrant to flushing should be removed from the restoration site.

Nipa palm use in South East Asia and its potential use in the Niger Delta

The sketchy benefit of nipa palm in the Delta is presently limited to its passive use to produce thatch for building make-shift huts and roofing mud houses in fishing camps and coastal rural villages. The fruits are used in cast-net fishing. The cast-net fishers throw the nipa fruits to the surface of the water and then cast their nets to cover the fruits to catch the fish that are attracted to and congregate round the fruits.

However, in South East Asia, nipa palm has multiple uses. The palm sap yields nipa juice (nira), vinegar, alcoholic beverages, sugar; the leaves are used to produce roofing thatch, baskets, sunhats, mats, brooms, rope, and bags, and used as wrappers for cigarettes and cooked rice; nipa is also used in the treatment of various ailments (for example, burnt nipa leaves are used to treat toothaches and headaches, and juice from nipa young shoots combined with coconut milk is potent for treating herpes); young nipa leaves are consumed as snacks; dried leaves, petiole, stem, and fruits are used as fuelwood; and the petioles are also used as floats for fishnets (Hamilton and Murphy, 1988; Langenberger et al., 2009; Lim, 2012; Hidayat, 2015; Saputro et al., 2019; Juan et al., 2020).

Complementary efforts would stop the spread of nipa palm in the Niger Delta. Drawing from the extensive uses of nipa in Asia, the coastal population in Nigeria should utilize nipa palm for various local needs. The utility option will reduce exploitation pressure on the native mangroves. Research is required to optimize the nipa value chain.

For example, it has been suggested that nipa could serve as a readily available feedstock to produce bioethanol and remedial agents for the extensive polluted sites in the Niger Delta (Okugbo et al., 2012). Nipa palm now occupies a significant area of former native mangroves (about 11,447 ha, Nwobi et al. 2019). This makes restoring native mangroves in some of the nipa-colonized areas imperative. In addition, mainstreaming the local use of nipa effectively with the right adaptive technology would create alternative livelihoods to bunkering (artisanal oil theft and refining) in the Niger Delta.

5. Methods for Rehabilitation/Restoration

The global goal of mangrove restoration is to achieve no net loss and preserve ecological services. This entails reducing the annual estimated 0.13 - 2% rate of mangrove loss (Lewis et al., 2019; Goldberg et al., 2020) as much as possible while recovering degraded areas.

It is highly recommended that planting of mangroves be done only when it is certain that natural or aided natural recovery by hydrology is not realistic (MAP, 2006). If normal hydrology is in place and sufficient viable propagules are dispersed to the restoration site, it takes mangroves 15-30 years to self-recover only if ongoing oil spills are stopped and re-oiling prevented (Duke, 2016). Contextually, natural re-establishment of mangroves in the Niger Delta will take several decades.

For example, in Bodo Creek, where approximately 1,000ha of mangroves were killed by oil spills, only 4 ha were naturally recovered in the past seven years (from 2013 to 2020), implying natural restoration of the degraded mangroves would take an estimated 200 years (Gunlach et al., 2022). The main factors limiting mangrove colonization and population growth are low rates of propagule dispersal and establishment (McGuinness, 1997).

Therefore, restoring degraded mangroves in the Niger Delta should not be left to multi-decade unpredictable natural recovery. It fundamentally requires human agency (planting). More so, natural reforestation is not a viable option for the Delta because of harvesting pressure, the cause of mangrove loss (dominantly oil pollution), and the paucity of viable seeds for recolonization.

Limited floating seeds in some parts of the Niger Delta could be a result of overharvesting mature seed-bearing mangroves for energy and other uses (e.g., sticks for staking yams, building trusses). Unregulated harvesting of mangroves leads to a scarcity of propagules. In the Delta, it is "normal practice" to cut down mature mangrove trees loaded with propagules to harvest wood.

As discussed in section 4.1, mangroves in the Niger Delta are common properties and their exploitation is by open access. In addition, some propagules in transit strand and die within oiled areas or lose vigour before arriving at the intended rehabilitation sites. Therefore, direct planting is essential in the Delta.

5.1. Mangrove nursery (red, white and black mangroves)

The different mangrove species in the Delta are ecologically important. However, amongst the mangrove trees the red, black and white mangroves deserve restoration priority. Though the bottonwood (C. erectus) is rare, in terms of its natural relative abundance amongst the representative mangrove trees (Table 3), it is not a priority restoration species. First, the species is comparatively less impacted by tide-driven oil spills due to the extreme landward (HAT) intertidal zone it occupies. It is rarely flooded by tidal waters. Second, C. erectus is not locally harvested for fuel wood.

Globally, most mangrove restoration initiatives involve the planting of monospecific red mangrove because it is convenient (Primavera and Esteban, 2008). The red mangrove pencil-like propagule is relatively large and may remain viable for a year or more after being dispersed tens of kilometers (Rabinowitz, 1978; Hogarth, 2007). The propagule is easy to collect from the wild and raise in the nursery.

Virtually all mangrove restoration in the Delta (past and ongoing) had taken the trajectory of planting only the red mangroves because of the above convenient reasons. As at the time of writing this manual, there is no black and white mangrove nursery in the region. This has to change, if the genetic diversity and ecological health integrity of the Delta mangrove ecosystem are to be preserved.

Relatively, the red mangroves, principally *R. racemosa*, dominate the mangrove plant community in the Delta (Table 2). In terms of zonation, the black and white mangroves occupy next to the frontal red mangrove (Figure 18). This makes the black and white mangroves, like the red mangroves, suffer heavy toxicity damage when there is an oil spill.

From the standpoint of oil mortality, the black and white mangroves in the Delta are more threatened because of their relative low abundance. Losses due to crab feeding on propagules is disparately more for the black mangrove (50%) compared to 10 - 27% for the red mangroves (Farnsworth and Ellison 1997). Below is a technical guide to setting up red, black, and white mangrove nurseries.

5.2. Importance of nursery

If seedlings are nursery grown before planting out, they have a better chance of survival and growth. This allows the seedling to develop a strong root system before being implanted. Seedlings grown in a nursery have a higher success rate than propagules (Seanger, 2002). Nurseries guarantee the supply of large seedlings with more leaves, which are known to have higher survival rates in the field than seedlings of propagules planted directly (Trench and Welber, 2011; Ravishankar and Ramasubramanian, 2004).

Furthermore, the season of mangrove fruiting and the availability of mature propagules or wildings may not coincide with the period of out-planting at restoration sites, but nurseries provide necessary seedlings all year. Another important function of the nursery is the protection of propagules and seedlings from pests (e.g., crabs and barnacles) and to enable the outplanting of seedling sizes that will withstand the inhospitable conditions of a degraded environment (Sinohin and Baconguis 2000)

5.3. Collection of propagules

Most mangroves are viviparous (Text Box 2). The red mangroves (Rhizophora spp.) are viviparous and produce large propagating structures (propagules) (Figure 22). That is, after pollination, the embryo grows on the parent tree for some months and becomes a seedling, which grows out of the seed coat and fruit wall before abscission (detach from the mother plant) (Das, 2001; Hogarth 2007).

Mangrove Reproduction Strategies

The red mangroves (*Rhizophora spp.*) are viviparous and produce large propagating structures (propagules). That is, after pollination, the embryo grows on the parent tree for some months and becomes a seedling, which grows out of the seed coat and fruit wall before abscission (Das, 2001; Hogarth 2007).

Similarly, the black mangrove (*A. germinas*) exhibits cryptovivipary, whereby the embryo grows to break through the seed coat but not the fruit wall before it splits open (Das, 2011; Seanger, 2001; Hogarth, 2007). The white mangrove (*L. racemosa*) is also cryptoviviparous (Seanger, 2001). The use of propagules in this manual covers the viviparous and cryptoviviparous seedlings.

Similarly, the black mangrove (*A. germinas*) (Figure 23) and white mangrove (L. racemosa) (Figure 24) exhibit cryptovivipary, whereby the embryo grows to break through the seed coat but not the fruit wall before it splits open (Das, 2011; Seanger, 2001; Hogarth, 2007). The use of propagules in this manual covers the viviparous and cryptoviviparous seedlings.

Figure 22: Red mangrove with propagules (Photo: Nenibarini Zabbey).

Figure 23: Black mangrove with propagules (Photo: Nenibarini Zabbey).

Figure 24: White mangrove with propagules (Photo: Nenibarini Zabbey).

Matured propagules or seedlings can be collected directly from the parent plant or handpicked afloat or from the forest floor. In the Delta, propagules are produced throughout the year, with a peak season in January and February. As outlined in CEHRD (2021), the following template is needed to collect the mangrove propagules:

- Collect only mature, healthy propagules that have not been rotted or attacked by insects.

- Pick off propagules from healthy, mature trees. Rhizophora produces propagules from three years of age when the plant could be less than a meter tall. However, propagules from trees at least over five years old with the heights greater than five to six meters are preferable (Ravishankar and Ramasubramanian 2004).

- Only gather large propagules since they tend to grow more vigorously than smaller ones (Figure 25).

- Gather seedlings early in the day and keep them in the shade because the sun's heat could harm them.

- Propagules and seeds should be handled carefully to avoid damage.

- The seedlings should not be kept out in the rain or in a moist environment for an extended amount of time as this could cause rot and death. However, a 24-hour soaking in salt water is needed to remove the seed coat of black and white mangrove propagules (see description below).

- Collected propagules should not be kept in plastic bags since this could cause the seedlings to overheat and perish. Use a basket or jute bag instead. The viability of the seedlings may be reduced if they are not planted within 48 hours of harvesting of the propagules.

5.4. Red mangrove nursery

Whether the nursery is temporary or permanent, the method of raising the seedlings is the same. Mature red mangrove propagules show brown colouration, darker coloration and swelling of the radicle/root portion when they are more mature (Trench, 2007). Propagules with red or orange color exhibit poor germination success (Trench, 2007).

Nursery steps (modified from Ravishankar and Ramasubramanian 2004; MAP, 2006; Owen Bovell, 2011; Primavera et al., 2012; CEHRD 2021):

- Standard black nursery polypot (polythene) bags of 5"x8" should be used for the raising of red mangrove propagules. Such material allows the seedlings to have the required space to grow to a height of 35 cm or more without the roots curling up. It is possible to improvise the above by using empty bags of sacket water locally called pure water littered in the streets. Small holes should be made at the bottom of the bags to allow for effective draining of water.
- Chikoko mud should be collected from the mudflats during low tides. This is the I deal soil to be used in the nursery. However, loamy soil can also support good nursery growth.

- The soil in the polybags should be watered before planting the propagule (Figure 26).
- Planting should be done either in the early morning or later in the evening to avoid the scotching effect of the sun.
- The root part (swollen part) propagule should be pushed straight seven to eight centimeters into the soil at the center of the polythene bag. Plant only one propagule in each bag (Figure 27).

5.5. Hardening-off

Hardening-off is a process of making the seedlings to experience the typical weather conditions in the field. It is not required for in-creek nurseries whereby the seedlings are inundated daily with tidal waters. The seedlings must be tough to survive conditions at the restoration site. Hardening off is done two months before planting in the field. It is done by:

- Decreasing water one month before seedlings are transplanted. This is necessary to prepare the plants for the harsh environment at planting site.
- Seedlings should be watered half the amount it was previously watered with every other day.
- Seedlings should be wet thoroughly one day followed by being moist the next day. The soil should not be allowed to dry out or let the leaves of the plant to dry up (appear burnt).

All seedlings that have undergone these processes are ready for planting and should now be carefully transported to the restoration site for planting. The nursery duration before transplanting is between three to eight months.

Figure 25: Selecting large, mature, and uninfested propagules (Photo: CEHRD).

Figure 26: Bagging the polypots with sediment and inserting selected propagules into the sediment-filled polybages (Photos: CEHRD).

Figure 27: Planted propagules under the palm frond shade of a makeshift nursery (Photo: CEHRD)

5.6. Black mangrove

The propagules of the black mangrove when dropped from the tree are lima-bean shaped or oblong-elliptical (resemble a flattened 39acem), weigh about 1 g and are about 2 centimeters long (Odum et al., 1982). Mature black mangrove seedlings have light green to a light purple and/or brown coloration (Figure 23).

Nursery steps (modified from Ravishankar and Ramasubramanian 2004):

- Larger propagules greater than one centimeter in diameter should be collected. Collect fallen propagules from the floor beneath the mother tree, or pluck mature seeds directly from the parent plant. The seeds can also be handpicked from stranded water marks or by net-fencing the fruited trees.
- Selected mature and healthy seeds (removed diseased and insect-damaged seeds).
- Soak the propagules in brackish water overnight to remove the seed coats. This treatment reduces the establishment time by two to three days.
- Propagules without seed coats should be used for planting in polythene bags. After 24 hours of soaking, planted seeds with an unbroken seed coat break their seed coat two to three days later. However, seedlings that break out of seed coats after 24-hour soaking in brackish water show relatively faster growth rate.
- The selected propagules must be planted in the polythene bags immediately. Bag the perforated polypots with up to three centimeters of sediment to the top with chicoco sediment or loamy soil. Allow the soil to harden by placing in the

sun outside the nursery bed, then water the soil to make it completely wet. Plant the seeds by gently pushing the radicle (1/3 of the seed) into the soil. Plant one seed per polythen bag. Trials show that seeds raised in loamy soil tend to do better than those in chicoco (Figure 28).

- When storage of propagules is unavoidable, the seeds should only be kept in the shade for one or two days at most.
- During the initial stages, water should be sprinkled twice (early in the morning and late evening). After germination, the polythene bags can be transported to intertidal nursery beds where the seedlings will be watered naturally by tidal flooding.
- Transplant seedlings about three to eight months old, 35-50 cm tall with about four to twelve leaves.

A B

C

D

Figure 28: Black mangrove nursery experiment. A) Two weeks old black mangrove seedlings nursed in loamy soil, B) Two weeks old black mangrove seedlings nursed in chicoco soil, C) three weeks old with first leaves, and D) two months old seedlings (Photos: Nenibarini Zabbey).

5.7. White mangrove

The seeds are small almond shaped and change from their original light green to a golden brown or dark brown colouration (Trench, 2007). The seeds can be collected as discussed for the black mangrove. Similarly, adopt the nursery steps for the black mangrove. However, soaking of the seeds should be done three to five days (Trench and Webber, 2011). The soaking may last five to ten days until the radicle emerges about one centimeter, and then the seed is carefully sown in the nursery bag by inserting the radicle into the soil (Allen 2002). It is important to renew the soaking water daily.

Nursery Management:

- Shading at the early stage of upland nursery is important as it serves to protect the propagules and seedlings from direct contact to heavy rains and sunlight. Always use transparent shade such as the roofing with palm fronds. It allows for light penetration and natural watering by rainfall.
- After the germination of propagules to become seedlings, the health of seedlings should be monitored two to three times weekly including checking for the presence of pests. Watering with brackish water is effective in getting rid of insect larvae that attack the seedlings of mangrove plants like Avicennia.
- Seedlings should be watered with freshwater and brackish water. Brackish water is recommended over seawater as salinity (above 34) causes stunting and wilting of the seedlings. Watering should be done twice daily (early morning and late evening). Before watering, always check soil moisture on a daily basis. This is because if the soil is too dry, the roots will die and plants may appear wilted or burnt, whereas too much water can cause poor growth, damping off disease and root rot of seedlings. Watering can be done with a watering-can or perforated jerrycan.
- Fertilizer should be applied if the soil nutrient is found to be extremely low which is rarely the case. About 3-4 g of N:P:K (15:15:15) dissolved in 1 litre of water can be used to irrigate seedlings. Coconut coir dust (2:1 soil to coconut coir dust) has been reported as a viable alternative to conventional fertilizer (Sinohin and Baconguis, 2000). However, the use of fertilizers and manure is highly discouraged as this does not encourage roots to spread in search of their own nutrients (MAP, 2006). In-creek nurseries will benefit from nutrients exported from adjacent mangroves (Barbier et al, 2011; Polanía, 2015; Ronnback et al., 2017).
- Regular weeding should be done when the need arises.
- Pest control: the use of chemical control method should be the last option when other methods (e.g., physical removal) have proved abortive. Diseased plants should be removed and buried.
- If seedlings will be grown in the nursery for more than six months (to grow up to 1m tall), recycled plastics sheets can be used to line the floor of the nursery to prevent the roots from reaching the ground and becoming damaged during transfer for field planting. Bigger bags should also be used to prevent stunting.

Investment costs are a critical factor in establishing and managing mangrove nurseries. Transportation and the cost of irrigation could escalate the overall cost if the distance between the nursery site and the water source is great.
As a cost compromise and to enable landless locals in the Delta to have free space to set up nurseries, establishing the nurseries on open landward intertidal shores is recommended. Such nurseries will be inundated twice daily and acclimatized to dynamic conditions of the environment.

However, such open-space nurseries are more prone to theft and other physical stressors (e.g., oil re-pollution and plastic smothering) (Figure 29). On the average, each Nigerian generates 0.1 kg plastic waste per day amounting to estimated 200,000 tons of plastics per day (Jambeck et al., 2015). About 12% of the resulting waste is recycled, while more than 80% of the plastic waste ends up in landfills and waterways, including mangrove creeks and forests, as well as estuaries and the adjacent ocean (Babayemi et al., 2018).

Figure 29: Plastics trapped on a mudflat in Bundu Creek, Port Harcourt, in a small-scale red mangrove nursery. Such massive plastic entrapment will smother the seedlings. To reduce plastic entrapment in high incidence areas, the nursery should not be enclosed as the net tends to trap litter (Photo: CEHRD).

5.8. Sourcing wild established seedlings and saplings

In some places, a considerable number of seedlings get trapped and grow near the parent plant, which can be transplanted to the restoration site. It is important to collect the wildlings (Figures 30 and 31) from a nearby forest to maintain the region's genetic stock and reduce the handling duration (transportation stress and cost) (Ellison and Fiu 2010).

The seedlings and saplings (> one meter height) carefully dug from the wildling bank need be carefully transplanted by avoiding as much as possible root damage and retain the ball of soil round the roots.

Figure 30: Black mangrove propagules and seedlings at different stages of growth on the forest floor (Photo: Nenibarini Zabbey).

Figure 31: Dense wildling bank of the black mangrove (A. germinas) near the parent tree (Photo: Nenibarini Zabbey).

5.9. Planting

Planting can be by direct planting of mature propagules and seeds by dibbing, by broadcasting the propagules on the water surface to be dispersed naturally by tidal water, by transplanting wildlings, and by out-planting nursery-raised seedlings. However, some of the broadcasted propagules will not strand and establish at the restoration site.

The region also has a relative propagule limitation due to harvesting pressure, which limits the number of mature trees. In comparison to smaller mangrove trees, larger (mature) trees produce more viable propagules (Blanchard and Prado, 1995). For these reasons, broadcasting the propagules is not recommended for the Delta. Direct field planting of the small propagules of black and white is not productive. It involves dibbing one-third of the propagules (from the tip of the radicle) into the sediment. The propagules die when submerged in sediments, which is easily the case. Tidal actions (swash and backwash) and boating disturbances will cause dislodgement of a significant number of the partially dibbled propagules from the restoration site.

Planting nursery-raised or wild seedlings having at least six to twelve leaves is preferable; the older the seedling, the better the growth performance (Trench and Welber, 2011; Ravishankar and Ramasubramanian, 2004; Seanger, 2002). Seedlings or sapplings of Rhizophora spp. A. germinas and L. 47acemose can be carefully transplanted from wild or wildling banks near the mother plant.

It has been demonstrated that nursery-raised seedlings show 50% greater survival than those planted by direct dibbing (Ravishankar and Ramasubramanian 2004). Nursery-raised seedlings or saplings have well established root systems. The relative survival advantage of nursery seedlings over direct dibbing would depend on the availability and intensity of crab herbivory in the restoration site. Crabs devour the hypocotyl, which harms the sprouting propagules. The chemical process that occurs in the emerging seedling produces a gaseous odour that attracts crabs (Ravishankar and Ramasubramanian 2004).

Planting guide (adapted from MAP, 2006 and CEHRD, 2021):

- Make sure the holes you dig are big enough to fit the seedling's roots. The length of the mangrove seedling's roots will determine how deep the hole needs to be dug.
- Place the seedling vertically in the hole, being careful to avoid having the roots curl upward. Curl roots may cause the seedlings to grow slowly or even die. Give the roots room to hang out in the hole. If the seedlings are from nursery bags, carefully rip the bag off and plant the seedling with the dirt from the nursery still at the root.
- To guarantee adequate aeration, fill the hole with the seedling with loose sediment.
- Planting spaces need to be spaced between 1.2 and 1.5 m (see spacing justification below).
- Mangrove ecosystems should be replicated by mimicking the natural distribution pattern. There are no straight lines where mangroves grow. As a

result, planting should not be done in a row. Planting should be done in a zigzag pattern.

Planting is only one step - the larger picture will include maintaining the hydrologic regime, preventing new spills, (re-oiling) and preventing the cutting of newly planted and immature mangroves.

5.10. Spacing

Different spacing between planted mangrove stands has been reported, such as 0.5m (Cabahug et al., 1986), 1.2 m (Saenger and Siddiqi 1993), and 2m (Lewis et al. 2019). In the Niger Delta, Zabbey and Tanee (2016) and BMI (2021a) adopted one meter and two meters, respectively, and the CEHRD (2021) restoration manual recommends spacing of 1-2 m between stands. The varied spacing choices have their merits and demerits (see details in Aiken et al., 2021).

For example, well-spaced planted mangroves can minimize competition and maximize biomass yield. On the other hand, wide gaps between seedlings lower the sediment redox potential that could result in restoration failure (Mossman et al., 2012).
In contrast, closely spaced (clumped) mangrove seedlings may benefit from reduced evaporation and predation and share oxygen supply, which promotes colonization of other species (Castellanos-Galindo et al., 2013).

However, denser planted mangroves may limit the survival of natural recruits, thereby resulting in low diversity, as a closely packed canopy does not promote understory growth. Oxygen leaking from nearby plants will have the dual function of promoting the growth of neighboring plants and catalyzing the oil-removing action of oxygen-dependent microbes.

As a trade-off, we recommend a planting spacing of 1.2 1.5 m, depending on the proximity of the site to natural mangrove forest, and the potential supply of propagules to minimize the time lag for natural recruitment of the leftover gaps.

5.11. Replanting

Planted mangroves experience various degrees of post-planting losses depending on how the planting was done, damage to roots or stress incurred during transplanting from the wild or from the nursery. Replanting, or corrective planting, is required to replace the dead plants. Die-back can occur a few years after planting and should be remedied as part of monitoring. Monitoring, maintenance, or supplementary planting should be done for at least five years (López-Portilloet al., 2017) and the replanted mangroves must be documented in order to accurately calculate the survival rate.

5.12. Planting precautions

Minimize transplantation stress: it is important to reduce outplanting stress to the barest minimum to optimize the survival of planted seedlings. A sure way would be to site the nursery at, or close to, the restoration site. Avoid root damage by raising seedlings individually in polybags (Figure 32). This will prevent root damage associated with separating seedlings raised together in one bag during transplanting

(Figure 33). In the field, the polybags need only be torn and removed gently to retain the ball of soil/sediment that enclosed the seedling roots (Figure 34a and b).

Figure 32: A nearshore medium scale red mangrove nursery. Raising the seedlings in individual polybags shown here is the right approach. It minimizes competition between the stands and enables outplanting with the soil ball and roots intact, which ultimately enhances the survival rate (Photo: Nenibarini Zabbey).

Figure 33: Nursing of multiple seedlings in a single polypot is wrong. It creates intraspecific competition and reduces the vigour of the seedlings to withstand environmental vagaries at the restoration site. Isolating the seedlings during transplanting will damage some of the roots and planting the seedlings with intact soil-ball is not achievable. Only few will survive post planting (Photo: Nenibarini Zabbey).

Disused polybags (nursery bags) should be safely evacuated from the restoration site and trashed following best practice. Planting of non-native species is absolutely discouraged. Similarly, planting mangroves in naturally unvegetated, low intertidal flats should be avoided.

Figure 34(a)

Figure 34(b)

Figure 34: The planting of a nursery-reared red mangrove seedling (a) polybag removed and the seedling roots enveloped in intact ball of sediment (b) the seedling planted with the root-wrapped ball of sediment (Photo: Nenibarini Zabbey).

6. Monitoring Rehabilitation Success

The parameters and scope of monitoring activities largely depend on the restoration objectives and the size of the reforested area. It requires a clear set of applicable criteria, methods and realistic timelines (Dale et al., 2014). Overall, it takes an average of 25 years for restored mangroves to be fully established and compares in status to a reference natural forest (Severino et al 2014).

Monitoring serves two basic functions, namely:

- To inform corrective restoration; and
- To determine if the effort was successful or failed with respect to the defined objectives.

Based on duration and the aspect of restoration parameters, monitoring is divided into short, medium and long-term.

6.1. Monitoring protocol

The first three years of monitoring would require assessing the plants physically on-site. Post three years monitoring could be achieved by combining remote sensing with occasional ground-truth visits (Figure 35). Remote sensing datasets, in other words, are only complementary to on-the-ground site performance data. This is due to the fact that, while satellite measurements provide information about mangrove cover, they do not provide minute, useful details like flowering and fruiting. Data on the plant performance should be collected on specific tagged plants within monitoring plots. The monitoring plots could be 5m x 5m, 10m x 10 m or 20 m x 5 m depending on the planted area, established in the different zones of the restoration site (BMI, 2021b; Primavera et al., 2013).

The monitoring datasheet is presented in Appendix 2. A select number of plants (five plants) in the monitoring plots should be tagged. Tagging is done with dyma labels (or with geena cloth) and stainless-steel wire/plastic placed at a known position of the monitored plant upper node for future reference.

It is critical to use tags with a unique code that will not easily wear and tear, and to leave tag-space that will allow for future growth tagged area. Tag the five plants within five meters of a central point and photograph them with a GPS camera from a fixed location where future photos will be taken (Lewis et al., 2019; BMI, 2022). Also photograph each tagged plant and measure the plant features listed on the monitoring sheet (Appendix 2).

Figure 35: Monitoring red mangroves planted three years ago, BMI pilot site (Photo: Erich Gundlach).

6.2. Monitoring parameters

These depend on the objectives of the restoration project. For the Niger Delta, broadly, mangrove restoration should recover the goods and services that mangroves provide because of the high dependency of the coastal population on the ecosystem for livelihoods.

The monitoring parameters for a) the mangrove plants, b) for the ecological parameters, and c) for the socioeconomic performance (aspects) are provided in Table 5.

The ecological performance monitoring datasets would include recolonization of associated fauna including species richness, abundance and diversity. Animals that live in or on sediments > 0.5 mm (known as macrozoobenthos) are good indicators of mangrove restoration success (Bosire et al., 2014).

In addition, many commercial fishes visit mangroves either to forage or for breeding and nursery purposes (Table 3). As a result, one of the critical indicators of success is fish utilization of rehabilitated mangroves, which requires monitoring (Lewis and Gilmore, 2007). Data on the animal diversity (species richness and abundance) would form an essential component of the socio-economics of the restored mangrove ecosystems in the Niger Delta. Given that livelihoods of most of the local communities depend on mangroves, socio-economic factors are more important to the locals than the vegetative and ecological parameters.

Table 5: Some variables monitored in mangrove rehabilitation sites (adapted from Dale et al., 2014).

Broad category	Variables monitored	
Plant	Species	# Voluntary (natural) regeneration (colonization of natural recruits in the case of planted area)
		# Voluntary new species
		Changes in relative abundance (e.g., dominance)
	Structure and growth	% Survival
		Growth rate (total height to the topmost leaf node, hypocotyl height, girth just above the hypocotyl)
		Branching
		Development of prop roots
		First flowering and fruiting
Fauna	Macrobenthos and shellfishes	Species richness (crabs, periwinkle, dog whelk, etc.) and abundance
	Fin fishes	Species richness and abundance
Environmental	substrate	Litterfall and litter decomposition, nutrients, soil organic matter, soil particle sizes
	Water quality	Salinity, pH residence time
	Topography/hydrology	Elevation (accretion), tidal height, current
Impacts	Pests and diseases	Outbreak of pest (e.g., insect larvae, barnacles, algae)
	Land use practices	Wood harvesting

6.3. Monitoring phases

Short-term monitoring covers the first five years of the mangrove restoration. The frequency of obtaining the monitoring data should be relatively intense at the early stage of the project and gradually elongate overtime. The sequence recommended is shown in Table 6.

Table 6: Schedule of monitoring visits (adapted from Lewis et al., 2019).

No	Months		
1	0	÷	3
2	0	÷	6
3	0	÷	9
4	0	÷	12
5	0	÷	18
6	0	÷	24
7	0	÷	36
8	0	÷	48
9	0	÷	60
10	0	÷	8-year biannual visit
11	0	÷	Sustain 5-year interval monitoring visit until 25 – 50 years

If more than 5% of the planted seedlings die in the first three to six months, mid-course corrective planting (replanting) should be done.

Medium and long-term monitoring: Monitoring of vegetative cover and ecological functions (including human subsistence use of restored mangroves) takes place >10 or >20 years, respectively (Bosire et al., 2008).

Medium term monitoring covers five to twelve years, while long-term monitoring should last for a minimum of 25 years, which is the average duration it takes a restored mangrove to be fully established/matured. Of course, monitoring of the restored mangrove can continue up to 50 years and beyond.

In practice, the project funds or life cycle of most mangrove restoration do not exceed five years. Post five years, physical assessment of the monitored parameters should be done yearly or once every two years. Remote sensing mapping can generate useful off-site datasets on the vegetative conditions of the restored mangrove. This means remote sensing analysis could inform an unanticipated ground-truth visit to the site when obvious loss is detected. In addition, this monitoring phase include mining data on the economic benefits (i.e., the return of ecosystem goods and services) the local communities derive from the restoration project.

6.4. How to sustain monitoring of rehabilitated sites in the Niger Delta

Governments, especially at national and sub-national levels, should be responsible for formulating and implementing policies for sustainable mangrove management. Moreso, mangrove management includes land-use allocation.
However, to manage mangrove resources sustainably, a contextual co-management framework involving the state and local government, the communities, environment-focused civil society organizations, and the private sector is necessary. These stakeholders would perform different but mutually inclusive or reinforcing roles. The co-management framework should be worked out by means of participatory consultations.
As an interim guide, the government should formulate data-informed and citizen-friendly regulatory policies while the communities that depend on mangrove resources for livelihoods drive conservation and sustainable use on the ground. The policy regime should encourage the creation of a network of mangrove protected areas as well as the creation of community-level conservation areas (such as the Kono Nwinua mangrove conservation area - see 'Ogoniland and the Niger Delta: Mangrove Restoration and Conservation Strategy'.

Civil society organizations (CSOs) could initiate, facilitate and participate in developing the co-management framework with adequate engagement of the academia and the private sector, especially the oil and gas industry, whose production activities and infrastructure interact with and impact directly on mangroves.
Obviously, the private sector can invest in sustainable mangrove management (conservation and restoration) by integrating it into their corporate social responsibility (CSR) regimes. They can leverage existing carbon financing mechanisms to promote the sustainability of mangroves in Nigeria. The public enlightenment and sensitization role of the CSOs is crucial in mainstreaming the sustainability agenda and cannot be overemphasized.

Most mangrove rehabilitation projects are usually funded by external parties and the duration rarely exceed five years. Moreover, the project implementer might be a hired contractor that would operate within an agreed schedule. This limits the monitoring of rehabilitated mangroves to the short-term phase.
To overcome the duration shortcoming, the monitoring endeavour could be transferred to a research institution in the project neighborhood, although remote sensing evaluation can be done from anywhere in the world but would still require some degree of ground-truthing.
Some university departments that can potentially be assigned medium and long-term monitoring tasks in the Niger Delta include the departments of Plant Science and Biotechnology, Animal and Environmental Biology, Fisheries, Forestry and Wildlife Management, and Geography and Environmental Management.
To achieve integrative monitoring, specialists can be drawn from the above departments to form a consortium in a centre of excellence. The Centre of Excellence for Environmental Restoration (CEER) should work in synergy with the state ministry of environment by sharing data that will inform policies.
At the minimum, creating a Chair of Excellence for Mangrove Research and Development would help coordination of the monitoring efforts. A Centre of

Excellence for Wetland Research and Management is long overdue in the Niger Delta, which is the world's third largest wetland and home to the world's fifth largest expanse of mangrove.

Mangrove research and restoration should form an integral component of HYPREP's CEER. Besides monitoring the planted or restored mangrove performance, faculties, students and research fellows of the monitoring department(s) or Centre of excellence would undertake state-of-the-art research within and outside the rehabilitation sites to advance knowledge and management of mangroves in the region.

At the community level, formal (schools) and informal (out-of-school) environment club members can be trained to collect the time series monitoring data. This underscores the importance of community inclusion from the planning stage of the restoration effort.

The community science data can then be channeled to a research institution or centre of excellence in the region for archiving and analysis to inform policy and management decisions. This means networking with agencies and ministries of government that formulate and implement policies relating to mangroves and wetland resources is imminent.

6.5. Dissemination of results

A restoration effort is worthless, in the longer term, if it does not contribute to knowledge advancement. The strategy and methodology of the restoration process and the results thereof (positive or negative) should be adequately documented and made publicly accessible.

The bits and pieces of lessons learned (or data generated) from both failed and successful mangrove rehabilitation projects are important to advance knowledge of the science and practice of wetlands restoration (López-Portillo et al., 2017). This underscores the need for effective data gathering and curating throughout the entire restoration process.

Follow-up research will be driven by testable hypotheses that attempt to explain the causes of a mangrove restoration project's success or failure, which would lead to knowledge advancement.

7. Summary of Recommendations

Livelihoods in the Niger Delta depend greatly on the vast mangrove resources in the region. The Delta mangroves are a key biodiversity hub as well as an enabler for climate change mitigation and adaptation.

However, extensive areas of the Delta mangrove ecosystem have been degraded by human activities, most notably oil spills, conversion and reclamation for development, dredging and sand mining, and poorly planned road construction that disrupt the flow of tidal waters through the network of creeks and creeklets in the mangrove forest. Flow of river and tidal water is a prerequisite for survival and growth of mangroves. The spread of the invasive nipa palm is also a serious threat to the native mangroves in the Niger Delta. A recent estimate shows that in the past seven years (2010 - 2017), the expanse of native mangroves has been reduced by 12%, while the area colonized by nipa palm has increased 600 times (Nwobi et al., 2019)

Robust, ecologically sound mangrove restoration is needed to reverse the unsustainable trend and preserve the environmental legacy of the Niger Delta. This includes sustained efforts to restore oil degraded and nipa palm colonized mangroves in the region.
While rehabilitating the damaged or destroyed mangroves, it is imperative to preserve species and genetic diversity by restoring critical multi-species mangroves as opposed to the common and convenient planting of the region's dominant red mangrove.

This manual provides a user-friendly guide for the restoration of mangroves in the Niger Delta and lays down the underlisted responsive recommendations:

1. Mangrove forests of the Niger Delta are rapidly disappearing due to oil spills, overharvesting, the transformation of mangrove covered land into agricultural or built-up areas or as an effect of road construction interfering with the hydrology of the landscape. In view of the socioeconomic role of well-functioning mangrove forests, efforts should be made to protect remaining mangrove stands, and restore damaged or dead mangrove areas. A sustainable mangrove management plan should be developed before the end of 2024 by the Federal Ministry of Environment in collaboration with other stakeholders. The stakeholders include the subnational ministries of environment, the academia, nongovernmental organizations (NGOs), the private sector and representatives of coastal communities. This report discusses the strategy and methods to be used in connection with mangrove restoration in the Delta.

2. The local communities constitute both critical drivers of a successful mangrove restoration project and the direct beneficiaries. It is important to include the local communities in the entire restoration process from the planning including defining the project objectives to on-the-ground restoration operations, monitoring, and evaluation. Expectations (e.g., livelihoods and land- use) of the communities should be integrated by the Chief Restoration Officer

into the project design to promote local support and ownership for their optimal benefit.

3. The restoration project should create direct jobs for the locals. With the requisite capacity development, the local people can be in the forefront of the supply of propagules, wildlings and nursery-borne seedlings (i.e., "mangrove seedprenuers"). Specifically, the capacity of the local community (e.g., the youths, periwinkle pickers, wood harvesters, and fisher folks) should be developed in mangrove nursery management. The trained locals will establish small or medium-sized nurseries in their backyards or along creek banks. Selling the nursery seedlings/saplings creates alternative livelihoods or incentivizes local communities to participate in and own the restoration process. This could be leveraged as an alternative livelihood option to dissuade youths who are, or may get, involved in artisanal oil refining. HYPREP and other restoration investors (e.g., oil companies) should embed in contractual agreements that mangrove restoration contractors buy seedlings from the locals, not create their own nurseries. It will diversify and enhance the local economy.

4. When planning the cleanup and performing the planting of mangrove seedlings, it is important to consider the shifting water levels due to tides. In most areas there is only a short window of time (a few hours) when it is possible to reach the sites to be cleaned and planted. Forward planning bearing in mind the shifting tides is therefore a critical element in order to be able to accomplish the work successfully.

5. Removal of oil and nipa palm from sites intended for mangrove restoration is an initial step and should be well planned as part of the overall initiative. Oil and nipa palm invasion top the scale of threats to mangroves in the Delta. Concentration of oil in the sediment above the tolerance threshold of mangrove seedlings will kill newly planted recruits. Training and employing local community members in the initial site clearance and subsequent planting activities should be prioritised.

6. Presence of mangrove volunteers (natural recruits) indicates the readiness of the designated site for planting. Oil degraded swamps with no significant re- oiling can have reduced oil concentration due to microbial and tidal flushing natural attenuation processes. The ultimate goal of a restoration initiative is to achieve net environmental benefit. Therefore, planting of mangrove seedlings and saplings can start at sites having natural recruits and SCAT-confirmed low level of oil. Flushing may not always be necessary.

7. Clear-cutting of dead mangrove stumps should be avoided as much as possible. The nipa palm should be uprooted from the restoration sites. However, nipa removal should be avoided at steep gradients along subtidal fringes until native mangroves planted behind are established to prevent coastal erosion.

8. Assisted mangrove re-establishment is highly recommended for the Niger Delta. Though mangroves can self-recover in 15-25 years or more, depending on prevailing environmental conditions, natural regeneration is not a preferred option for the Delta. Re-oiling toxicity and scanty wild-dispersed seedlings are limiting factors. Due to the socio-ecological roles mangroves play in the Delta, especially the livelihood support services, waiting decades for secondary succession is not acceptable.

9. Avoid monospecific plantations, planting in rows and in the low, naturally unvegetated mudflats. It is convenient to plant only the red mangroves, but the practice has to stop for obvious ecological reasons. The ultimate goal of mangrove restoration is to return the structural and functional conditions at the restored site to their pre-degraded or pristine state. Therefore, planting multi-species (black and white mangroves alongside the red mangroves) is needed to preserve the species/genetic diversity and the spectrum of mangrove ecosystem's goods and services. The planting should also mimic the natural mangrove zonation pattern, which is determined by elevation, flooding, salinity and sediment preferences. However, it must be stressed that the re-establishment of mangrove areas is highly desirable, even if only with one species. Thereafter, supplemental planting of other species can be done if natural re-establishment of those species at the restoration site is poor or unrecorded. In general, if the right conditions exist (e.g., a sufficient quantity of propagules and unimpeded dispersal and establishment), the success of any species in a site will aid in the natural recruitment of other species.

10. Because of the many years it takes mangrove to re-establish naturally and the likelihood of various degrees of die-back post-planting, monitoring is required beyond three to five years that most restoration projects last. Replacement planting (replanting) of the dead ones is necessary. The anticipated HYPREP centre of excellence or a Chair for Wetland Research set up in any of the local universities should coordinate long-term monitoring of restored mangroves. A dedicated centre for wetland research is long overdue in the Niger Delta. Collaboration with NGOS can also fill the monitoring gaps. They can use volunteer groups such as school environment clubs (Figures 25 to 27) to conduct sustainable community science monitoring (Zabbey et al., 2021). Overall, state Ministries of Environment should create a Mangrove Monitoring Desk that will liaise with the above monitoring platforms to mine data that will inform mangrove management policy. The creation of the monitoring desks should be done in 2023, preceding the development of the Sustainable Mangrove Management Plan.

11. Prevent re-pollution. Mangrove seedlings are highly vulnerable to fresh oil and get killed by the highly toxic soluble fraction of new oil spills. The UNEP (2011) Environmental Assessment of Ogoniland strongly recommends the prevention of re-pollution of remediated and restored sites. This manual reinforces the recommendation. The Nigerian Upstream Petroleum Regulatory Commission

(NUPRC) should coordinate with NOSDRA, HYPREP, oil companies, security agencies, and the local community to collaboratively prevent re-pollution

12. A robust Conservation Plan should be developed that will complement restoration efforts to recover lost mangrove areas in the Delta. The Plan should have co-management principles and practices in order to be sustainable. This implies that the local people will not only participate in the design of the conservation plan but will also own and lead its implementation on-the-ground under the coordination of the State Ministry of Environment. The Federal Ministry of Environment should lead the development of the Conservation Plan in close collaboration with the Ministries of Environment of the coastal states, local communities, the academia and the private sector. This will snowball into creating a network of mangrove protected areas (MPAs). At the community level, pockets of mangrove conservation areas (MCAs) should be created. A typical example is the multi-decade old Nwenua MCA in Kono Creek. The MPAs and MCAs will act as effective buffers for the region's mangrove biodiversity.

13. Sustainable mangrove wood harvesting is very important (Figure 11) to encourage regrowth of cut trees. NGOs, with funding support from the government, the private sector, and conventional granting agencies, should sensitize local communities on sustainable harvesting. The public's enlightenment should start in the coastal communities in 2023.

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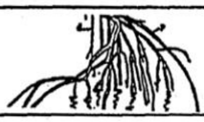
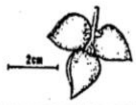
Appendices

Appendix 1: A Field Guide for Identifying Mangroves in Nigeria

A Field Guide for Identifying Mangroves in Nigeria					Jackson & Lewis, 2000
	Rhizophora			*Avicennia*	*Laguncularia*
Leaves	Dark green in clusters			Pointed tips	Rounded tips pair of glands at leaf base
Roots	prop roots drop roots 			pneumatophores 	no prop roots no pneumatophores occasional pneumathodes
Fruit	elongated propagules 			lima-bean shaped fruits 	small almond shaped 
Flowers	small, white			small, white	small, white
Location	fringe waterfront			landward from *Rhizophora*	landward from *Rhizophora*
Species	*R. racemosa*	*R. harrisonii*	*R. mangle*	*A. germinans*	*L. racemosa*
leaves	elongate	broader	broader		
flower buds per stem	multiple with blunt tips 	multiple with pointed tips 	two to four 		

Appendix 2: Mangrove Monitoring Form

Adapted from the BMI Mangrove Monitoring Protocol 2021.

Date	Start	Time	End	Site/Grid	Page of
Recorder					
Site conditions/ Notes					
Plant ID					
Plant total height (cm)					
Hypocotyl height					
# Nodes along main the stem					
# Secondary branches					
# Tertiary branches					
# Leaves					
# Leaves <25% pitting					
# Dead leaves					
# Prop roots					
Stem diameter above the highest etsblished prop root					
# Props reaching soil					
Pest on the plant					
Oil at base < 50cm Type					
Oil at base <50cm					

%					
Scale 1-5 plant condition (5 is great!)					
Periwinkle (none, few, many) within 1m of plant					
Other shellfishes sighted					
Crabs (none, few, many) within 1m of plant					
Fish fry in tide pools					
Notes					

Organization	Name/signature	Organization	Name/signature

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