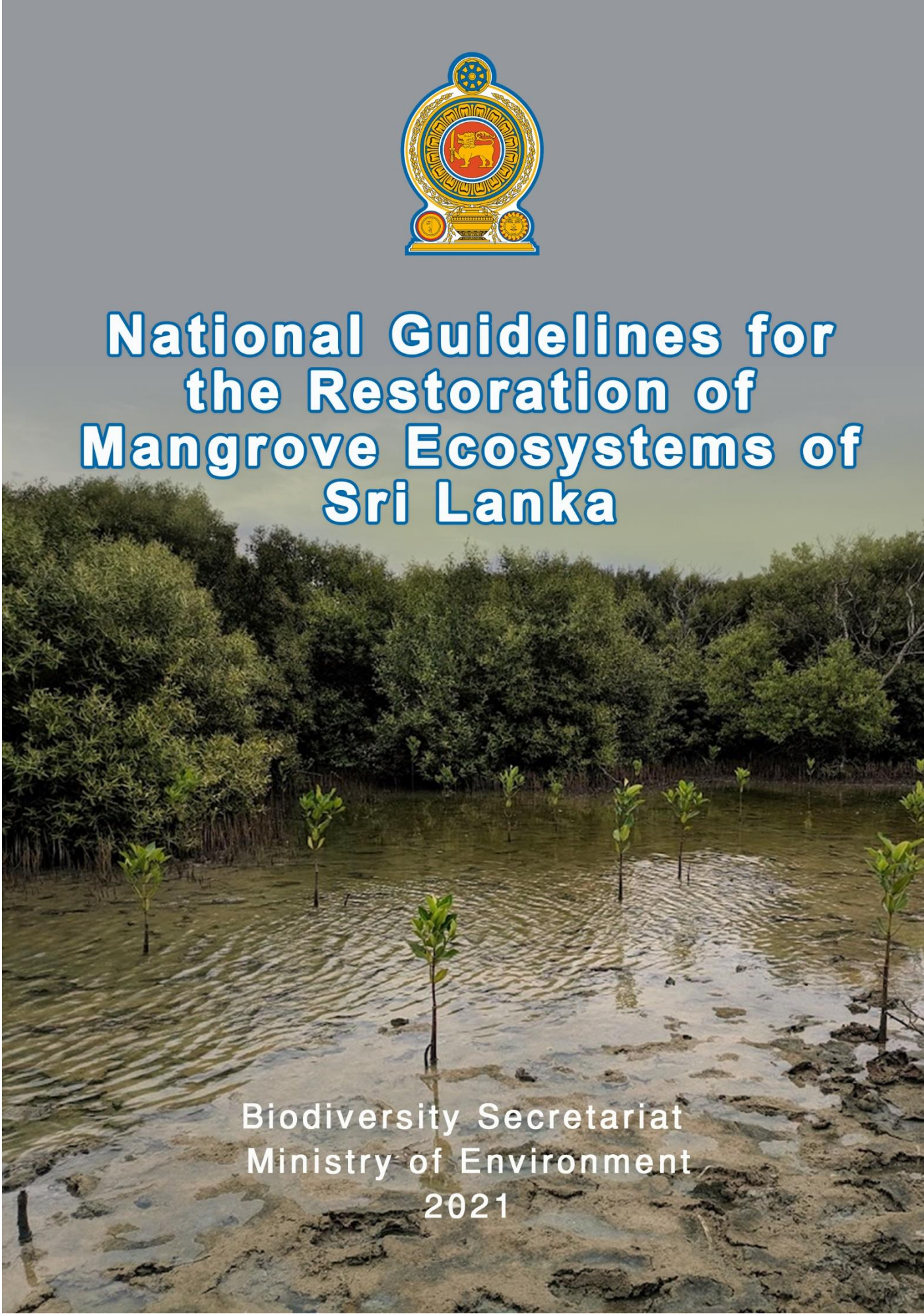
National Guidelines for the Restoration of Mangrove Ecosystems of Sri Lanka



Biodiversity Secretariat
Ministry of Environment
2021

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Message from Hon. Minister of Environment

The Constitution of the Democratic Socialist Republic of Sri Lanka emphasises the importance of protecting the Environment in Article 27 (14) stating that “the State shall protect, preserve and improve the environment for the benefit of the community” and Article 28 (f) states that it is the duty of every person in Sri Lanka to protect nature and conserve its riches. Ratification of the UN Convention on Biological Diversity is one of the main steps taken forward for committing Sri Lanka to address the conservation and sustainable use of biodiversity within a broader framework of sustainable development.

Further to that, Chapter 8 in the National Policy Framework of the “Vistas of Prosperity and Splendour” of the present government identifies the need to, “control human impact on marshy lands and mangrove ecosystems and to conserve them”, and pledges that “Natural ecosystems will be conserved while actively restoring and rehabilitating degraded ecosystems”.

In Sri Lanka, mangrove forests are immensely valuable coastal ecosystems that thrive at the border between land and sea and serve as an important bridge between marine and terrestrial biodiversity. The livelihoods of coastal communities in Sri Lanka are highly dependent on marine and coastal ecosystems. In spite of all the benefits derived from mangroves, several factors including climate change and human activities are threatening this unique ecosystem.

Sri Lanka has pledged to be the champion in mangrove restoration at the Commonwealth Heads of States meeting held in London in April 2018. Accordingly, Sri Lanka shall be the leader of countries on protection and restoration of mangroves across the Commonwealth. As the champion in mangrove restoration, Sri Lanka has to demonstrate successful practices in science-based restoration of mangroves while generating benefits to local communities through development of an effective legal and institutional framework for conservation. In order to fulfill these requirements, Ministry of Environment has taken several steps in collaboration with relevant government institutions, private institutions, non-government organizations, academia, researchers and public to conserve and restore mangrove ecosystems for future generations.

Thus, “National Guidelines for the Restoration of Mangrove Ecosystems of Sri Lanka” can be identified as one of the main publications to provide guidance in scientific restoration towards increasing the mangrove forest cover.

I wish to extend my sincere appreciation to all the contributors, experts, and officials of the Biodiversity Secretariat of the Ministry of Environment for their commitment for the successful completion of this publication.

Mahinda Amaraweera
Minister of Environment

Message from Secretary of Ministry of Environment

Mangrove forests are extremely important coastal resources, which are vital to our socio-economic development. The mangrove ecosystem plays a key role by providing the link between marine and terrestrial ecosystems. This link will provide and maintain stability, not only in the mangrove habitats itself, but also in other related coastal ecosystems, such as seagrass beds and coral reefs. Much of the ecological services of mangroves lie in protecting the coast from “greenhouse” effects, and the fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangroves contribute significantly to the global carbon cycle and produce large amounts of litter in the form of falling leaves, branches, and other debris. Besides, mangrove habitats contribute to complex food webs and energy transfers.

Sri Lanka is home to nearly 16,000 ha of mangroves with 21 true mangrove species which is almost one third of the global diversity of true mangroves and several mangrove associates. Despite all the above benefits delivered by mangroves, a considerable extent of mangroves in Sri Lanka is being destroyed and degraded by various factors. Accordingly, the country has taken a number of significant measures to restore and conserve mangroves in order to safeguard biodiversity and to ensure the ecosystem services of mangroves as well as opportunities for livelihoods.

In January 2020, Government of Sri Lanka adopted the National Policy on Conservation and Sustainable Utilization of Mangrove Ecosystems in Sri Lanka with a vision of “A healthy mangrove ecosystem with rich biodiversity supporting the nation with direct and indirect services”. Here, I like to highlight one of the policy statements, “Promote environmental offsetting and restoration of degraded mangrove ecosystems with the aim of rebuilding lost environmental services with scientifically sound techniques”.

Mangrove restoration is an inherently complex task that is prone to failure when the necessary conditions are not met. Publishing the “National Guidelines for the Restoration of Mangrove Ecosystems of Sri Lanka” is one of the milestones to guide government, private, non-government institutions and general public who are interested in restoration of mangrove ecosystems in Sri Lanka.

It is my great pleasure to thank all the members of the “National Expert Committee on Mangrove Conservation and Sustainable Use” for initiating this national task and their tremendous services, and the members of “Task Force for the Restoration of Mangroves” and all relevant stakeholders for their generous contribution to the successful completion of this task. Also, I wish to extend my sincere gratitude to the Director, and relevant officials of the Biodiversity Secretariat of my Ministry for their excellent effort in publishing this national document.

Dr. Anil Jasinghe
Secretary, Ministry of Environment

Message from the Director of Biodiversity Secretariat

The Importance of developing the “National Guideline for the Restoration of Mangrove Ecosystems of Sri Lanka” was identified at the National Expert Committee on Mangrove Conservation and Sustainable Use established under the Ministry of Environment. This national guideline is developed and presented as a result of great teamwork.

I would like to express my sincere gratitude to Hon. Minister of Environment, Mr. Mahinda Amaraweera who took a keen interest in restoration of mangroves in Sri Lanka for his encouragement in the successful completion of this compilation.

I wish to thank Dr. Anil Jasinghe, Secretary to the Ministry of Environment, Mr. Wasantha Dissanayake Additional Secretary (Environment Policy) and Dr. R.D.S. Jayathunga, Additional Secretary (Environment Development), for their guidance and leadership provided for the success of this nationally important task.

My special thanks go to Prof. Sevvandi Jayakody, Wayamba University of Sri Lanka, Chairperson of the National Expert Committee on Mangrove Conservation and Sustainable Use, for her expert knowledge, leadership, hard work and commitment extended towards to successful completion of this national task. I am extremely grateful to Prof. Mala Amarasinghe, University of Kelaniya who played a key role in developing the initial draft of these national guidelines.

Also, I wish to thank, Dr. T. Mathiventhan (Eastern University of Sri Lanka), Dr. Manoj Prasanna (MoE), Mr. E.A.P.N. Edirisinghe (Forest Department) and Mrs. Kumudini Ekaratne (IUCN), Mr. Douglas Thisera (Small Fishers Federation) and Ms. Achini Fernando (NARA), for their technical support provided in the development of this national endeavor effectively.

The members of the “National Expert Committee on Mangrove Conservation and Sustainable Use”, members of the “Task Force for the restoration of mangroves”, officials from the relevant stakeholder institutions, academia, representatives from private sector and non-governmental organisations who provided the information necessary for the compilation of these guidelines are acknowledged with the highest gratitude.

I am also thankful to Ms. Surani Pathirana (Assistant Director), Himali Gamage (Development Officer) of the Biodiversity Secretariat for coordinating and facilitating the publication of the National Guidelines for the Restoration of Mangrove Ecosystems of Sri Lanka.

Finally, I wish to thank all the contributors and their respective organizations for making this publication a reality.

R.H.M.P. Abeykoon
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Site assessment in Achchankulam for restoration. Documenting peripheral mangroves by the Forest Department

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What is Ecosystem Restoration?

Ecosystem restoration is the “process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed” (Society for Ecological Restoration International, Primer, 2004)

With the arrival of the right habitat, other inhabitants slowly settle in. Some species of genus *Perenella* among *Avicennia marina* in Kinniya area of the Eastern Coast, seen here, is an example of a good restoration project.

©Isuru Siriwardena

Excoecaria agallocha awaiting to shed salt laden leaves.

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Glossary

Accelerated Natural Regeneration of Mangroves (ANRM)	Nature based solutions for restoration of mangroves with strategic management of hydrology and soil and if required by introduction of species to enable the natural regeneration of ecosystem and its services.
Acid sulphate soil	Naturally occurring soils, sediments or organic substrates that are formed under waterlogged conditions which contain iron sulfide minerals (predominantly as the mineral pyrite) or their oxidation products.
Afforestation	Afforestation is the establishment of a forest or stand of trees in an area where there was no previous tree cover. Accordingly, cultivating mangrove plants in an area where they have not been found to grow naturally can be afforestation. This is not recommended.
Air layering	A method of vegetative propagation where a branch of a tree or a shrub is stimulated to produce roots while still attached to the tree, by removing part of the bark and keeping the area moist.
Benthic	Relating to the region found at the lowest level of a water body.
Cotyledon	Leaf forming part of the embryo or a newly emerged seedling.
Creek	A shallow waterway within a mangrove area that drains into a lagoon or an estuary.
Ecosystem	Part of the environment that can be recognized with geographical margins due to the presence of characteristic plants and animals that live in them and perform ecological functions and services as a result of the interactions that take place between biotic and abiotic components.
Epifaunal	Benthic animals living on the surface of a substrate such as vegetation, rocks or any piling.
Fauna	All the animals living in an area or belonging to a particular geographical period.

Flora	The plants of a particular area, type of environment or geographical period.
Gastropods	A faunal class belong to a large taxonomic class of invertebrates within the phylum Mollusca which comprises snails and slugs from saltwater, from freshwater, and from the land.
Geographical period	A period of time from the history of Earth when a particular layer of the Earth built up.
Habitat	Physical space in which an animal or a plant lives.
Hypocotyl	Prominent green or greenish brown part of the germinating seed (of viviparous mangrove seeds) that produces roots at its pointed end.
Infaunal	Aquatic animals such as clams and burrowing worms living under the surface (usually sediment) of a water body.
Inter-tidal zone	Area between land and sea that is flooded during high tide and exposed during low tide.
Manglicolous fungi	Fungi associated with mangroves. They include mostly marine fungi, as well as a small group of terrestrial fungi found in the mangrove ecosystems.
Mangrove associates	Plant species that can grow in mangrove habitats as well as in freshwater wetlands.
Natural selection	The process through which populations of organisms better adapt and change to their environment for survival of the species.
pH	A scale used to specify the acidity or basicity of an aqueous solution. Acidic solutions (solutions with higher concentrations of H^+ ions) have lower pH values than basic or alkaline solutions.
Physico-chemical properties	Intrinsic physical and chemical characteristics such as appearance, density, texture, acidity, salinity etc.
Pneumatophore	Roots that grow out of the soil (aerial) and maintain an air passage with the underground roots, also known as breathing roots.

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Propagule	A partially germinated seed with a prominent hypocotyl or a seed, fruit or any other part of a plant which is able to produce a new plant.
Reforestation	Cultivation of plants (mangroves) in a deforested area.
Rehabilitation	Process of repairing the degraded ecosystem processes, productivity and services, but not necessarily to attain its original structure.
Restoration	Process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed to attain its original structure.
Salinity	The quantity of dissolved salt content of the water. Salts are mineral compounds like sodium chloride, magnesium sulfate, potassium nitrate, and sodium bicarbonate which dissolve into ions.
Sapling	A young tree.
Seedling	A very young plant emerged from a seed.
Stem cutting	A cut branch of a tree, 12-15 cm long with 3-5 or more nodes, used for vegetative propagation.
Stomata	Pores on plant leaf surfaces through which water is lost due to transpiration.
Supra-tidal zone	Area that lies immediately inland to the highest flood level.
True mangrove species	Mangrove plant species that occur exclusively in the inter-tidal areas or the typical mangrove habitats.
Umbonal	Having the shape of an umbo (lateral prominence just above the hinge of a bivalve shell).
Viviparity	Germination of seeds while the fruit is attached to the parent tree.

List of Abbreviations

ANRM	Accelerated Natural Regeneration of Mangroves
BDS	Biodiversity Secretariat
CBD	Convention of Biological Diversity
CBO	Community Based Organisation
CEA	Central Environmental Authority
CR	Critically Endangered
DWC	Department of Wildlife Conservation
E	English Name
EN	Endangered
FD	Forest Department
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
LC	Least Concerned
MELAG	Mangrove Ecosystems and Livelihood Action Group
MEPA	Marine Environment Protection Authority
MoE	Ministry of Environment
MoMDE	Ministry of Mahaweli Development and Environment
NCS	National Conservation Status
NGO	Non-Governmental Organization
NR	National Report
NT	Near Threatened
PAH	Poly Aromatic Hydrocarbon
PVC	Polyvinyl chloride
S	Sinhala Name
T	Tamil Name
VU	Vulnerable

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A well-mixed mangrove stand (top) and a monostand of *Avicennia marina* (bottom). To mimic what nature does with mangroves, study the differences in mangrove stands and appreciate the way they are ordered in different gradients

How to use this guideline

- This guide starts with the basic science one needs to know for restoration.
- It introduces the forms developed by the Ministry of Environment to plan and to implement restoration projects.
- All key agencies and personnel that you need to know are listed.
- It provides a logical key for decision making that you can follow to select the best approach for a given site.
- It introduces basic instruments required to obtain measurements.
- This guide provides tips on how to collect, store and plant seeds and manage seedlings.
- It provides additional reading material that will support you.
- Many pictures, diagrams and flowcharts are given for easy reading.
- Most importantly, this book is made for anyone with a passion to restore mangroves. Here, we communicate science in a form that is digestible to all!

Sharing the lessons with the next generation restorers by the Forest Department.

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This guideline is your one stop solution to many questions that you need to ask before restoration. The questions were picked from frequently asked.

Section 1: Answers general questions on mangroves, their biology, ecosystem and current distribution

Section 2: Answers questions regarding restoration, agencies and equipment

Section 3: Introduces a logical key for decision making regarding mangrove restoration

Section 4: Is an appendix to all forms to be used in restoration

Section 1
General questions on mangroves, their biology, ecosystem, and current distribution

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1.1 Why do we need guidelines?

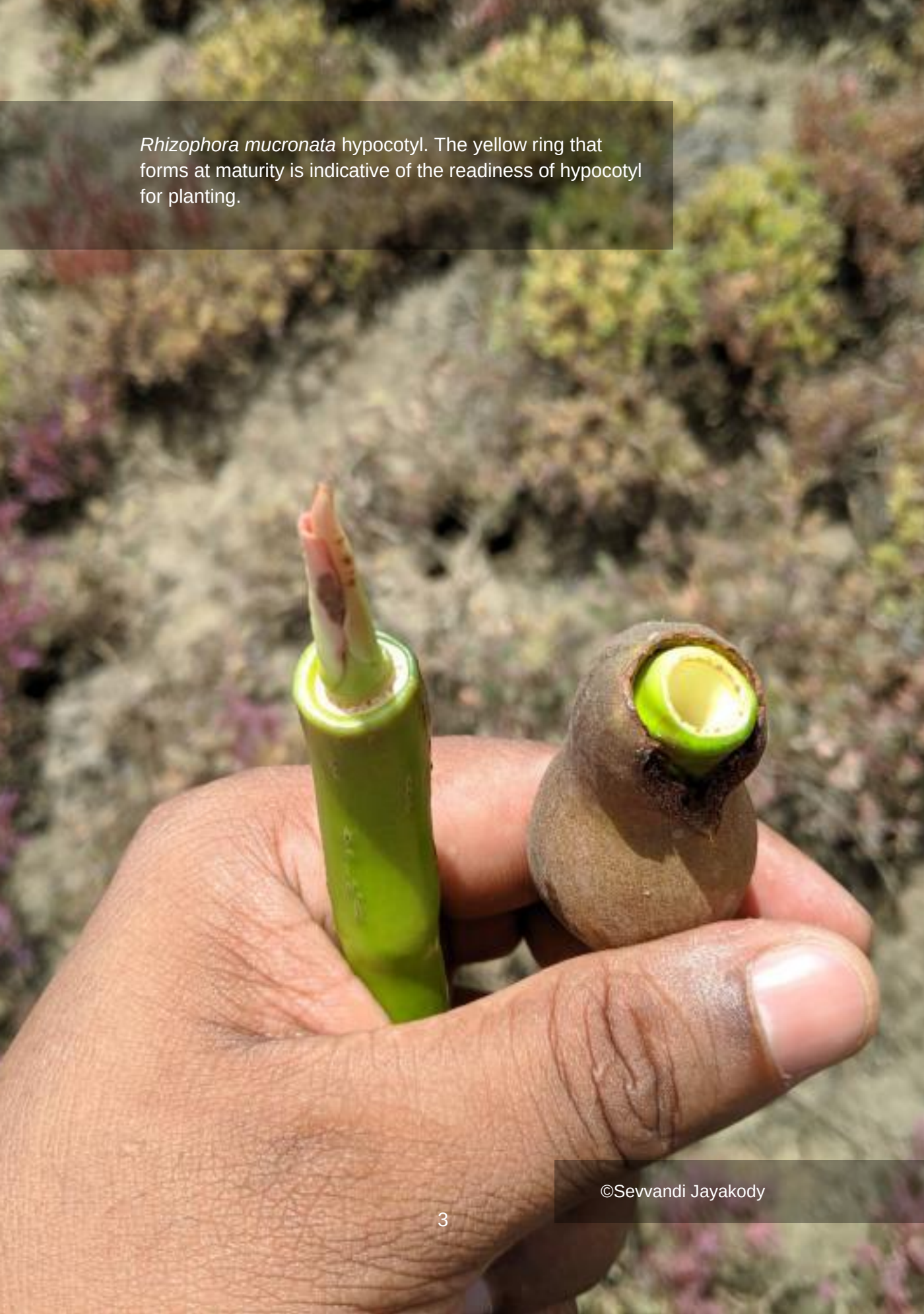
Mangrove ecosystems have been long used as the place to go for replanting. Although a substantial amount of funds, efforts and time has been invested in planting mangroves, this has not realistically assisted in restoring mangrove ecosystems nor in expanding the mangrove cover. The key weakness for the failure has been the absence of proper guidance for scientific restoration of mangroves.

As the Champion for Mangrove Restoration under Commonwealth Heads of the States, Government of Sri Lanka is committed to share lessons on restoration. Also under Commonwealth Blue Charter, Sri Lanka leads the “Mangrove Restoration and Livelihood Action Group” since 2018. In 2020, Government of Sri Lanka also adopted the National Policy on Conservation and Sustainable Utilization of Mangrove Ecosystems in Sri Lanka.

This publication will assist in achieving the set goals of the said policy and the strategies therein. Recent gazettes approved by the parliament have also given the directives to pursue the set target of restoration of mangroves as well as to effectively manage the existing mangroves.

In order to streamline the process and also to ensure data are managed to evaluate the outcomes, this publication is written and presented to you. It is anticipated that this publication will serve as a key reference to those who engage in mangrove restoration in future. The data forms given are intended to be used for recording maintenance and reporting to relevant national institutions.

With this publication, Sri Lanka will be in a better position to draw meaningful restoration plans and also to monitor the restoration progress. Accordingly, it is expected that every restoration project complies with the guidelines including the reporting hereinafter which should be adopted as a good practice. All forms and supporting documents should be handed over to Biodiversity Secretariat of the Ministry of Environment for the purpose of record keeping, to obtain necessary assistance and for the visibility to the project. At the ground level, contacting the Divisional Secretariat, and officers of the Forest Department and Department of Wildlife Conservation is also recommended. Approval from the Forest Department/ Department of Wildlife Conservation is mandatory if the restoration is within a protected area.



Rhizophora mucronata hypocotyl. The yellow ring that forms at maturity is indicative of the readiness of hypocotyl for planting.

1.2 What is a mangrove ecosystem and how to identify them?

Mangroves are a group of trees and shrubs that live in the coastal intertidal zone. The ecosystem they create is known as mangrove ecosystem. In addition to mangrove plants (true mangroves), it consists of other plants commonly found in coastal areas (mangrove associates), micro and macro fauna adopted to live permanently or seasonally within this ecosystem as well as the unique physico-chemical conditions created by tides, freshwater flows and silt. Mangrove ecosystems are found in low-oxygen soil, where slow-moving waters allow fine sediments to accumulate. They are distributed in tropical and sub-tropical regions (Figure 1).

Under the strictest guidelines, there are roughly 54 true species of mangroves belonging to 16 different families (Smithsonian Institute, 2020). However, because distinguishing a mangrove species is based upon physical and ecological traits, rather than family lineage, scientists often differ in what they consider to be a true mangrove.

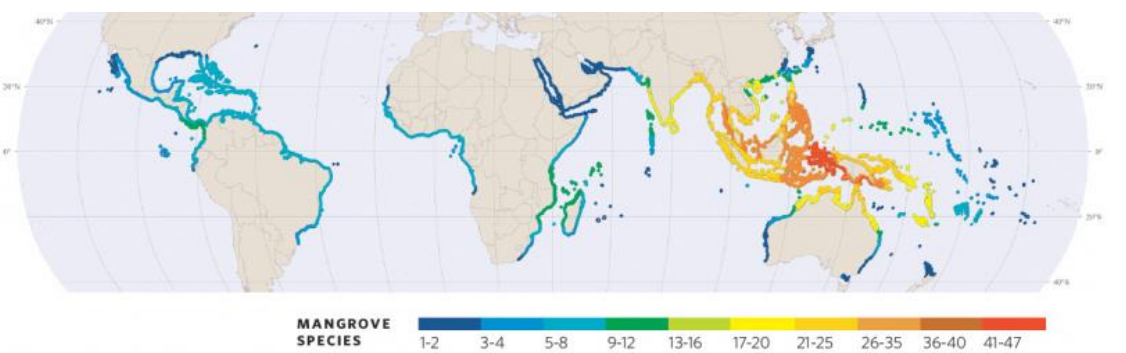


Figure 1: A map of the distribution and the number of mangrove species along each region in the world (Deltares, 2014)

Many mangrove forests can be recognised by their dense tangle of prop and stilt roots and other anti-gravity root types (respiratory roots and pneumatophores) and already germinated fruits adapted to this unique environment known as hypocotyls. Roots allow the trees to handle the daily rise and fall of tides, which means that most mangroves get flooded at least twice per day. The roots also slow the movement of tidal waters, causing sediments to settle out of the water and build up the muddy bottom.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The level of anatomical adaptations to stay erect determines the distribution of mangrove plants from tidal water. Landward mangroves may limit their adaptations to salt extrusion and intensive sunlight. Hence, a large variation in physical and anatomical modifications are seen in true mangroves. Accordingly, they tend to distribute in the most suitable area within a mangrove ecosystem.

1.3 Why do we need to protect mangrove ecosystems?

- Mangroves are the first line of defense for islands.
- Mangrove forests stabilise the coastline, reducing erosion from storm surges, currents, waves, and tides.
- The intricate root system of mangroves also makes these forests attractive to fish and other organisms seeking nurseries, food and shelter from predators. They are the key to maintaining thriving fin and shellfish populations near coastal areas.
- They are also excellent carbon storages and are considered as one of the best carbon storing ecosystems in the world to combat climate change.
- The direct and indirect services of mangroves have enabled thriving coastal communities to live alongside the mangrove ecosystems.
- Presence of mangroves ensures that coastal communities thrive both socially and economically.
- The aesthetic and spiritual attraction is key to blue green economy.

1.4 What are the key features of mangroves one needs to know before restoration?

1.4.1 Feature 1: They need specific site requirements to grow

They grow in the area between land and sea that is flooded with saline water during high tides and are exposed during the low tide, as in inter-tidal land, on sheltered coasts of lagoons and in estuaries (Figure 2).

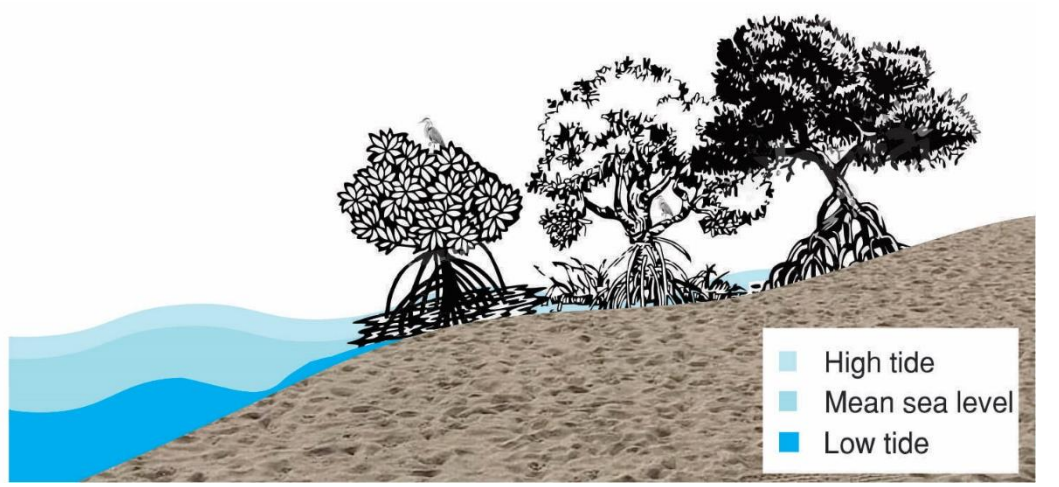


Figure 2: Occurrence of mangroves on a tropical/ sub-tropical coast

Depending on the location of formation and exposure directly to sea, or to a river mouth, mangrove forests are classified as fringe, riverine, basin, over wash and dwarf types (Figure 3).

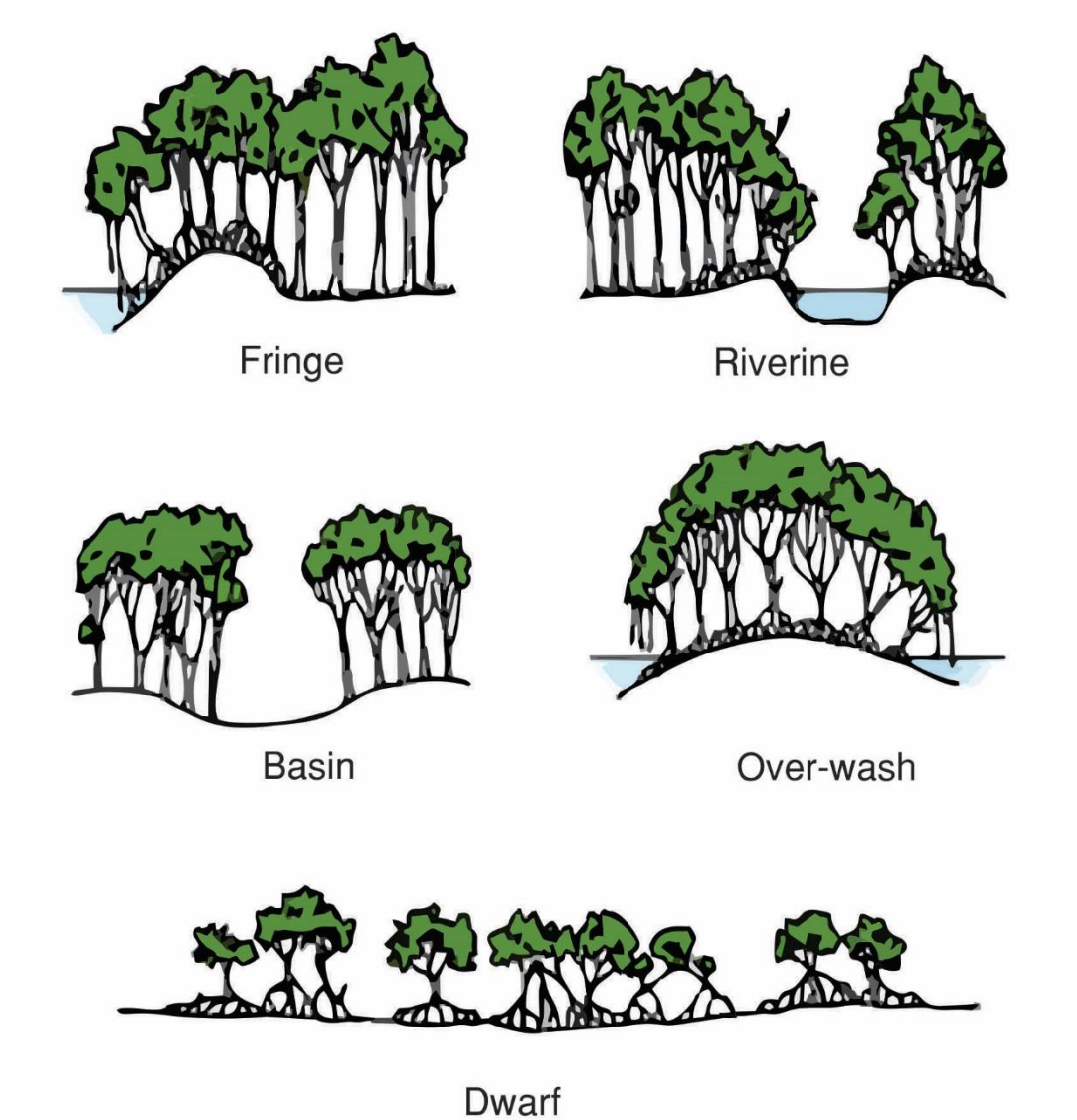
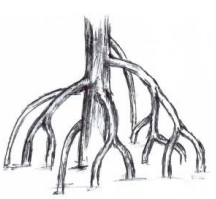


Figure 3: Mangrove forest types (redrawn from Lugo and Snedaker 1974)

1.4.2 Feature 2: They have specific morphological and physiological adaptations to survive

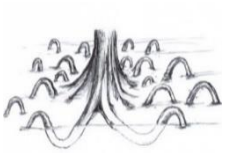
The unique capacity to perform well in the harsh inter-tidal conditions is due to the abnormal morphological and physiological characteristics or adaptations that they have developed over millions of years. This enables them to cope with unfavourable conditions in the inter-tidal zones. These adaptations, especially the morphological features make it easy for one to identify the mangrove species and Table 1 summarises some of them.

Table 1: Salient morphological adaptations that can be used for identification of mangrove species

<table>
<tr><th>Unique morphological characteristics</th><th>Examples of mangrove species</th></tr>
<tr><td colspan="2">Aerial roots</td></tr>
<tr><td>Prop roots and stilt roots provide support for the plant to be upright on unstable soil and maintain the air passage to flooded soil during high tide.
 
©Navodh Waduwawala</td><td> 
©Sevvandi Jayakody
Rhizophora mucronata
 
©Sevvandi Jayakody
Rhizophora apiculata</td></tr>
</table>

Knee roots

Radial roots that grow out of the soil and appear like the knee of a bent leg allows the root to jut out of water during inundation and maintain connection to atmosphere through lenticels.



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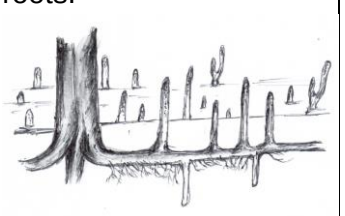
Bruguiera cylindrica

Pneumatophores/ pencil roots/ peg roots are roots that grow out of the soil and extend beyond the flood level and maintain air passage to underground roots. Root tissues contain air spaces among cells and are capable of growing fast to raise their tips above water level or any other material such as sand or mud that cover them and block the air passage to roots.



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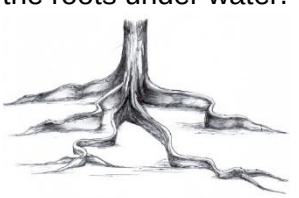
Avicennia marina

Sonneratia alba

Buttress or ribbon roots also provide support for the plant to be upright on unstable soil. They grow to a height that exceeds the flood water level and the pores (lenticels) of the roots then maintain the air passage to the part of the roots under water.



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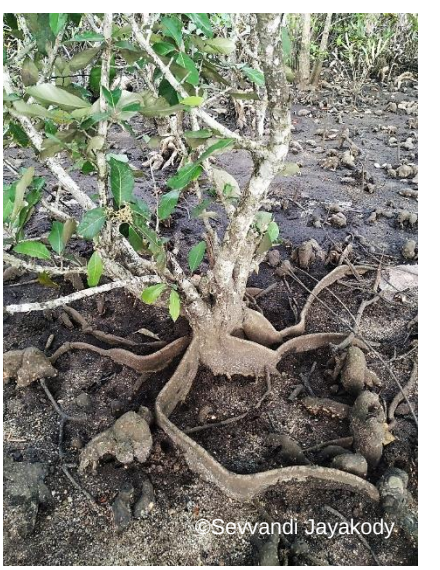
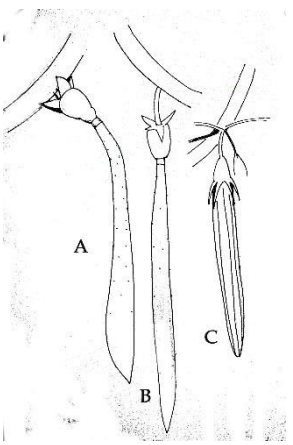


Heritiera littoralis

Viviparous fruits

Viviparous fruits
The seeds inside these fruits can germinate while they are attached to the parent tree and it provides a salt-free environment and freshwater required for germination.



A = *Rhizophora apiculata*
B = *Rhizophora mucronata*
(Matured hypocotyl about to be detached from cotyledonary collar)
C = *Bruguiera gymnorhiza*

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Rhizophora apiculata

Rhizophora mucronata

Ceriops tagal

Bruguiera gymnorhiza

Semi-viviparous fruits

Seed partially germinates inside the fruit and the seedling falls off. Full germination happens only after reaching the soil.

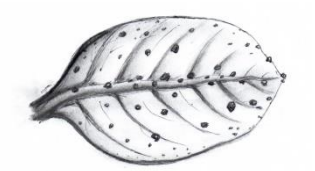
Avicennia marina

Avicennia officinalis

Aegiceras corniculatum

Nypa fruticans

<table>
<tr><th colspan="2">Adaptations of leaves</th></tr>
<tr><td>Salt secreting glands

 
©Navodh Waduwawala</td><td> 
©Sevvandi Jayakody
Avicennia marina</td></tr>
<tr><td>Salt depositing leaves</td><td> 
©Isuru Siriwardena
Excoecaria agallocha</td></tr>
</table>

1.4.3 Feature 3: Some plants found in mangrove ecosystems are adapted to live only in tidal influence zone (true mangroves) and they are frequently mixed with other plants commonly found in the coastal zone of Sri Lanka (mangrove associates)

For successful restoration it is important to know what are the true mangroves and their natural distribution in Sri Lanka. Some true mangroves have limited distribution. Restoration plans should incorporate such information accordingly. True restoration mimics the natural mangrove ecosystems in a given area. As per the 6th NR to CBD (MoMD&E, 2019), 21 true mangrove species (Table 2) are recorded with specific and restricted distribution of some species.

Nypa fruticans is restricted to the wetter coastal area; between Northwestern to Southern coast and some of the species restricted to the Northeastern drier coastal parts of the island are *Cynometra iripa* and *Pemphis acidula*. Also, this phenomenon has resulted in unique species assemblages and compositions in different parts of the island such as *Lumnitzera littorea* in Madu Ganga and Benthara river, *Ceriops decandra* in Northeastern coastal belt around Trincomalee and Kinniya, and *Scyphiphora hydrophyllacea* is found in few locations in Northwestern coast.

Accordingly, two distinct zones of mangrove distribution have been identified.

Ceriops decandra in Kinniya

©Sevvandi Jayakody

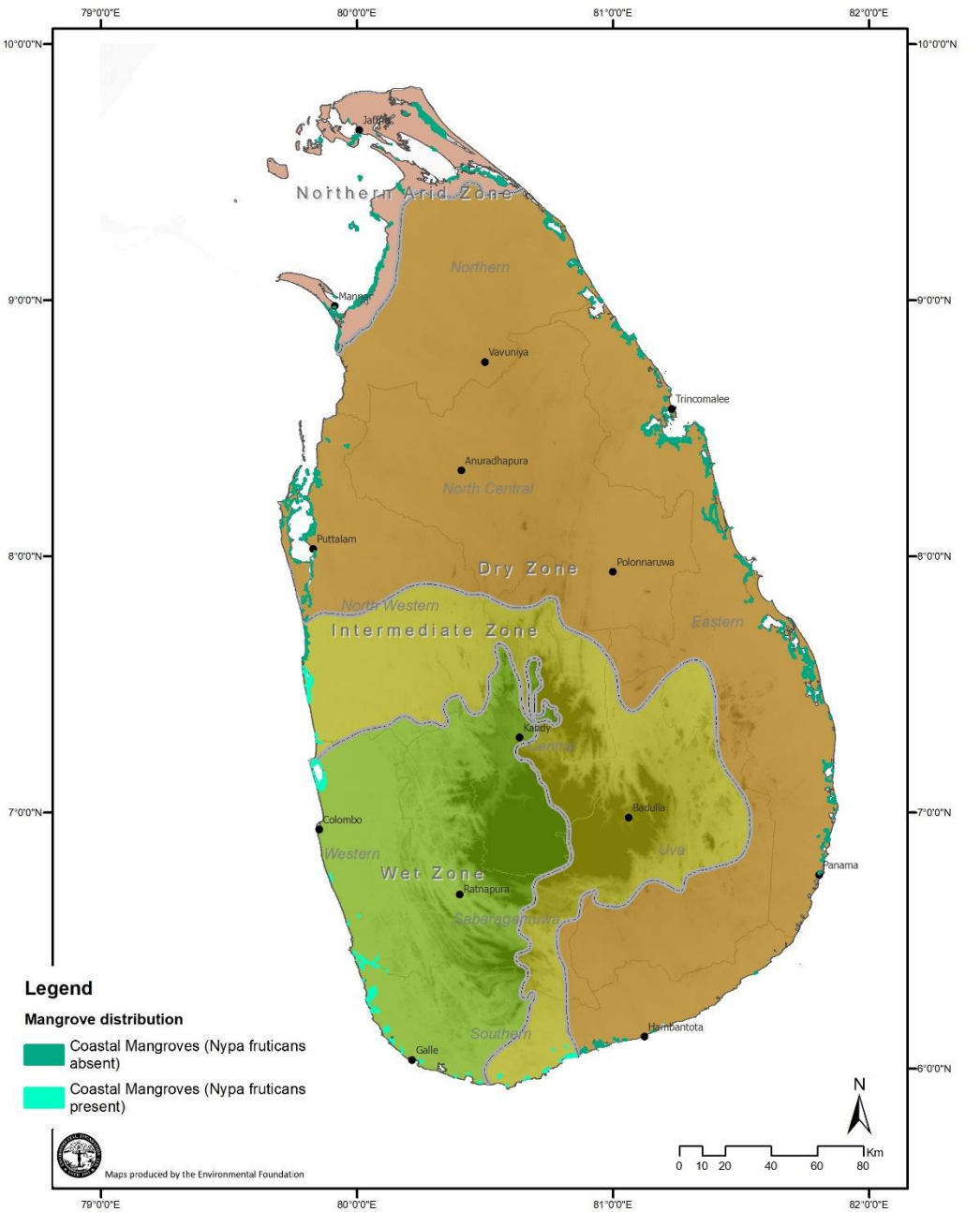


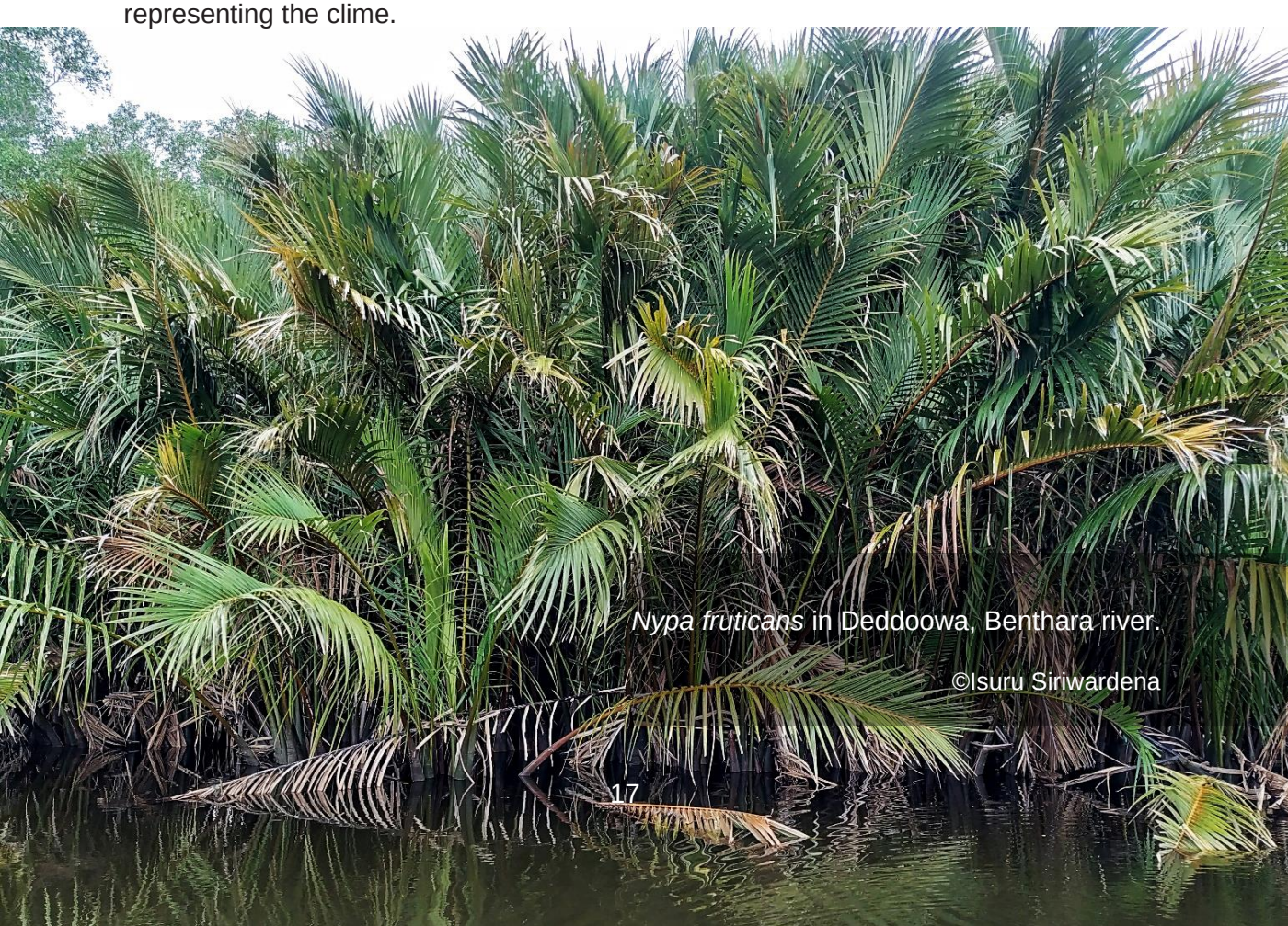
Figure 4: Mangrove zones and current distribution in Sri Lanka, MoMD&E (2019). 6th National Report to Convention on Biological Diversity

1.4.3.1 *Nypa fruticans* absent zone

This zone covers the dry and arid coastal zone of Sri Lanka to a larger extent (Figure 4). In addition to the absence of *Nypa fruticans*, presence of *Ceriops decandra* in Northeastern coastal belt can be mentioned. The associated species of mangroves are equally distinct here, as the species composition is determined by the dry climatic zone. Ma dan (*Syzygium cumini*), Palu (*Manilkara hexandra*), Weera (*Drypetes sepiaria*), Indi (*Phoenix pusilla*) and other typical coastal flora are interspersed with true mangroves. Here, mangrove ecosystems have evolved with salt marsh, and in the ecotone between the two ecosystems, species such as *Avicennia marina* are seen in stunted dwarf form.

1.4.3.2 *Nypa fruticans* present zone

Nypa fruticans demarcates the mangroves which traditionally receive the supply of perennial rivers and hence the more freshwater influenced mangroves. A larger proportion of wet and intermediate zone falls within here. The true mangroves as well as the associated species are unique to these habitats (Table 3). In wet and intermediate zone, Gon Kaduru (*Cerbera manghas*), Kottamba (*Terminalia catappa*), Domba (*Calophyllum inophyllum*), Diyadanga (*Dolichandrone spathacea*), Gansooriya (*Thespesia populnea*), are some examples of typical flora found as associates representing the clime.



Nypa fruticans in Deddoowa, Benthara river.

©Isuru Siriwardena

1.4.3.3 What is the list of true mangroves in Sri Lanka?

Table 2**:** The list of true mangrove species recorded in Sri Lanka (The status of the species is based on National Red List 2020).

Family	Scientific Name	Sinhala Name සිංහල නාමය	Tamil Name தமிழ் பெயர்	NCS
Acanthaceae	*Avicennia marina* (Forssk.)Vierh.	උල් මන්ඩ	கண்ணா	LC
Acanthaceae	*Avicennia officinalis* L.	මොටමන්ඩ	கண்ணா	NT
Arecaceae	*Nypa fruticans* Wurmb	ගිංපොල්	நீர்தேங்காய	VU
Combretaceae	*Lumnitzera littorea* (Jack)Voigt	රතමිල්ල		CR
Combretaceae	*Lumnitzera racemosa* Willd.	බෑරිය	திப்பரெத்தை	NT
Euphorbiaceae	*Excoecaria agallocha* L.	තෙල/ තෙල කීරිය	தில்லை	LC
Euphorbiaceae	*Shirakiopsis indica* (Willd.) Esser	කිරිමකුළු		VU
Lythraceae	*Pemphis acidula* J.R.Forst. & G.Forst.	මුහුදු වරා	கீர	NT
Lythraceae	*Sonneratia alba* Sm.	යක්කිරල/ ගල් කිරල	கிண்ணை	EN
Lythraceae	*Sonneratia caseolaris* (L.) Engl.	කිරල	கிண்ணை	LC
Malvaceae	*Heritiera littoralis* Aiton	ඇටුන		NT
Meliaceae	*Xylocarpus granatum* J. Koenig	මුට්ටි කඩොල්		EN
Primulaceae	*Aegiceras corniculatum* (L.) Blanco	ඇවරි කඩොල්	வெற்றிலைக்கண்ணா	LC
Rhizophoraceae	*Bruguiera cylindrica* (L.) Blume	මල් කඩොල්		EN
Rhizophoraceae	*Bruguiera gymnorhiza* (L.) Lam.	රතු මල් කඩොල්		VU
Rhizophoraceae	*Bruguiera sexangula* (Lour.) Poir.	කහ මල් කඩොල්		VU
Rhizophoraceae	*Ceriops tagal* (Perr.) C.B.Rob.	පුංකණ්ඩ		NT
Rhizophoraceae	*Ceriops decandra* (Griff.) W.Theob.	රතු පුංකණ්ඩ	சிறுகண்டல	CR
Rhizophoraceae	*Rhizophora apiculata* Blume	මහ කඩොල්		NT
Rhizophoraceae	*Rhizophora mucronate* Poir	එල කඩොල්		LC
Rubiaceae	*Scyphiphora hydrophylacea* C.F.Gaertn.	කළු කඩොල්	நிலா	EN

1.4.3.4 What are some common mangrove associates?

The types of associates vary from zone to zone and henceforth reflects the general coastal flora of wet, intermediate and dry zone.

Table 3**:** Some common associates of mangroves (The status of the species is based on National Red List 2020).

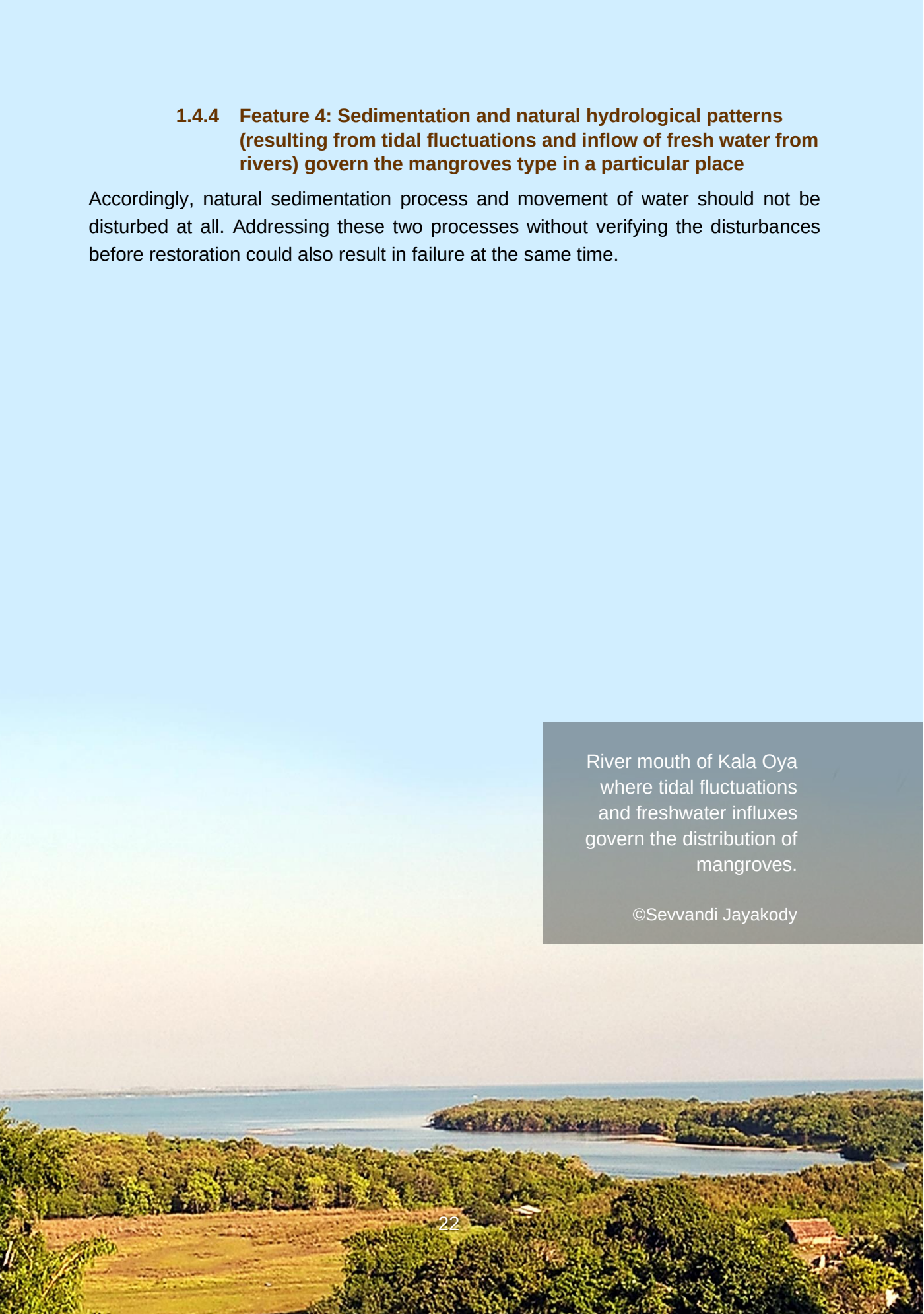
Family	Species	Common Name/s (S: Sinhala/ සිංහල ; T: Tamil/ தமிழ்)	NCS
Acanthaceae	*Acanthus ilicifolius* var. *ilicifolius* L.	S: Ikili, Katu Ikili	LC
Aizoaceae	*Sesuvium portulacastrum* (L.) L.	S: Maha Sarana T: Vankiruvilai	LC
Amaranthaceae	*Salicornia brachiata* Roxb.		VU
Amaranthaceae	*Suaeda monoica* Forssk. ex J.F.Gmel.		NT
Annonaceae	*Annona glabra L.*	S: Wel Aatha, Wal Anoda	
Apocynaceae	*Calotropis gigantea* (L.) W.T.Aiton	S: Ela Wara, Hela Wara, Wara, Moodu Wara T: Errukalai, Manakkovil, Urukkovil	LC
Apocynaceae	*Cerbera odollam Gaertn.*	S: Gon Kaduru T: Nangi Ma	
Asphodelaceae	*Aloe vera (L.) Burm.f.*	S: Komarika	
Asteraceae	*Launaea sarmentosa* (Willd.) Kuntze		LC
Bignoniaceae	*Dolichandrone spathacea* (L.f.) Seem.	S: Diya Danga T: Vil Padr	NT
Calophyllaceae	*Calophyllum inophyllum L.*	S: Domba	LC
Combretaceae	*Terminalia arjuna* (Roxb. Ex DC.) Wight & Arn.	S: Kumbulu, Kumbuk T: Marutu	LC
Combretaceae	*Terminalia catappa* L.	S: Kottamba	
Convolvulaceae	*Ipomoea pes-caprae* (L.) R.Br.	S: Moodu Bin-tamburu, Muhudu Bim Thamburu, Bin Tamburu	LC

Family	Species	Common Name/s (S: Sinhala/ සිංහල ; T: Tamil/ தமிழ்)	NCS
Fabaceae	*Acacia cornigera (L.)* Willd.	S: Kukul-katu, Andara	
Fabaceae	*Cynometra iripa* Kostel.	S: Opulu T: Attukaddupuli, Kadumpuli	EN
Fabaceae	*Derris trifoliata* Lour.	S: Kala Val T: Tekil, Tilankoddi, Uppu, Thailan Kodi	LC
Fabaceae	*Guilandina bonduc* L.	S: Kalu Vavuletiya, Kumburu Val, Wel Kumburu T: Punaikkalaichchi	LC
Fabaceae	*Senna auriculata* (L.) Roxb.	S: Ranawara T: Avarai	LC
Goodeniaceae	*Scaevola taccada* (Gaertn.) Roxb.	S: Takkada	VU
Lamiaceae	*Premna odorata* Blanco	S: Wal midi	LC
Lamiaceae	*Premna serratifolia* L.	S: Middee Gas, Maha Midi T: Erumaimulla	LC
Lamiaceae	*Volkameria inermis* L.	S: Wal Gurenda, Boerende, Gulinda T: Sangam, Dangamkuppi, Pinari, Koika	LC
Lecythidaceae	*Barringtonia asiatica* (L.) Kurz	S: Diya Moodilla	LC
Lecythidaceae	*Barringtonia recemosa* L.) Spreng.	S: Goda Midella, Diya Midella, Midella	
Malvaceae	*Hibiscus tiliaceus L.*	S: Wal beli, Belipatta	LC
Malvaceae	*Thespesia populnea* (L.) Sol. ex Corrêa	S: Suriya, Gan-suriya T: Kavarachu, Puvarachu	LC
Melastomataceae	*Memecylon umbellatum* Burm.f.	S: Kora Kaha T: Kaya, Kurre Kaya, Pandikaya	LC
Myrtaceae	*Syzygium cumini* (L.) Skeels	S: Madan, Maha Dan T: Naval, Perunaval	LC
Pandanaceae	*Pandanus odorifer* (Forssk.) Kuntze	S: Moodu Keyiya, Weta Keyiya T: Talai	LC

Family	Species	Common Name/s (S: Sinhala/ සිංහල ; T: Tamil/ தமிழ்)	NCS
Poaceae	*Spinifex littoreus* (Burm.f.) Merr.	S: Maha Ravana Ravula T: Ravana Meesai	LC
Pteridaceae	*Acrostichum aureum L.*	S: Karan	LC
Rubiaceae	*Hydrophylax maritima* L.f.		LC
Salvadoraceae	*Azima tetracantha* Lam.	S: Katu niyada T: Iyanku	LC
Sphenocleaceae	*Sphenoclea zeylanica* Gaertn.	S: Wal idi	LC

1.4.4 Feature 4: Sedimentation and natural hydrological patterns (resulting from tidal fluctuations and inflow of fresh water from rivers) govern the mangroves type in a particular place

Accordingly, natural sedimentation process and movement of water should not be disturbed at all. Addressing these two processes without verifying the disturbances before restoration could also result in failure at the same time.



River mouth of Kala Oya where tidal fluctuations and freshwater influxes govern the distribution of mangroves.

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1.4.5 Feature 5: Specific physico-chemical parameters of soil and water needs to be recorded and understood for effective restoration

Mangrove species distribute along gradients of salinity, pH, soil moisture level and depth of aerobic soil layer. Hence, for effective restoration these parameters should be measured in advance. Salinity level is determined by the influx of salt water with tides. Hence, it is recommended to have a fair idea (or a measurement) of the tidal fluctuation for any type of mangrove restoration.

In addition, mangroves are sensitive to several physico-chemical parameters, and records of these parameters should be maintained regularly during restoration including the level of light. Trees possess mechanisms to deal with the high sunlight. For example, *Avicennia marina* shows good resistance to high sunlight, hot and dry conditions and is well adapted to arid zones (ElAmry, 1998). However, there is evidence that intense light can damage the mangroves despite these adaptations. This could explain why *Rhizophora* seedlings would readily establish and sprout under the shady canopy of larger trees (Kathiresan and Ramesh, 1991; Kathiresan, 1999). Similarly, because of the environment they live in, mangroves may experience episodic, or chronic Oxygen stress.

Whilst flooding and anoxia can reduce the total biomass of *Avicennia* species the biomass of some *Rhizophora* species are known to increase. Areas of high wind should also be carefully assessed before selection for restoration as soil erosion can reduce the growth. Interspecific differences in tolerance for physiological stress is perhaps the best demonstrated cause of mangrove zonation. Physiological responses to physico-chemical conditions undoubtedly influence mangrove distributions in some habitats, therefore measuring these parameters in undisturbed mangroves will enable deciding how to manage these parameters in areas selected for restoration.

Blue Carbon is the Carbon stored in coastal and marine ecosystems

Mangroves, seagrasses, tidal marshes are some of the most productive coastal ecosystems on Earth. They bestow us with a range of essential ecosystem services, such as Oxygen to breath, coastal protection from storms and nursery grounds for fish, which were well known services for a long time. But today these three ecosystems are hailed for another integral service - sequestering and storing "blue" carbon from the atmosphere and oceans. Therefore, they are an essential piece of the solution to global climate change (www.theblue carboninitiative.org).These ecosystems sequester and store large quantities of blue carbon in both the plants and the sediment below.

Climate change is one of the most important threats to humanity and it will increasingly challenge the way we manage our development. Stabilising the climate system, as envisaged under the Paris Agreement, demands mitigation and adaptation measures to reduce climate-change impacts and increase the resilience of essential ecosystem services.

In this context, nature-based solutions for climate change adaptation and mitigation are gaining traction as a no-regrets option. A Carbon market allows investors and corporations to trade both Carbon credits and Carbon offsets simultaneously. This mitigates the environmental crisis, while also creating new market opportunities (IUCN, 2021).

1.4.6 Feature 6: Soil biota of mangroves have special associations and play a vital role in maintaining mangrove health

Conservation importance of mangrove soils

Mangroves are among the richest carbon stored forest with annual average sequestration has been estimated as 6-8 Mg CO_2 equivalent/ ha. The nearby land use changes causing erosion and finding organic matter accumulates over the flood plains making them substantially large soil carbon stocks from terrestrial ecosystems. The threat is on releasing these stored carbon back to atmosphere due to turn over by the heterotrophic microorganisms with the land conversion and degradation of the mangrove ecosystems.

The deposition of essential minerals, heavy metals and other potential toxic metals in soil and protection of inland ecosystems are other major services provided by these ecosystems.

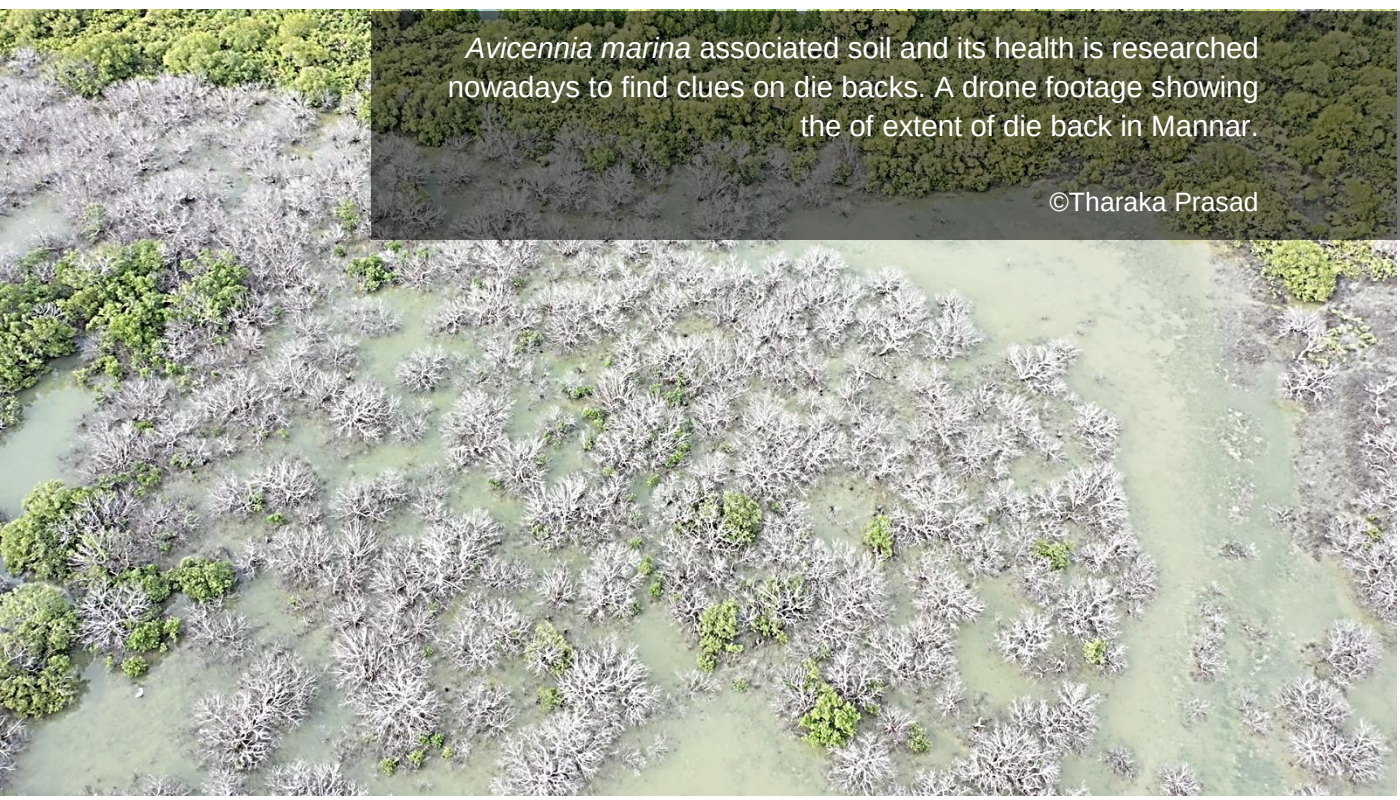
Mangroves are identified for their potential to contribute in mitigating climate change as carbon sinks. The inherent biological and hydromorphological factors as well as environmental changes can cause changes in the reference carbon composition within the carbon pool. Studying this and the association of soil nutrients to organic carbon in detail will be worthwhile as there are minimal or no studies reported so far.

The ground is a complex food web. It consists of producers, consumers, scavengers and decomposers. Energy trapped by phytoplanktons thus passes through zooplanktons, and other microorganisms to invertebrate and vertebrate fauna such as molluscs, arthropods and birds living in this ecosystem.

Hence, the great role played by mangroves and inherent soil ecosystems, emphasise their importance for conservation. It is known that the physical, chemical and biological properties of soil are the controlling factors for the prevalence of these ecosystems.

Just like in other ill planned conservation programmes, restoration of mangroves has also been carried out neglecting the soil. As a result, they have become great failures.

In recent years, soil and soil associated biota of mangroves have attracted attention. This is partly due to emerging diseases of mangroves. Among soil biota, fungi have been investigated extensively. Associated fungi masses have been identified from *A. ilicifolius, A. marina, A. officinalis, B.cylindrica, E. agallocha, L. racemosa, R. apiculata,* and *R. mucronata* in India (Ananda and Sridhar (2004), Gilna and Khaleel (2011), Kumaresan and Suryanarayanan (2001), Manimohan et al. (2011), Maria and Sridhar (2003), Nambiar and Raveendran (2008, 2009), Rani and Panneerselvam (2009), Sarma et al. (2001), Sridhar (2009), Vittal and Sarma (2006).



Avicennia marina associated soil and its health is researched nowadays to find clues on die backs. A drone footage showing the of extent of die back in Mannar.

©Tharaka Prasad

Over 400 species of fungi, most of which are ascomycetes, have been identified to be associated with mangroves. Mitosporic fungi as well as higher marine fungi are amongst them. The majority of manglicolous fungi are found all across the tropics and occur mostly on dead wood. There are a few host-specific fungi that are limited to one host genus or species. In mangrove ecosystems, marine fungi (and bacteria) have been identified to be essential in the breakdown of leaves and preconditioning of wood by boring organisms. Both vertical and horizontal differences in the distribution of manglicolous fungi have been recorded and these findings emphasise the possible influence of parameters such as salinity acting as limiting factors (Vittal and Sarma, 2006).

Recent attention to die backs, seen among mangroves across Asia, as well as in Africa, has led to research that unearthed the possible links of fungi such as Fulvifomes (Basidiomycota, Hymenochaetales) associated with rots on mangrove tree *Xylocarpus granatum* in Thailand (Hattori, 2014).

Each dying tree impacts the community structure and function. *Avicennia marina* die back in Mannar.

©Sevvandi Jayakody

In addition to fungi, the role of bacteria in mangrove ecosystems have also been investigated. Spatiotemporal assessment of the mangrove soils have revealed that decomposition rate of the organic matter is lower in the anoxic condition than that of the oxic condition (Das et al., 2016).

A higher degree of enzyme activity in the oxic soil compared to that in the anoxic condition suggested that slower biomineralization in anoxic condition would facilitate long-term storage of organic matter in that particular ecosystem.

Microbial population of nitrifying bacteria, phosphate solubilising bacteria, free living Nitrogen (N_2) fixing bacteria, and cellulose degrading bacteria have shown significant reduction in anoxic incubation than that in oxic incubation. On the contrary, sulfate reducing bacteria are known to show higher population in anoxic incubation indicating their preference for anaerobic condition.

Excessive influx of pollutants and changes to physico-chemical parameters of soil and water due to hydrological changes can alter the diversity, composition and functions of soil biota. Therefore, in mangrove ecosystems, equal attention should be paid to maintaining healthy soil biota during restoration.

1.4.7 Feature 7: Mangroves form ecotones with salt marshes, sand dunes, mudflats and other ecosystems and in the case of river mouths, with riparian and riverine ecosystems.

These ecotones have very specific characteristics and they need to be preserved. The species in these ecotones are naturally evolved and selected for the environment. Firstly, it is essential to understand these features and not to disturb the natural ecosystems. Mudflats and salt marshes can be misidentified as barren lands in dry season (Figure 5). As salt marshes also contain *Avicennia marina*, and are usually found alongside mangroves, ensuring the correct identification and demarcation of salt marshes is essential in restoration (Figure 6). This can be done using the forms given with this publication. Usually, salt marshes have a dominance of flora given in Table 4. However, these species are seasonal. Therefore, absence of them may not mean that the land is barren.

A

B

Figure 5**:** Salt marshes occur intermittently with mangroves specially in low lying areas where incoming salt water concentrates during dry season creating hyper saline conditions (A). *A. marina* is a common true mangrove associated with salt marshes (B)

C

D

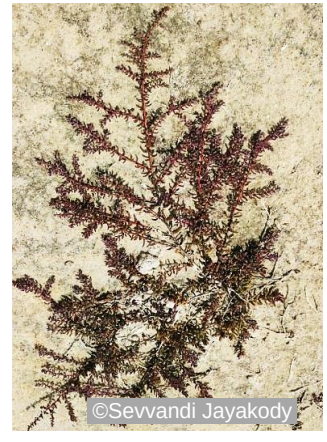
Figure 6**:** Sometimes they are stunted and are found in dwarf form (C). Salt marshes are seen as barren lands but when the right conditions are available, plants emerge and flowering sets in creating beautiful vistas (D)

Table 4**:** Dominant flora in salt marshes (The status of the species is based on National Red List 2020).

Family	Species	Life Form	Conservation Status (2020)	Photograph
Aizoaceae	*Sesuvium portulacastrum* (L.) L. S: Maha-Sarana T: Vankiruvilai	Herb	LC	
Amaranthaceae	*Tecticornia indica* (Willd.) K.A.Sheph. & Paul G.Wilson T: Kotanai	Herb	EN	

Family	Species	Life Form	Conservation Status (2020)	Photograph
Amaranthaceae	*Salicornia brachiata* Roxb.	Herb	VU	 ©Sewandi Jayakody
Amaranthaceae	*Suaeda maritima* (L.) Dumort T: Umiri, Umuddi, Umunddi	Herb	NT	 ©Thilina Kumarasiri

Family	Species	Life Form	Conservation Status (2020)	Photograph
Amaranthaceae	*Suaeda monoica* Forssk. ex J.F.Gmel.	Shrub	NT	

Family	Species	Life Form	Conservation Status (2020)	Photograph
Amaranthaceae	*Suaeda vermiculata* Forssk. ex J.F.Gmel. T: Umiri, Umuddi, Umunddi		NT	
Lythraceae	*Pemphis acidula* J.R.Forst. & G.Forst. T: Kiri-Maram	Shrub or Small tree	NT	

With right conditions, salt marsh vegetation (*Salicornia brachiata* seen here) emerges from previously barren land. These areas should not be used for mangrove planting.

©Sevvandi Jayakody

A mature *Tecticornia indica* is important to hold this fragile soil together. They are excellent carbon storing plants. Site assessments are vital to ensure these types of lands are left untouched.

©Nishantha Edirisinghe

Hence, site identification guidelines given in the booklet need to be followed in order to:

(a) avoid mistakenly converting ecotones and other habitats into mangrove ecosystems
(b) deciding right species composition

A mudflat planted with mangroves: a unique ecosystem that should not be afforested with mangroves.

©Isuru Siriwardena

Salt marsh- mangrove ecotone

In the dry and arid zones of Sri Lanka, *Avicennia marina* is found in dwarf form in this ecotone. If the level of disturbance has been high, *Excoecaria agallocha* is also seen. Sometimes *Avicennia marina* forms extensive dwarf patches. The extreme sunlight, salinity and high temperature in this zone do not permit the trees to grow taller. These ecosystems are very important feeding grounds for birds throughout the year.

Mangrove-salt marsh ecotone in wet season.

©Sevvandi Jayakody

Mangrove-salt marsh ecotone in dry season.

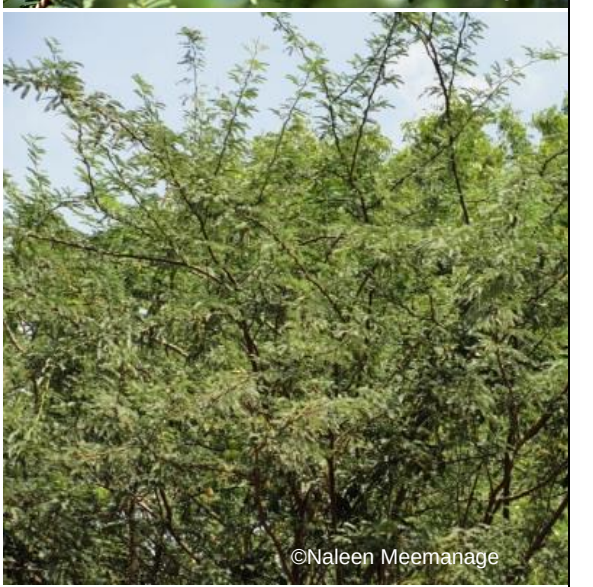
©Sevvandi Jayakody

1.4.8 Feature 8: Mangroves are infested with invasive and opportunistic species. Hence, restoration should be aimed at their management too

In recent times, some common invasive species and range expanding species (Table 5) such as *Prosopis juliflora* are replacing natives in mangrove ecosystems of dry and arid zones of Sri Lanka. In intermediate and wet zones, two invasive species, namely *Annona glabra, Dillenia suffruticosa,* creeper - *Mikania* spp and reed - *Typha angustifolia* have invaded the mangroves, extensively and are fast altering the ecosystem. In the case of *Annona glabra*, mono stands with new ecosystem characteristics are seen. When such ecosystems are to be restored, clear scientific decisions should be taken regarding the replacements of mono stands.

Table 5**:** Some common invasive and range expanding species associated with mangroves

Species	Common names	Photograph
Family: Annonaceae		
Annona glabra	S: Wel anoda/ Wel aaththa E: Pond apple	
Family: Dilleniacecae		
Dillenia suffruticosa	S: Kahapara, Diya para E: Shrubby Dillenia	

Species	Common names	Photograph
Family: Fabaceae		
Prosopis juliflora	S: Kalapu Andara E: Mesquite plant	 
Family: Typhaceae		
Typha angustifolia	S: Hambu pan E: Narrowleaf cattail	

Species	Common names	Photograph
Family: Asteraceae		
Mikania micrantha	E: Bitter vine / Climbing hemp vine	 ©Sevvandi Jayakody

1.4.9 Feature 9: Prominence should always be given to true mangroves and naturally occurring mangrove associates in restoration

In the past *Barringtonia asiatica* (S: Moodilla) has been planted in mangrove ecosystems around the country, however it is a coastal plant commonly seen in sandy beaches and naturally it is confined to the wet zone of the country. Therefore, selection of plants should be based on the information gathered from Form 1A, and the species should be confined to that area.

Barringtonia asiatica
©Manoj Prasanna

Common redshank (*Tringa totanus*) feeding in Kalamatiya.

©Tharanga Herath

1.4.10 Feature 10: Mangroves harbour remarkable faunal diversity: migratory, epifaunal and infaunal as well as permanent residents that add vibrancy to the system

Mangroves tend to be the first stop for many a migratory bird. Mammals including elephants venture into mangroves seeking food and shelter. However, the most interesting group of all are the epifauna and infauna that are highly specialised to the sediment layer of this unique environment. They are indicators of the health of mangrove ecosystems.

1.4.10.1 Mangrove snails, slugs and clams

The mangrove molluscan fauna in Sri Lanka - consisting of gastropods (snails and slugs) (Figure 7), and the bivalved clams (Figure 8) - has not been studied in detail. We know the identity of many but have very little knowledge about their islandwide distribution. This identification guide is provided to enable mangrove managers and interested persons to improve the quality of their biodiversity records. This is not an exhaustive list as much more species are likely to be present - especially those that burrow deeply into mud, such as the white-shelled, circular, chemosynthetic species of the family Lucinidae, and members of other families.

1.4.10.2 Where are we likely to find molluscs?

Molluscs could be found on the muddy mangrove floor, on stems and roots of mangrove plants, in mangrove water channels and pools, and among low grassy vegetation fringing mangroves, while others are found in salt marsh pools and on mudflats. Different species have their preferences. There are also those that bore into dead wood and burrow deep into anoxic mud.

1.4.10.3 What are the differences between snails, slugs, and clams?

Snails live inside coiled shells which they secrete around their bodies. The animal can withdraw into the shell when in danger, some fully, others only partially. Many have a calcareous plate called an operculum that seals the snail inside its shell when it retreats into it. This feature enables them to remain alive (aestivate) during dry spells, resuming activity during wet weather.

Slugs are snail-like soft-bodied animals without an external shell. Like snails, they glide on the substrate on a ‘foot’- a muscular organ with which tree dwelling snail species can climb vertical surfaces.

Clams are animals with two valves (shells) joined by a hinge. The valves can open to allow the animal to circulate water through its gills from which it extracts plankton and Oxygen or shut tight. They too have a 'foot' - but not for walking.

Some species that live on soft bottoms like sand or mud use the foot to burrow into the substrate. Many mangrove faunal species (the oysters) are sedentary. They attach one valve firmly to plants, stones, or other clams or snails. Other sedentary species in marine habitats use the foot to attach themselves to rocks by secreting fibrous strands.

1.4.10.4 What information is needed to identify shells?

Classification of molluscs is based on the anatomy of the animal - the soft parts - a procedure best left to taxonomists. Fortunately for us, the external shells that remain even when the animal dies, is characteristic enough to enable identification in most cases. Some species of oysters that live in crowded conditions have distorted shells making identification by shape alone difficult.

1.4.10.5 Important features of snail shells to aid identification:

- Shape - small or large; egg-shaped, elongated, or conical; rounded or flattened
- Mouth (aperture) shape - whether outlined by teeth or not
- Exterior- texture (smooth and glossy or sculptured with ridges and knobs); colour pattern

1.4.10.6 Important features of clam shells:

- Shape - circular, elongated oval, triangular or irregular and variously shaped
- Exterior - smooth and glossy or rough with concentric grooves
- Colour of the shell, sometimes covered by a differently coloured outer covering called a periostracum
- Certain features on the inside of the shell are usually important, as well as the attachment details, especially to identify species of oysters

Figure 7 and subsequent explanations are for the largest mangrove gastropods collected from Sri Lanka.

Figure 7**:** Some largest mangrove gastropods distributed in Sri Lanka. Copyright of photos 1-14 Malik Fernando

Information of the above gastropods are given below in the following order: zoological name, average size, common English name, habitat (where known), and special features.

1. *Cassidula nucleus,* 22 mm, nucleus cassidula. Under leaf litter on moist mud in dry mangroves, otherwise on stems and leaves of mangrove vegetation.

2. *Ellobium gangeticum* 23 mm, Ganges ear shell. Under and amongst leaf litter in mangroves and fringing vegetation.
3. *Melampus ceylonicus* 14 mm, Sri Lanka coffee bean. Leaf litter and mangrove stems. Shell shouldered, small, even, teeth around aperture.
4. *Melampus fasciatus* 12 mm, marsh or striped coffee bean. Under and on leaf litter, mangrove stems, air roots. Shell smoothly oval, larger, jagged, teeth around aperture.
5. *Pythia plicata* 17 mm, plicate ear shell. Under leaf litter on moist mud, on mangrove stems. Shell rounded with conical spire viewed from above, flattened viewed from the side; large, jagged teeth on either side of the aperture.
6. *Littoraria scabra* 10.2 mm, rough periwinkle. Mangrove stems. Appears to have a restricted range.
7. *Nerita polita* 24 mm, polished nerite. Usually found on marine, rocky shores, on stones and gravel. Reported from Negombo lagoon by Pinto, 1986.
8. *Cerithidea quoyii* 23.4 mm. Reported from Negombo mangroves by Pinto, 1986.
9. *Pirenella cingulata* 25 mm, girdled horn shell. On mudflats and shallow pools associated with brackish water lagoons, mangroves and salt marshes. Very common.
10. *Pirenella conica* 19 mm, conical horn shell. Shallow pools in salt marshes on bottom leaf litter and mud. The white spiral stripes are characteristic. (The genus *Pirenella* was previously *Cerithidea*.)
11. *Telescopium telescopium* 98 mm, telescope shell. Mudflats and muddy mangrove floor. Appears to have a restricted range. The circular operculum is included in the photograph. The wide, anterior end of the shell squared off.
12. *Terebralia palustris* 99 mm, northern mud creeper. Common, widely distributed, on muddy beds of mangrove waterways. Shell colour varies with the organic content of the stream bottom. The wide, anterior end of the shell is rounded.
13. *Haloa crocata* 15 mm, Pease's paper bubble (formerly *Haminoea crocata*). Amongst leaf litter at the bottom of salt marsh pools, together with *Pirenella conica*; also, in brackish water lagoons. The living shells have a fleshy, brown mantle covering them, to which the animal cannot fully withdraw. The white shell is covered by a yellowish, translucent periostracum, as in the photo. Old dead shells are brilliant white.

14. *Faunus ater* 72 mm, black faunus. Found in fresh to brackish water mud bottoms of mangroves and lagoons.

Terebralia palustris (northern mud creeper)

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Mangrove Bivalves

Figure 8: Some large bivalves described from Sri Lankan mangrove ecosystems (15-24). Copyright of photos 15-21 and 23-24 Malik Fernando; 22 Isuru Siriwardena.

15. *Corbicula solida* 33 mm, solid basket shell. Described as a freshwater species based on old literature, with type locality in Sri Lanka (Pieris et al., 2015; MolluscaBase, 2021); has been found in brackish lagoons. Similar in shape to *M. casta* but a much lighter shell with a pale yellow-buff periostracum.

16. *Meretrix casta* 50 mm, common meretrix. A brackish water species found on the muddy bottoms of mangrove water bodies and lagoons. Usually smaller than 50 mm. The shell is white underneath the reddish-brown periostracum.

17. *Geloina coaxons* 107 mm, kadol mutti (S), common marsh clam. In muddy bottoms of mangrove associated waterways. A black periostracum covers the shell, usually rubbed off from the oldest parts exposing the ivory white shell underneath. Edible - used by local communities.

18. *Magallana belcheri* 100 mm, Belcher's oyster. Edible. Common. Shape varies from elongated to rounded. On muddy bottoms attached to small stones or empty shells by one end, or on rocks, in brackish water lagoons and mangrove waterways. Lower valve has a small triangular extension beyond the hinge line with a shallow (umbonal) cavity underneath.

19. *Magallana bilineata* 95 mm, Madras oyster (formerly called *Crassostrea madrasensis*). Shells irregularly circular to oval, attached by most of the underside to hard objects. Also attached to air roots of *Avicennia* (photograph shows a lower valve attached so). No extension beyond the hinge line.

20. *Saccostrea scyphophilla* 35 mm, mordax oyster. A small oyster attached on small objects such as large pebbles or large snails like *Faunus ater* and *Terebralia palustris* from the whole underside of the lower valve. Also forming clusters on mangrove trees at water level. Prominently ribbed, cupped, lower valve with no extension beyond the hinge line. The shells attached on a live *Terebralia* and a cluster of mangrove roots are given in the photograph.

21. *Saccostrea cucullata* 75 mm, rock or Bombay oyster. The shell shape varies greatly. Shells of those found in the mangroves are thinner compared to those in exposed rocky marine shores. A characteristic feature of the lower valve is the 'heel' elongated beyond the upper valve hinge attachment with a deep umbonal cavity beneath. Attached by the whole of the underside of the lower valve to mangrove trees or other shells, forming clumps. Photograph includes interior, underside and lateral views of a single shell from a mangrove habitat.

Mangrove slugs and wood borers

22. Airbreathing slugs in the family Onchidiidae have been observed on mangrove associated mudflats at Kalpitiya and Vanathavillu, and remain to be studied and identified. They have no external shell. The above photograph is a cleaned, live specimen of a slug from a mudflat at Pubudugama, Vanathavillu.

23. *Martesia striata* 22 mm, striate martesia. Bores into floating logs in marine waters. reported to bore into mangrove trees. Specimen collected from beached driftwood.

24. Unidentified Teredinid, 10 mm, shipworm. The animal is worm-like, boring into driftwood, wooden structures, and mangrove trees by means of the modified valves that are of the order of 10 mm. Creates burrows with calcareous linings. Sri Lankan species have only been collected as dead specimens from driftwood, so they remain unidentified, as live animals are required for identification. The composite photograph shows a calcareous tube, a log cut across to show burrows, and a pair of valves recovered from a burrow.

1.4.11 Feature 11: Mangroves are susceptible for long term pressure from anthropogenic threats. Hence, for effective restoration, threats and their magnitude should be identified and addressed.

The next chapter highlights the threats faced by mangroves in Sri Lanka. Addressing the threats requires consultations and entering into partnerships. Sometimes, demarcation of boundaries and due protection is also required. For an example, restoration may not be effective in an area with intense grazing, without finding ways to resolve the problem.

Section 2
Restoration and reasons for restoration

Obtaining measurements at a restoration site.

©Media Unit, Ministry of Environment

2.1 What are the main causes of mangrove degradation?

The world as well as Sri Lanka is fast losing mangroves, salt marshes, seagrass and sand dune ecosystems due to multiple, interconnected threats (Figure 9). The fact that these ecosystems are edaphically, physically, chemically and ecologically interconnected has been ignored in recent development projects, particularly in the development of aquaculture in the country. As of 2021 estimates, only 136,000 km^2 of mangroves are left (Global Mangrove Alliance, 2021).

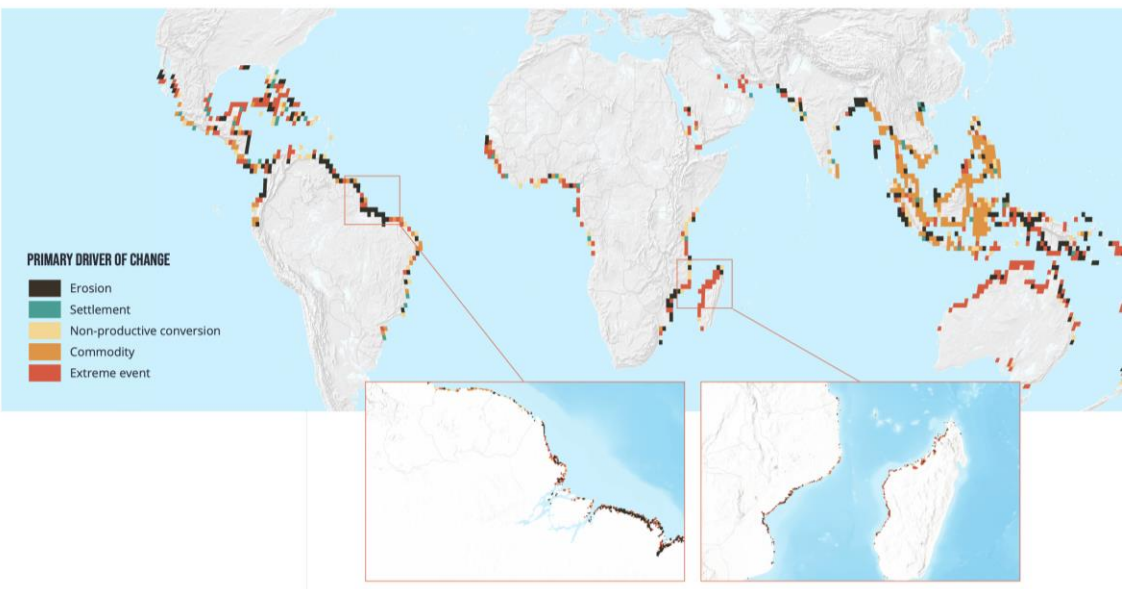

Figure 9: Depiction of various categories of threats affecting global distribution of mangroves (adopted from the state of the world's mangroves, (2021) by Global Mangrove Alliance)

Sri Lanka lost a significant percentage of its mangroves due to the growth in the shrimp farming industry between 1986-2016. It was propelled by the aquaculture of *Penaeus monodon* (Tiger shrimp) and crabs, especially in the Northwestern and Eastern provinces of the island. Salt industry has also taken up mangrove areas, some of which are now abandoned.

Additionally, the continued encroachment, land grabbing and alteration of mangrove habitats for development activities such as hotels, settlements and coconut cultivation in the Western and Southern provinces is a concern. Particularly the mangrove ecosystems around Negombo, Kalutara and Galle are the most at risk. Similarly, influx of freshwater to mangrove ecosystems due to river diversions as in Rekawa area, and restricting salt water intrusion by construction of barrages as in Thondaman Aru area are notable threats to mangroves.

In certain areas river diversions have resulted in an influx of freshwater, changing the salinity levels, thus decreasing the quality of the water within the ecosystem (Bundala). Attempts in the Northern Province to construct barrages to stop saltwater intrusion into lagoons can also be viewed as a threat to mangroves. These human impacts affect the salt marshes as well.

Accumulation of solid waste and substantial pollution of brackish water in estuaries are critical threats to all coastal habitats. At present, estuaries in Negombo and Chilaw are affected by pollutants including sewage, with long shore currents periodically bringing in solid waste from trans-boundary countries, further worsening the situation. Increasing tourism in mangrove areas such as in Madu ganga and Gangewadiya has resulted in fuel mixing with water due to operation of boats.

An abandoned saltern.

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An abandoned shrimp farm undergoing restoration by Forest Department.

©Sevvandi Jayakody

2.2 Are mangroves susceptible to climate change and are they likely to respond?

Climate change threatens the remaining mangrove areas mainly through rising sea levels and increased sedimentation caused by precipitation and shoreline change (Bosire *et al.,* 2016). During the 20th century, the global mean sea level rose by about 15 cm (IPCC, 2019).

There are several scenarios of mangrove responses to rising sea levels.

Four common scenarios depicted in Figure 10 shows

(i) no change in mangrove position,

(ii) mangrove margins transgressing seawards,

(iii) mangrove margins transgressing landwards, and

(iv) mangrove drowning when their expansion corridor is blocked through coastal development.

In addition to that

(v) species composition may change from less salt tolerance to high salt tolerance,

(vi) patching effects may occur where saltwater intrusion would connect the mangrove patches and favour the extensions of mangrove cover, and

(vii) some species may become locally extinct.

Prolonged flooding and extreme droughts can affect restoration areas. Recent mangrove diebacks, though unexplained, are attributed to climate change by some experts.

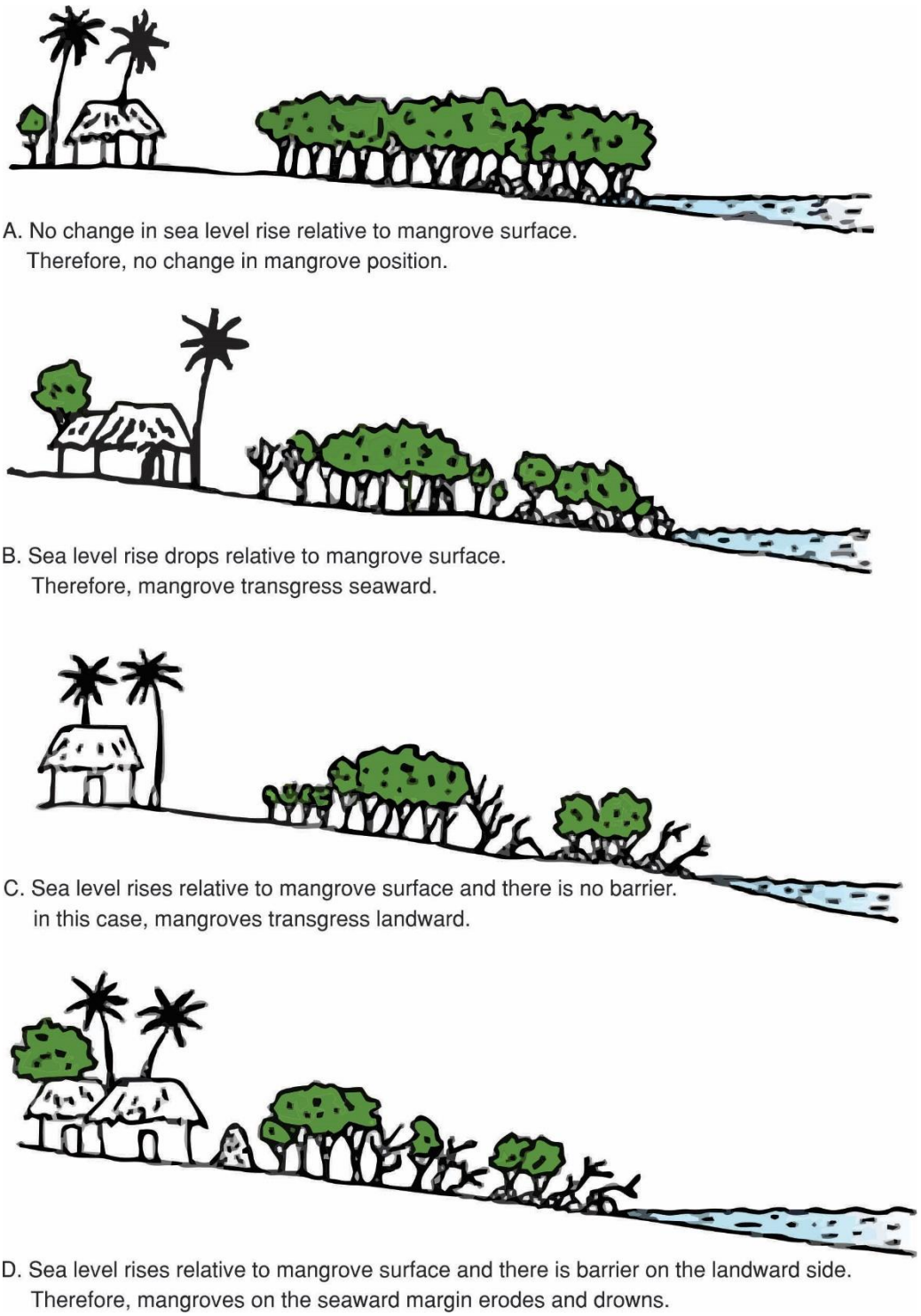

Figure 10**:** Scenarios for generalised mangrove responses to changes in relative sea level (adopted from Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region (2020))

2.3 What factors should be considered when planning for a successful restoration?

Success of mangrove expansion or restoration is largely dependent on the following factors.

- Stability and suitability of the substratum/ soil
- Hydrology of the site
- Combination of species
- Reference sites (similar sites near restoration sites)
- History of the restoration sites
- Types of disturbances, if any
- Elevation of the selected site within the inter-tidal zone
- Tidal and wave energy associated with the site
- Identification of engineering designs in land preparation to improve the suitability of the site for the purpose
- Availability of propagules / seed material
- Correct planting regime and planting densities
- Absence of invasive species and grazers
- Efficacy of nursery techniques and planting patterns
- Monitoring and after-care
- Cost / monetary resources available
- Cooperation of the local inhabitants
- Land ownership


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2.4 Restoration is not just a one-time planting. Are you committed to complete the cycle?

It is essential that you know the ownership of land. Areas suitable for mangrove restoration can either be a

a) protected area declared under the Forest Department, Department of Wildlife Conservation or Central Environmental Authority, or

b) government land or a land belonging to/ managed by an institute, or

c) private land.

Therefore, the first thing to do should be finding out the land ownership. Local forest office, DWC office or Divisional Secretariat can provide you with information.

2.4.1 Key government departments to contact

Table 6**:** Key government departments and contact details

Key Government Department	Address	E-mail/ Website	Telephone
Forest Department (FD)	"Sampath Paya", 82, Rajamalwatta Road, Battaramulla	www.forestdept.gov.lk	0112866631
Department of Wildlife Conservation (DWC)	811/A, Jayanthipura, Battaramulla	dg@dwc.gov.lk	0112888585
The Biodiversity Secretariat (BDS), Ministry of Environment	"Sobadam Piyasa", 416/C/1, Robert Gunawardana Mawatha, Battaramulla	biodiversitysl@gmail.com	0112034208
Central Environmental Authority (CEA)	104, Denzil Kobbekaduwa Mawatha, Battaramulla	dg@cea.lk	0117877277 0117877278

Key Government Department	Address	E-mail/ Website	Telephone
Department of Coast Conservation and Coastal Resource Management (CC&CRM)	4th Floor, New Secretariat Building, Maligawatte, Maradana, Colombo 10	info@coastal.gov.lk	0112449754
Marine Environment Protection Authority (MEPA)	177, Nawala Road, Colombo 05	info@mepa.gov.lk	0112554006/ 0112554373

Section 3
A logical key for decision making regarding mangrove restoration

With the support given by channels constructed to improve hydrology, nature takes over and provides the solutions.
Natural germination of *A. marina.*

Task Force for Restoration of Mangroves has been developing and pilot testing methods for mangrove ecosystem restoration in a scientific manner since 2019. National experts and NGOs that have been working on mangrove restoration also provided their wealth of knowledge and skills to develop the guidelines given below.

3.1 Why is the Ministry of Environment introducing forms to be used in mangrove restoration planning and implementation?

We know that many mangrove replanting efforts have not been successful. Therefore, a scientific approach is essential for restoration. Successful restoration goes beyond one-time planting. It is about bringing an ecosystem back to life and reestablishing their services!

Additionally, Sri Lanka serves as the champion of mangrove ecosystems and livelihoods action group of the Commonwealth. Therefore, it is vital to set examples and share our experiences with other nations.

Efforts of all should be accounted for, and proper record keeping will enable us to understand the impact of our efforts. Biodiversity Secretariat of MoE will act as the focal body to collate data and share all such information with every stakeholder. BDS of MoE will also register each effort and will link each restoration activity to the right agency. Forest Department and Department of Wildlife Conservation, and all other agencies will be linked when and where necessary.

These forms will enable correct decision making, data governance, reporting and monitoring. With these forms, Sri Lanka will be able to report the progress we make in restoration in a much organised manner.

Every agency involved in restoration will also get better visibility.

3.2 What are these forms?

Each form is designed to obtain information required to make correct decisions. They will be used at different stages of restoration planning.

3.2.1 Form 1A: Recording floral diversity and composition in areas identified for restoration

This form allows recording the type of vegetation found in the areas identified for restoration, as well as the nearby mangroves and their diversity and density. Additionally, Form 1A will enable us to identify other sensitive ecosystems such as salt marshes. If the floral assessment indicates that it is another vegetation type, leave it untouched. The form also helps to detect the presence of invasive flora.

Decisions could be made on what plants are to be raised in the nurseries, based on the outcomes of Form 1A.

Form 1A should be used

a) at the beginning
b) every 6 months, for monitoring

3.2.2 Form 1B: Recording faunal diversity and composition in areas identified for restoration

Restoration should ensure connectivity of all species. Mangrove ecosystems are complex (Figure 11). All fauna currently living permanently as well as seasonally, should be recorded. Infauna and epifauna of the mangrove soil are also important as much as the fauna found with water. Faunal status before and after restoration are key indicators of success. Faunal surveys also enable us not to disturb existing assemblages.

Form 1B should be used

a) at the beginning
b) every 6 months, for monitoring

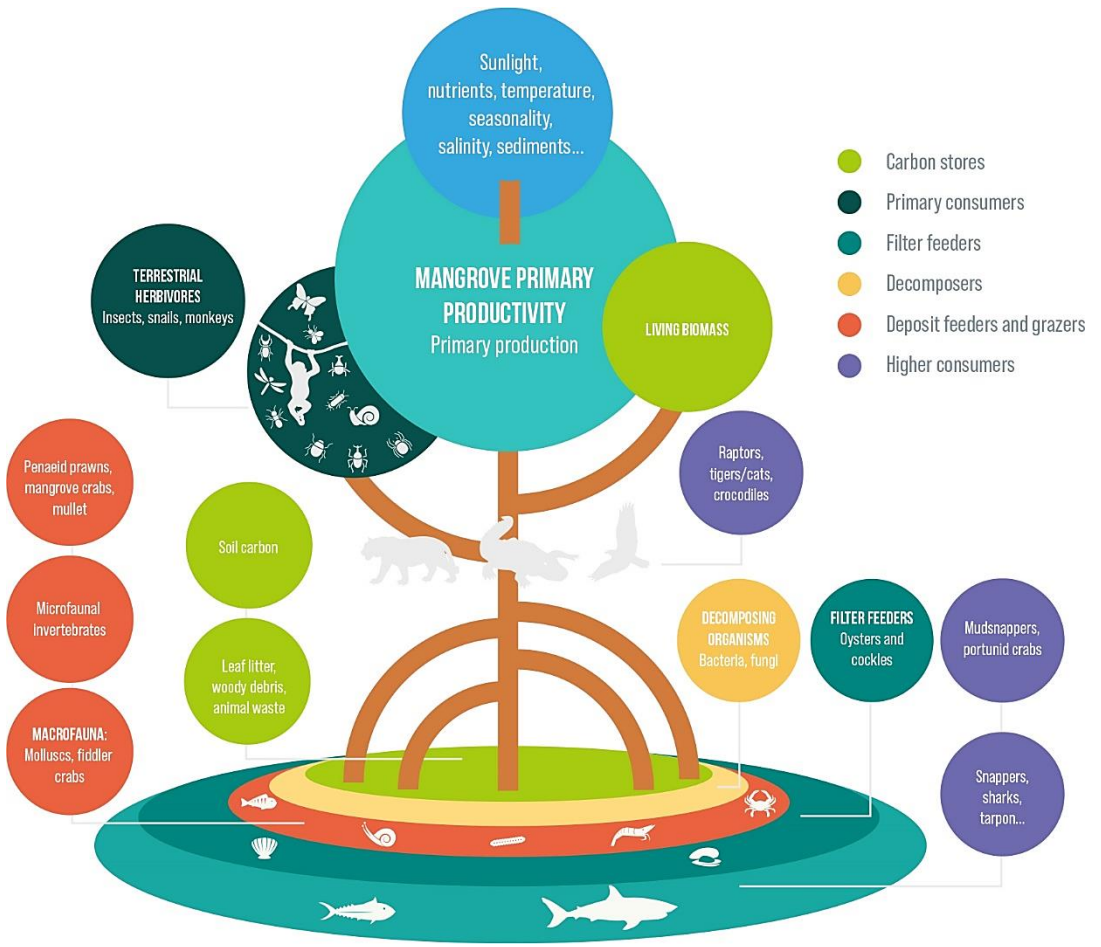


Figure 11**:** A schematic diagram of complex mangrove ecosystems showing the connectivity of all species (adopted from the State of the World's Mangroves, (2021) by Global Mangrove Alliance)

3.2.3 Form 2: Details regarding anthropogenic threats and other data

This form is used to record all current and previous threats that are affecting the restoration site. The information collected from this form will enable us to mitigate the threats, identify the causes of degradation and for how long the threats have been in place, etc.

There is no point in initiating restoration without addressing the threats. The data collected with this form will facilitate community engagement, stakeholder dialogues and planning of alternative business models and such to address the threats.

3.2.4 Form 3: Recording soil and water quality of areas identified for restoration

Form 3 is an important form. This helps to record the condition of soil and water in the area identified for restoration. Measuring parameters such as pH, salinity and temperature of water and soil will enable correct decision making.

The equipment used for water and soil quality monitoring are not available with everyone. Therefore, it is recommended to obtain support from a university or an expert. FD and DWC can also be contacted for help. If you are an NGO committed for long term restoration, why not invest on these instruments?

3.2.5 Form 4: Data from nursery

This form is intended for maintaining records of nurseries. Often, information on plants available for restoration programmes from the area are sought after. This form will give visibility to your nursery and will also allow maintaining records of survival.

3.2.6 Form 5: Accelerated Natural Regeneration of Mangroves (ANRM) Planting regimes and protocol

Mangrove restoration doesn't necessarily require us to plant mangroves all the time. Even removing the disturbances would be sufficient for the mangroves to bounce back. If you make the decision for planting mangroves, it should ideally be minimum planting to ensure that nature takes over with our assistance. Form 5 enables decision making and recording the details of the decisions made.

3.2.7 Form 6: Baseline data regarding the seedlings used for restoration

Form 6 is designed to record and monitor the growth of plants introduced to the area.

3.3 What are the basic instruments required for restoration?

Refractometer

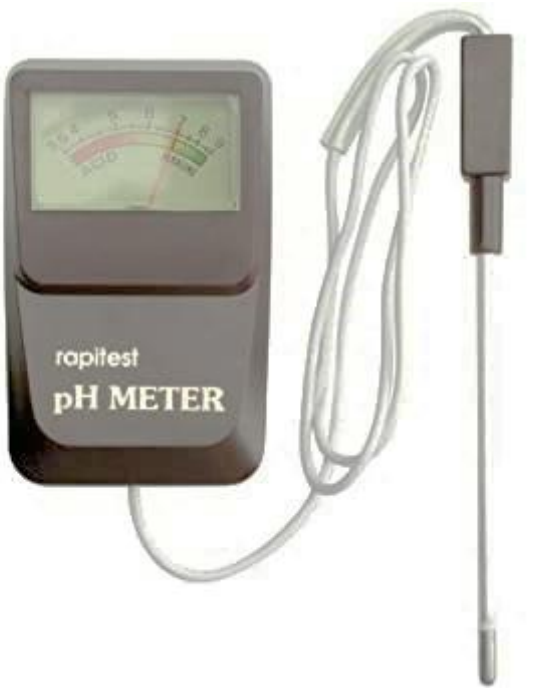
Refractometer is used in order to identify a liquid sample, analyse the sample's purity, and determine the amount or concentration of dissolved substances within the sample. This meter is commonly used to measure salinity.

pH meter

A pH meter is a scientific instrument that measures the hydrogen-ion activity in water-based solutions, indicating its acidity or alkalinity expressed as pH.

Soil pH meter

Soil pH meter is used to measure the pH value of soil.



Soil thermometer

A thermometer is used to measure the temperature of the soil.

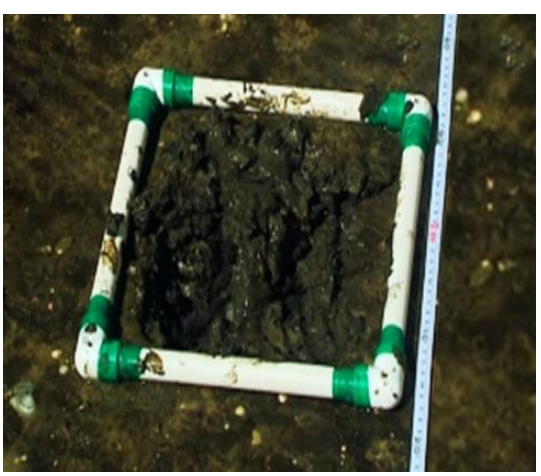
Soil corer (Soil auger)

A soil core is a vertical view (or soil profile) of everything below ground, contained in a long clear tube. The core tube contains soil that is removed from a hole drilled in the ground, or a borehole.

A simple soil corer can be made with a PVC tube. Soil sampling procedure can be referred from www.thebluecarboninitiative.org/manual.

Quadrats

A quadrat is a frame (usually a square), used in ecology and geography to isolate a standard unit of area for study of the distribution of something over a large area. Standard quadrats are 1 m x 1 m and 0.5 m x 0.5 m. They can also be locally manufactured using material such as steel and wood.



Measuring tapes

Measuring tape is a flexible ruler used to measure a length, a height or a distance.

Measuring the growth of seedlings.
Anavilundawa Restoration site,
Department of Wildlife Conservation.

©Ashan Jayathilake

3.4 How to decide the correct approach for restoration? A key for decision making

3.4.1 Decision 1: What are the areas to be avoided?

First and foremost, it is crucial that no other vegetation type is compromised for restoring or expanding mangroves. Use Form 1A to determine the vegetation in the area identified for restoration. If the information indicate that it is a mudflat, salt marsh, sand dune or any other near-coastal vegetation type, **do not** select them for mangrove restoration or expansion. Also, lagoon and estuarine shores should not be planted with mangroves as it will result in reducing the water body area and will disturb the tidal flow.

All coastal areas are not suitable for growing mangroves as they can occur only in the inter-tidal areas of the coast that get flooded either frequently, infrequently or rarely with saline water. Mangroves may also not be able to grow in all the inter-tidal areas, as their soils vary widely within the inter-tidal zone, especially with respect to salinity, pH (acidity or alkalinity), texture, oxygen and nutrient availability. Therefore, selecting suitable sites for successful mangrove planting, either to expand the extent of the mangroves, or to restore/ rehabilitate destroyed or degraded mangrove areas, is a critical task in mangrove restoration.

Planting inside lagoons should be avoided.

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3.4.2 Decision 2: What are the areas suitable for restoration?

The decision should be based on our knowledge on natural regeneration potential. If natural colonisation is possible, let the nature do the job. Work with the communities and local government bodies and empower them to ensure the area is least disturbed and protected. The following extract from the guidebook “Mangrove Restoration: the key elements to be considered in any restoration project. Technical guide pôle-relais zones humides tropicales”, (2018) summarises this very well.

There are two different fundamental approaches to ecological restoration.

Natural Colonisation

Forced planting of mangroves should be avoided in cases where the forest shows signs of self-regeneration (colonisation of the foreshore by new propagules). In this case, recolonisation will occur naturally. In some cases, the reestablishment of favourable hydrological conditions may be a necessary prerequisite to support spontaneous colonisation. This approach is recommended by experts in the field of mangrove restoration.

A. marina settling naturally along the banks of a constructed channel, Achchankulum restoration site, Forest Department.

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Mangrove Planting

It is preferable to plant mangroves in areas where natural recruitment is no longer occurring / is unlikely to occur. It could also be used to supplement an area with a particular species that has declined sharply. It can also be used to colonise an area where mangroves once stood – subject to favourable hydrodynamic parameters. Planting could also be a useful 'tool' for raising awareness among local stakeholders.

If the decision is to leave a site for natural colonisation with no external involvement, the site should still be monitored. Selecting at least one indicator for physico-chemical, hydrodynamic, topographic parameters will enable documenting and learning nature-based solutions which are essential to plan restorations where human intervention is needed.

Correctly selected species and timing are crucial when planting.

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3.5 Restoration guidelines

- Every restoration has three phases and commitment to all phases is essential (Figure 12).

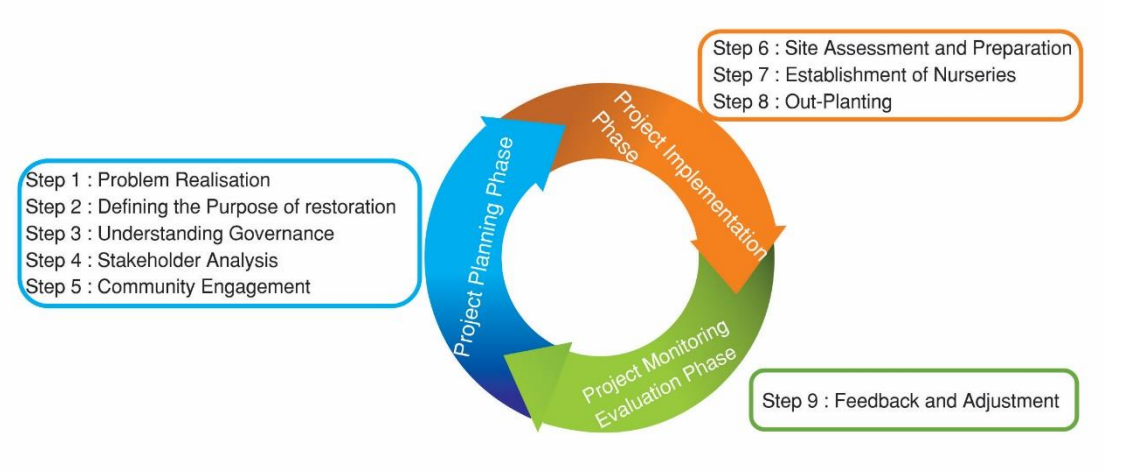


Figure 12**:** Three phases of Restoration (adopted from Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region (2020))

- Figure 13 provides a simple key to human assisted restoration.
- By following this simple key, correct decisions can be taken.
- The forms developed by the Ministry of Environment annexed herewith should be used throughout.

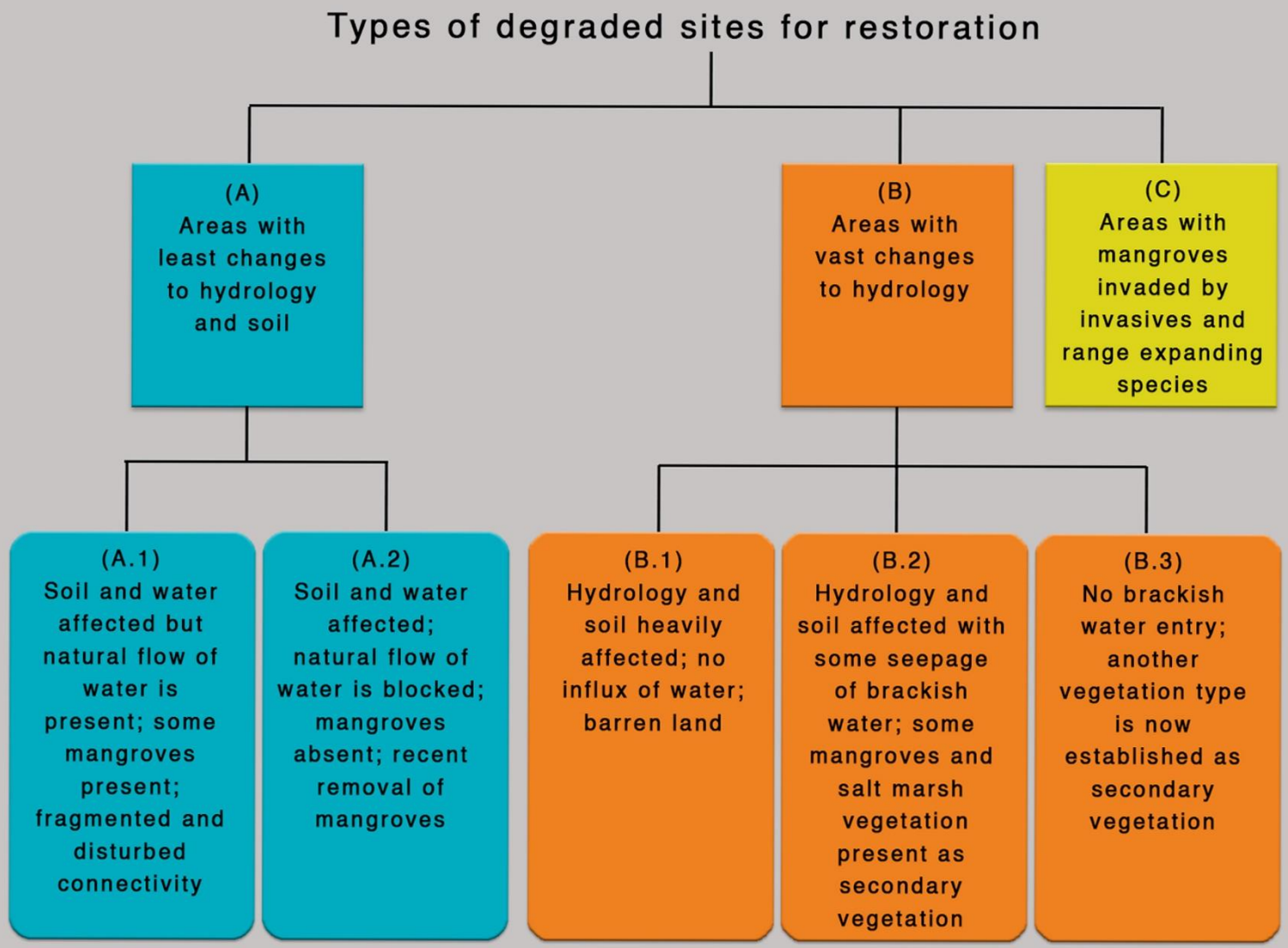
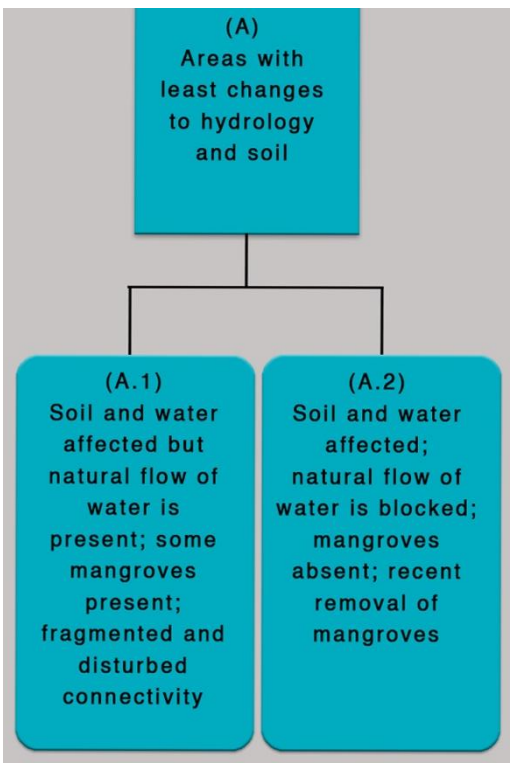


Figure 13**:** A key for decision making for restoration

3.5.1 Areas with least changes to hydrology and soil (A)

Sometimes mangroves are fragmented due to development and other activities (A.1). Sometimes the vegetation is completely cleared (A.2). When such disturbances have not affected tidal flow, hydrology and soil, restoration decisions should be made considering the presence or absence of mangroves. Generally, these areas are recently affected mangrove patches. Recovering the former mangrove cover is possible if restoration starts immediately.



A.1 Soil and water affected but natural flow of water is present; some mangroves present; fragmented and disturbed connectivity

1. This situation is normally seen in areas of recent removal of mangroves. Use Forms 1A,1B, 2 and 3 to gather data. Collect historical data from locals to determine what species were present. Observe the undamaged saplings.
2. Determine if the tidal flow is regular and whether it will naturally restore soil and hydrology. If so, do not make any physical changes to water flow.
3. Determine the threats from the data obtained by Form 3 and make a plan to mitigate threats before restoration.

4. Identify dominant mangroves in the area from Form 1A. Understand the zonation of mangroves from the coast towards the land and follow the same pattern in planting if planting is absolutely necessary. If the decision is to provide protection and let the nature do its job, ensure periodic assessments are done to see natural succession.
5. If it is decided that restoration should be accelerated by planting, use the same species found in the area.
6. Collect propagules and seeds from the area and pot them as per the guidelines given in Table 7 and Table 8.
7. Maintain nurseries in the site itself so that the fittest plants could be selected after natural selection. Use Form 4 to maintain records.
8. Use Form 5 to draw the restoration plan. Here, accelerated natural regeneration of mangroves could be applied. Planting should be minimal. Allow natural germination of seedlings by removing threats such as grazing, trespassing, pollutants, etc.
9. Ensure that invasive and range expanding species do not spread in the disturbed area during restoration.
10. Always try to connect fragmented mangrove patches.

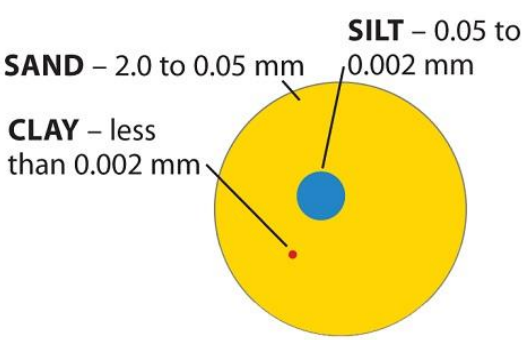
A.2 Soil and water affected; natural flow of water is blocked; mangroves absent; recent removal of mangroves

1. Use Form 1A,1B, 2 and 3 to gather data. Collect historical data from local knowledge.
2. Determine whether the tidal flow is regular and will naturally restore soil and hydrology. If so, do not apply physical changes to water flow.
3. Tidal flow is blocked in most of these cases. That is one reason for the absence of mangroves. If so, determine the causes that block the tidal influxes and freshwater flow.
4. Accordingly, decide if it is feasible to reintroduce water to the system by physical alterations. Physical alterations may include making of drainage channels, demolishing structures such as pond dykes, acquiring land rights to bring water from nearest brackish water source, removal of invasive species and desilting, etc.

5. Using a simple soil corer that can be made using plastic pipes, take soil cores. Determine the availability of silt in the restoration area. Absence of silt is one reason for the absence of mangroves.
6. Silt load is gradually lost when water flow is disturbed. In such areas, the soil becomes gradually sandy and mangroves struggle to colonise. Introducing brackish water to the system is an indirect way of introducing silt.
7. Allow time for the silt load to build up. Obtain repeated measurements of soil. Silty soil can be identified by following characteristics.

Characteristics of silty soil

Silty soil color ranges from beige to black. Particles are smaller than sand particles and larger than clay particles. Silty soil is fine and feels almost floury to the touch when dry. When wet, it becomes a smooth mud that you can form easily into balls or other shapes in your hand. When silty soil is very wet, it blends seamlessly with water to form fine, runny puddles of mud.



8. Obtain water quality measurements (salinity, pH, etc.) to determine whether they are optimal. If the acidity level is high, the pH value will be low. Do not plant in acidic soil as plants can get stunted. Check if acid sulphate soil has been exposed. Supply water to such areas to neutralise the acidity and to cover the exposed iron pyrite soil. Returning of bluish grey soil colour is indicative of soil returning to normalcy.

9. Identify dominant mangroves in the area from Form 1A. Understand the zonation of mangroves from the coast towards the land.

    9.1 If the decision is to provide protection and let the nature do the job, ensure periodic assessments are conducted to monitor the natural succession.

    9.2 If the decision is to plant, follow the same gradient and species composition found in the area.

10. Collect propagules and seeds from the area and pot them as per the guidelines given in Table 7 and Table 8.

11. Maintain nurseries in the site itself so that the fittest plants can be selected after natural selection. Use Form 4 to maintain records.

12. Use Form 5 to draw the restoration plan. Here, accelerated natural regeneration of mangroves can be applied. Planting should be minimal. Allow natural germination of seedlings by removing threats such as grazing, trespassing, pollutants, etc.

13. Ensure that invasive and range expanding species do not spread in the disturbed area during restoration.

14. Always try to connect fragmented mangrove patches.

X

Y

Figure 14**:** Maintaining nursery plants *insitu*. When this method is applied, the fittest saplings are naturally selected and they are well connected to the natural conditions of the restoration site. Status of the plants after two weeks (X) and eight months (Y) at Pubudugama restoration site.

3.5.2 Areas with vast changes to hydrology (B)

Construction of shrimp farms, crab ponds, salterns and such can make vast changes to the hydrology and soil. The uprooting of mangrove plants directly exposes the soil and sediments to sunlight and other harsh elements. Digging exposes iron pyrite soil to atmosphere, thereby oxidising pyrites to release sulphuric acid. Given bellow is one of the common questions asked about these areas.

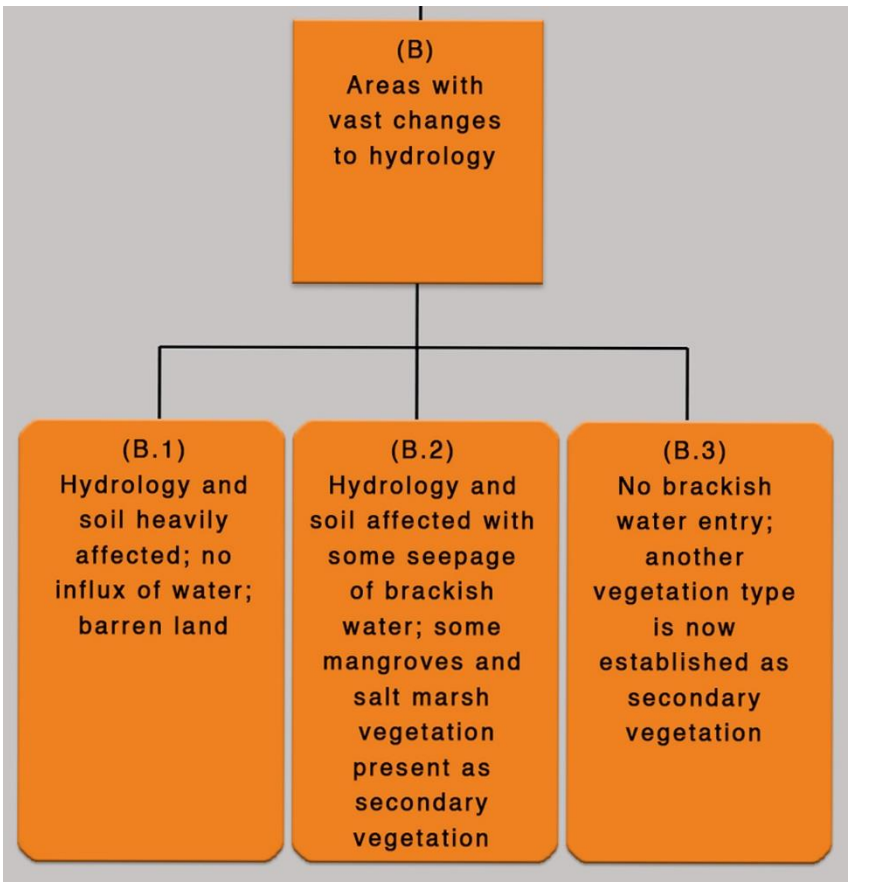
What is acid sulphate soil and why it should not be disturbed?

Acid sulfate soils are naturally occurring soils, sediments or organic substrates that are formed under waterlogged conditions. These soils contain iron sulfide minerals or their oxidation products. In an undisturbed state below the water table, acid sulfate soils are benign. New acid sulfate soils are formed naturally in swamps, especially mangrove forests and salt marshes.

Sulphuric acid gives this rustic brown colour.
©Sevvandi Jayakody

When acid sulfate soils are disturbed, they can generate large amounts of sulfuric acid, iron, aluminium and sometimes heavy metals. This can cause major impacts to the environment and to infrastructure. When acidity builds up to high levels in water, it poisons plants in and around affected creeks and ponds and kills the fish and other aquatic organisms.

In addition to the loss of plants, characteristic fauna of the mangrove environment also leave the area when soil and water become too inhospitable.
There are three situations associated to (B).



B.1 Hydrology and soil drastically affected; no influx of water; barren land

Typically, these areas are formally used as salterns or large scale shrimp ponds over 2 ha with no influx of water. In both the cases, the clearance of mangroves and subsequent deep digging of ponds have resulted in complete removal of topsoil. In situations like this, acid sulphate soil gets exposed and even after abandoning the land, the extreme acidic nature of the disturbed soil prevents formation of vegetation.

Even after 10 years of abandoning this saltern, it is deprived of plant and animal life, and acid sulphate soil dominates the landscape.

©Sevvandi Jayakody

These areas are usually far away from the water sources. In most cases, water has been brought to these areas through channels. With time, when the channels are obstructed, no water would enter this type of barren land apart from rain. Due to the absence of vegetation, soil will be blown away by the wind.

A detailed assessment of the environment before selecting for restoration is important here. Of all different types of restoration, **B.1 is the most challenging**.

1. Firstly, verify if there had been mangroves in the area by historic records as well as the land use types before the changes.
2. Secondly, use current information from computer applications (software) such as Google Earth and Google maps to identify drainage patterns, current vegetation and land use, etc.
3. Options in Google Earth enables looking at the past profiles of a land. Use that option to get a good understanding of the changes in land cover with time.
4. Determine the land ownership.
5. Use Form 1A, 1B, 2 and 3 to gather data. Collect historical data from local knowledge.
6. Often in these situations, tidal flow and other natural water flows are blocked. This is one reason for the absence of mangroves. If so, determine the causes to the blockage of tidal and water flow.
7. With the support of a land surveyor and hydrologist/ irrigation engineer, prepare contour maps of the area and plan the new hydrological regimes to the restoration site accordingly. This should be done for the entire restoration site rather than segment by segment.
8. Accordingly, decide if it is feasible to reintroduce water to the system by physical alterations. Physical alterations may include making of drainage channels, demolishing structures such as pond dykes, acquiring land rights to bring water from nearest brackish water source, removal of invasive species and desilting, etc.
9. Decide the least environmentally damaging option and the most cost effective.
10. Using a simple soil corer that can be made using plastic pipes, take soil cores. Determine the availability of silt in the restoration area. Absence of silt is one reason for the absence of mangroves.

11. Silt load is gradually lost when water flow is disturbed. In such areas, the soil becomes gradually sandy and mangroves struggle to colonise. Introducing brackish water to the system is an indirect way of introducing silt.

12. Allow time for silt load to build up. Obtain repeated measurements of the soil.

13. Obtain water quality measurements (salinity, pH, etc.) to determine whether they are optimal. If the acidity level is high, the pH value will be low. Do not plant in acidic soil as plants can get stunted. Check if acid sulphate soil has been exposed. Supply water to such areas to neutralise the acidity and to cover the exposed iron pyrite soil. Returning of bluish grey soil colour is indicative of soil returning to normalcy.

14. Allow the system to acclimatise to new changes. Give sufficient time for the system to adopt. It is best to cut channels to coincide with rain. Concurrently, nurseries should be raised so that plants are available when the system is acclimatised.

15. Measure soil and water quality repeatedly and maintain records.

16. Check the accumulation of sand and sediments in the channels periodically and clean them if required.

17. Details on how to determine the arrangement of channels are given below.

18. Planting should be done only after careful assessment of soil and water. It should ideally coincide with rain giving a better chance for survival. Check emergence period of seedlings in the area, so that it could be guided by nature. Follow the natural clocks.

19. Identify dominant mangroves in the area from Form 1A. Understand the zonation of mangroves from the coast towards the land.

    19.1 If the decision is to provide protection and let the nature do the job, ensure periodic assessments are conducted to monitor the natural succession.

    19.2 If the decision is to plant, follow the same gradient and species composition found in the area.

20. If it is decided that restoration should be accelerated by planting, use the same species found in the area.

21. Collect propagules and seeds from the area and pot them as per the guidelines given in Table 7 and Table 8.
22. Maintain nurseries in the site itself so that the fittest plants can be selected after natural selection. Use Form 4 to maintain data.
23. Use Form 5 to draw the restoration plan. Here, accelerated natural regeneration of mangroves can be applied. Planting should be minimal. Allow natural germination of seedlings by removing threats such as grazing, trespassing, pollutants etc.
24. Ensure that invasive and range expanding species do not spread in the disturbed area during restoration.
25. It is essential to maintain the channels if they were cut to restore hydrology.

Drainage systems for disturbed mangrove areas

Sometimes the only option is cutting channels to restore hydrology (Figure 15). When in such a situation, consult an expert on irrigation and hydrology to assess topography and current drainage patterns, and decide the best options.

Here's some guidance:

1. With the support of a land surveyor and hydrologist/ irrigation engineer, prepare contour maps of the area and accordingly plan the new hydrological regimes to the restoration site. This should be done for the entire restoration site rather than segment by segment.
2. Check the clues for natural water flow and follow that pattern when cutting channels.

A careful look at these abandoned salterns indicate natural patterns of drainage. It is important to study these patterns before deciding where to cut water channels.

©Google Earth

3. Determine the inflow and outflow. Align with the natural influx of tide and wash out.
4. Commonly adopted channel networks are either palmate (one main channel opening to main water source) or E shaped (many channels opening to main water source), depending on the land configuration.

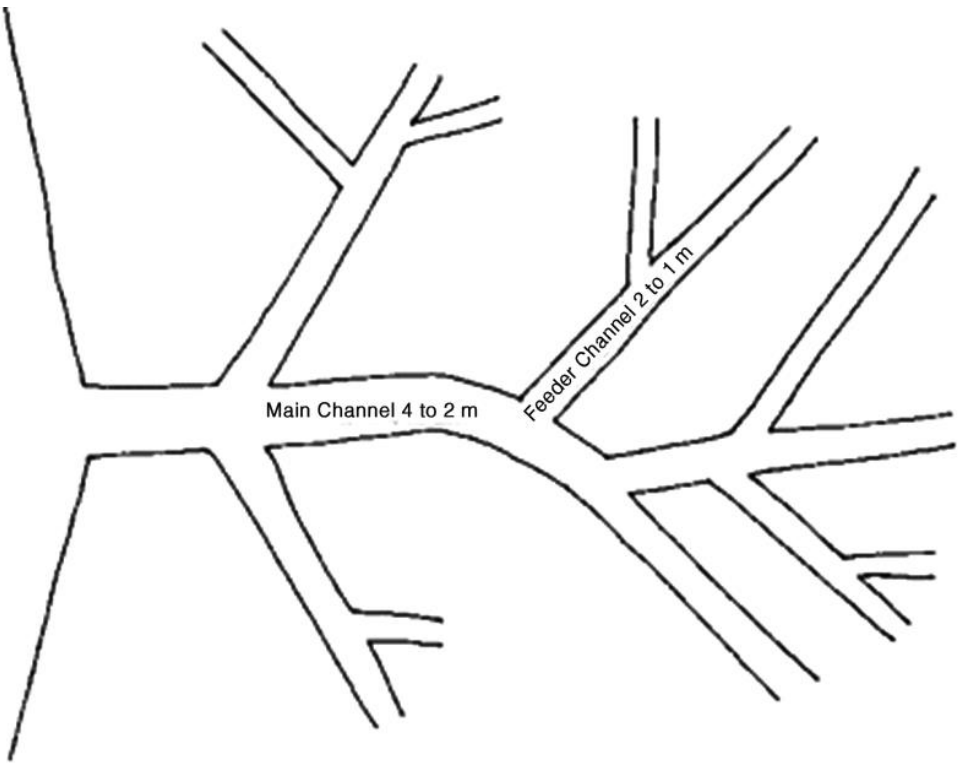


Figure 15**:** A typical palmate shaped water channel system. Adopted from Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region (2020)

5. Ensure that approvals/ permits are obtained as necessary and the community is made aware before the alterations.
6. Channels should be wide and shallow. Ensure that acid sulphate soil is not disturbed.
7. Unless the channels are wide, they would easily become silted after replanting. The plants could also block the channel. Therefore, it is essential for the channel to be wide.
8. Smaller sub channels can be cut along with the main channels to neutralise the acid sulphate.


2008
Copyright: omcar
2009
Copyright: omcar
2010
Copyright: omcar
2011
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Within 3 years the channel is almost blocked and as a result drainage is affected.


Wider and shallow channels.
©Sevvandi Jayakody

Subchannels to facilitate drainage.

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Channels can vary from site to site, depending on the elevation, slope and existing hydrology.

©Tharaka Prasad

Stacking the soil in situ is advisable, with time they create great wildlife habitats. Anawilundawa restoration site, Department of Wildlife Conservation (2020).

©Sevvandi Jayakody

Piled up soil in October 2021 in Anawilundawa restoration site, Department of Wildlife Conservation.

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Case study

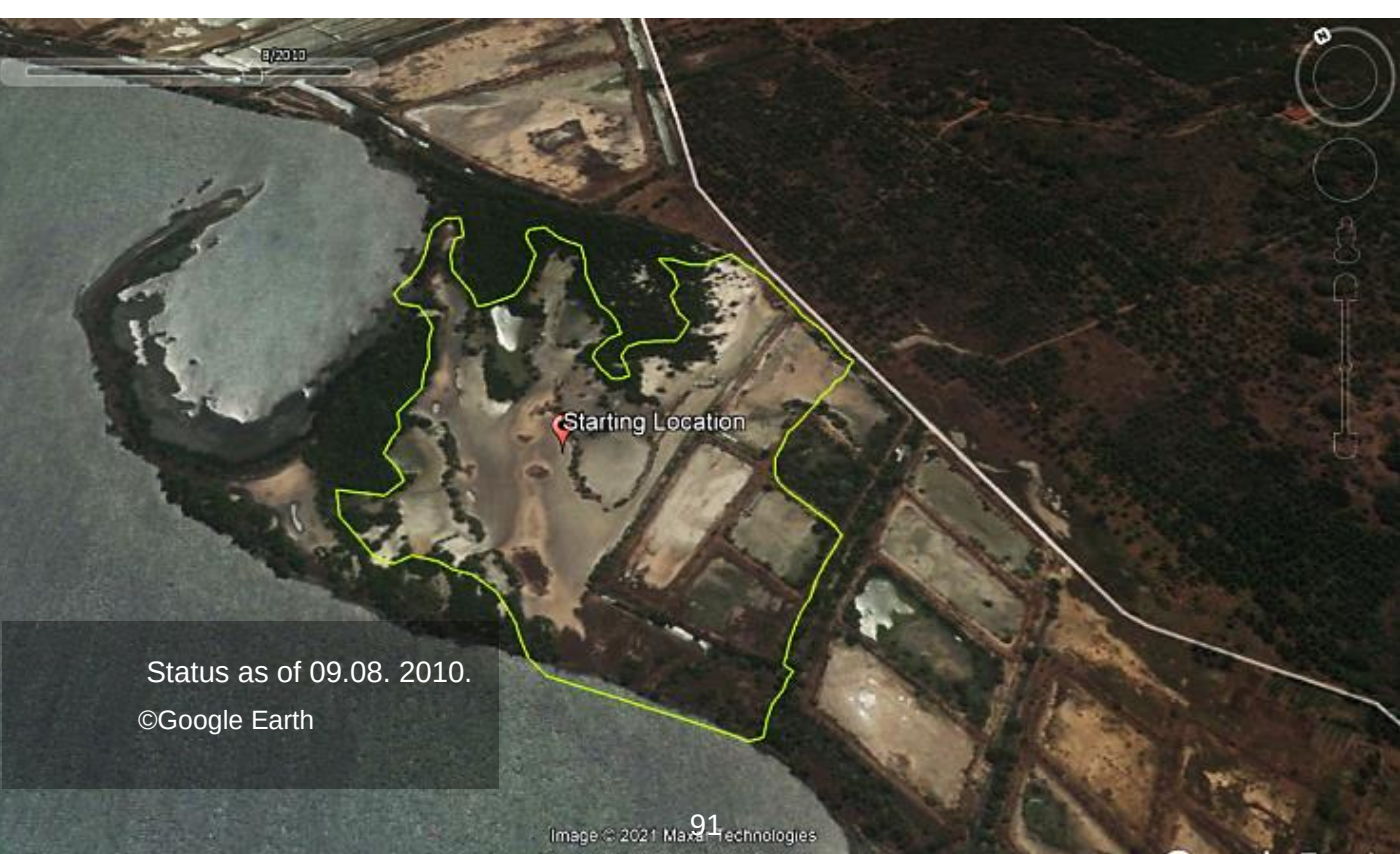
Palmate style channel constructions by the Forest Department in Pubudugama

This formally abandoned saltern was selected in 2019 for restoration. Notice the environment before restoration. Check how the natural drainage pattern seen in the land was mimicked in developing a palmate style channel system in 2020.

Dug soil (seen as white dots in the picture taken in 2020) was not removed and kept in isles, with the anticipation of natural levelling. They also create habitats for fauna with time.

Note the new additions of palmate structures to this area that are extending the restoration.

The Forest Department periodically attends to the channels. They are cleaned particularly before the fruiting season to facilitate natural dispersal and subsequent germination.



Status as of 09.08. 2010.
©Google Earth

Status as of 21.02. 2014.
©Google Earth

Status as of 15.03.2020.
©Google Earth

Status as of 04.02.2021.

©Google Earth

Now the plants are establishing their territories and colonising their preferred space. October 2021.

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B.2 Hydrology and soil affected with some seepage of brackish water; some mangroves and salt marsh vegetation present as secondary vegetation

These situations arise when the seepage is not sufficient and is restricted to certain areas. This is typically seen in abandoned shrimp farms with concrete/ or hard structured dykes with closed inlets. Yet, with time, these obstacles partially collapse to allow some water flow.

The seepage has enabled some mangroves to establish in these areas. Some characteristic fauna such as crabs and gastropods have recolonised as well.

In such a situation, if water and sediment flow is restored properly by removing the barriers, mangroves take over the system as the seepage has somewhat conditioned the soil and water.

However, replanting could accelerate establishment of mangroves to some extent. But **do not** remove any established vegetation. With time, the right combination of plants will take over.

Brackish water seeping through the inlet has enabled *A. marina* to grow inside this abandoned shrimp farm.

1. Use Form 1A, 1B, 2 and 3 to gather data. Collect historical data from local knowledge.
2. Often in these situations, tidal flow and other natural water flows are blocked. This is one reason for the absence of mangroves. If so, determine the causes to the blockage of tidal and water flow.
3. With the support of a land surveyor and hydrologist/ irrigation engineer, prepare contour maps of the area and accordingly plan the new hydrological regimes to the restoration site. This should be done for the entire restoration site rather than segment by segment.
4. Accordingly, decide if it is feasible to reintroduce water to the system by physical alterations. Physical alterations may include making of drainage channels, demolishing structures such as pond dykes, acquiring land rights to bring water from nearest brackish water source, removal of invasive species and desilting, etc.
5. Decide the least environmentally damaging option and the most cost effective.
6. Using a simple soil corer that can be made using plastic pipes, take soil cores. Determine the availability of silt in the restoration area. Absence of silt is one reason for the absence of mangroves.
7. Silt load is gradually lost when water flow is disturbed. In such areas, the soil becomes gradually sandy and mangroves struggle to colonise. Introducing brackish water to the system is an indirect way of introducing silt.
8. Allow time for silt load to build up. Obtain repeated measurements of soil.
9. Obtain water quality measurements (salinity, pH, etc.) to determine whether they are optimal. If the acidity level is high, the pH value will be low. Do not plant in acidic soil as plants can get stunted. Check if acid sulphate soil has been exposed. Supply water to such areas to neutralise the acidity and to cover the exposed iron pyrite soil. Returning of bluish grey soil colour is indicative of soil returning to normalcy.
10. Allow the system to acclimatise to new changes. Give sufficient time for the system to adopt. It is best to cut the channels to coincide with rain. Concurrently, nurseries should be raised so that plants are available when the system is acclimatised.
11. Measure soil and water quality repeatedly and maintain records.
12. Check the accumulation of sand and sediments in the channels periodically and clean them if required.

13. Determine the best patterns of channels suitable for the area.

14. Planting should be done only after careful assessment of soil and water. It should ideally coincide with rain giving a better chance for survival. Check emergence period of seedlings in the area, so that it could be guided by nature. Follow the natural clocks.

15. Identify dominant mangroves in the area from Form 1A. Understand the zonation of mangroves from the coast towards the land.

    15.1 If the decision is to provide protection and let the nature do the job, ensure periodic assessments are conducted to monitor the natural succession.

    15.2 If the decision is to plant, follow the same gradient and species composition found in the area. Use the same species found in the area for planting if it is decided to accelerate the restoration by planting.

16. If it is decided that restoration should be accelerated by planting, use the same species found in the area.

17. Collect propagules and seeds from the area and pot them as per the guidelines given in Table 7 and Table 8.

18. Maintain nurseries in the site itself so that the fittest plants can be selected after natural selection. Use Form 4 to maintain records.

19. Use Form 5 to draw the restoration plan. Here, accelerated natural regeneration of mangroves can be applied. Planting should be minimal. Allow natural germination of seedlings by removing threats such as grazing, trespassing, pollutants, etc.

20. Ensure that invasive and range expanding species do not spread in the disturbed area during restoration.

21. It is essential to maintain the channels if they were cut to restore hydrology.

B.3 No brackish water entry; another vegetation type is now established as secondary vegetation and it is thriving

This is a clear indication of what can optimally grow after disturbance. It can be coastal shrub vegetation, salt marsh, salt marsh and shrub, intermediate and wet zone coastal vegetation etc.

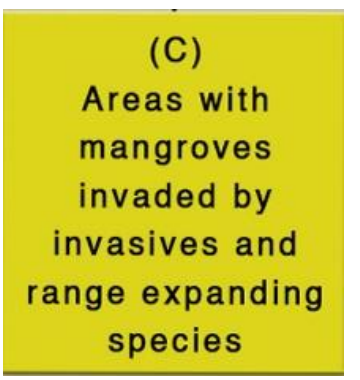
Do not select such areas although mangroves may have been there historically.

Nature has selected what is best for the location now.

3.5.3 Areas with mangroves invaded by invasives and range expanding species (C)

See page 50 (Table 5) to get an idea about common invasive species seen with mangroves.

Recently, some mangroves appear to have a completely altered community structure due to dominance of invasive and range expanding species. In some cases, mangroves are replaced entirely by species such as *Annona glabra* (S: Wel anoda/ Wel aaththa) creating monostands. In such situations, the system is converted to a new vegetation type.



Annona glabra inside the mangrove wetland in Madu Ganga area Such areas require careful assessment if they are to be restored, as invasive species have the ability to alter chemical and physical parameters of the ecosystem to make it unsuitable for natives.

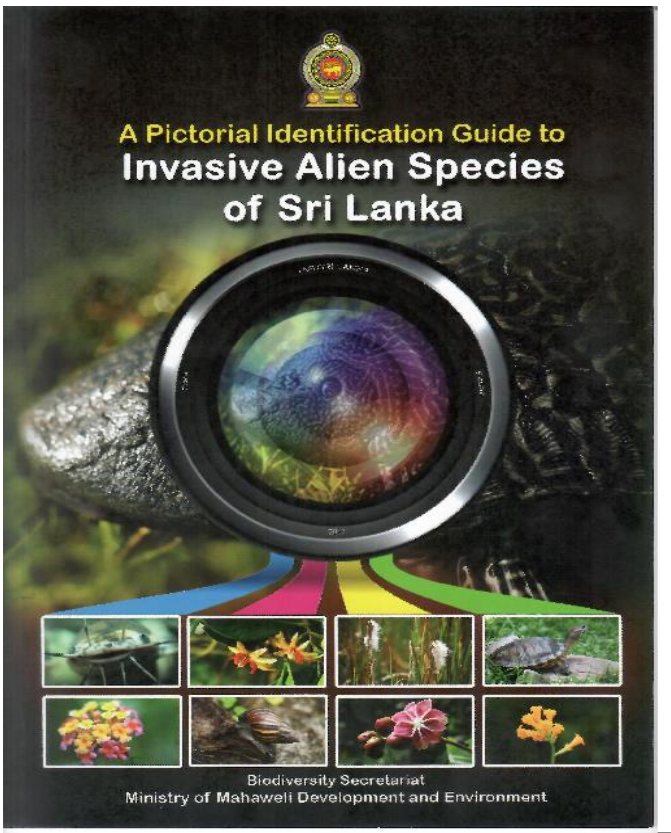
©Kelum Wijenayake

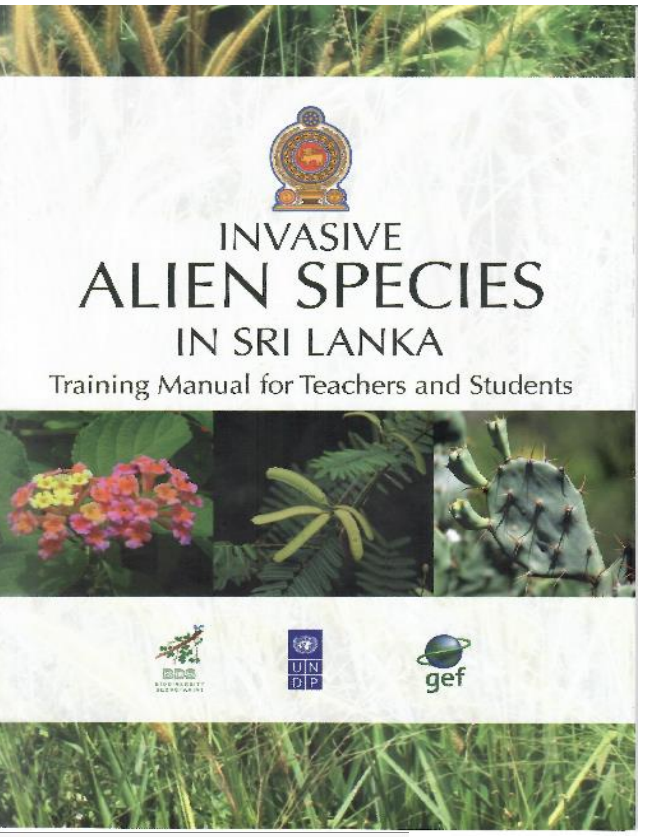
Repeated clearance does not support natives to emerge, until a cure for the issue is found, as invasives take over once again.

Similarly, as the invasive species becomes established, other invasives and native species get adapted to them (e.g. butterflies depending on invasive flowers for nectar). This way, sudden removal of invasives could also affect native fauna. The best restorations happen with minimal impacts to ecosystem.

1. Use Form 1A,1B, 2 and 3 to gather data. Collect historical data from local knowledge.
2. Determine if the tidal flow is regular and whether it will naturally restore soil and hydrology. If so, do not change the physical water flow.

3. Determine the threats from the data obtained by Form 3 and prepare a plan to mitigate those threats before restoration. Devise plans for invasive containment.
4. Identify dominant mangroves in the area from Form 1A. Understand the zonation of mangroves from the coast towards the land and follow the same pattern in planting. Use the same species found in the area for planting.
5. Document the invasive species, their current distribution, and specific locations of occurrence.
6. Confirm the duration of occurrence (how long the invasive species existed in the environment) by talking to communities and referring to literature. If the invasive is of recent origin, it may not have formed ties with other biota.
7. Check any species dependencies and record them.
8. It is best to create subplots and take a step-wise approach in restoring mangroves infested with invasive species.
9. Maintaining a pilot plot will help in learning how to reframe the approach when required.
10. You may also read the following documents to get a better idea about invasive species and their removal.


A Pictorial Identification Guide to
Invasive Alien Species
of Sri Lanka
Biodiversity Secretariat
Ministry of Mahaweli Development and Environment


INVASIVE
ALIEN SPECIES
IN SRI LANKA
Training Manual for Teachers and Students
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ශ්‍රී ලංකාවේ ආක්‍රමණික ආගන්තුක ශාක ප්‍රමුඛතා ලැයිස්තුවේ සඳහන් විශේෂ කිහිපයක්
இலங்கையில் ஆக்கிரமிப்பு செய்யக்கூடிய அந்நிய தாவரங்களின் தேசிய முன்னுரிமை பட்டியல்
(Prosopis juliflora)
(Salvinia molesta)
(Eichhornia crassipes)
(Panicum maximum)
(Clusia rosea)
(Typha angustifolia)
(Lantana camara)
(Annona glabra)
(Austroeupatorium inulifolium)
(Dillenia suffruticosa)
(Cuscuta campestris)
(Alstonia macrophylla)
gef

11. Removing the invasive species may mean repeated uprooting, until the seed bank in the soil cannot support new growth.
12. Sometimes, invasive species overtake riverbanks and replace fringing mangroves as in the case of *Dillenia suffruticosa*. Removal of such invasive species could result in riverbank erosion. Restoration in such areas should start from the land towards the riverbank.
13. Sometimes, invasive species could be epiphytes or lianas (creepers). Creepers such as *Mikania micrantha* can spread over the canopy, cutting off sunlight to mangroves. They can be managed by cutting the invasive creepers from the base. This should be done continuously.
14. Expand the efforts to remove invasive species when the mangroves are fruiting. Plan correctly so that the fruits of mangroves that fall to the ground/ water can sprout without disturbance due to this facilitation.
15. If seedlings are used for restoration, clear the surroundings. At least an area of 1 m^2 should be kept clean until the plant establishes. Use a shading to protect them from excessive sunlight.
16. Clean the perimeter repeatedly until the plant establishes.
17. Ensure that hydrology is restored, and plants are selected according to their preference to water.
18. Removal of invasive species before the flowering is essential.
19. Removal of invasive species only in the site is not effective enough. Plan accordingly and think about the surroundings.
20. From the data obtained by Form 3, determine the other threats and also make a plan to mitigate threats before restoration.
21. Identify dominant mangroves in the nearest area from Form 1A. Understand the zonation of mangroves from the coast towards the land and follow the same pattern in planting. Use the same species found in the area for planting.

3.5.4 Management of pollution in mangroves

One major issue for degradation of the quality in mangroves is the influx of pollutants to the system. Both solid and liquid waste end up in the mangrove ecosystems and surrounding areas. Waste of both organic and inorganic origin is abundant along the coastline of Sri Lanka. In Sri Lanka, chromic plastic pollution is one reason for decline of fauna from the mangrove ecosystems.

A recent study conducted along the coastline of Sri Lanka focusing on landing sites and adjacent beaches shed light to the level of pollution (Figure 16). The predominance of plastic is also obvious considering that the most frequent items found on beaches were all made of plastic. Most of the recognisable items were linked to consumption of food.

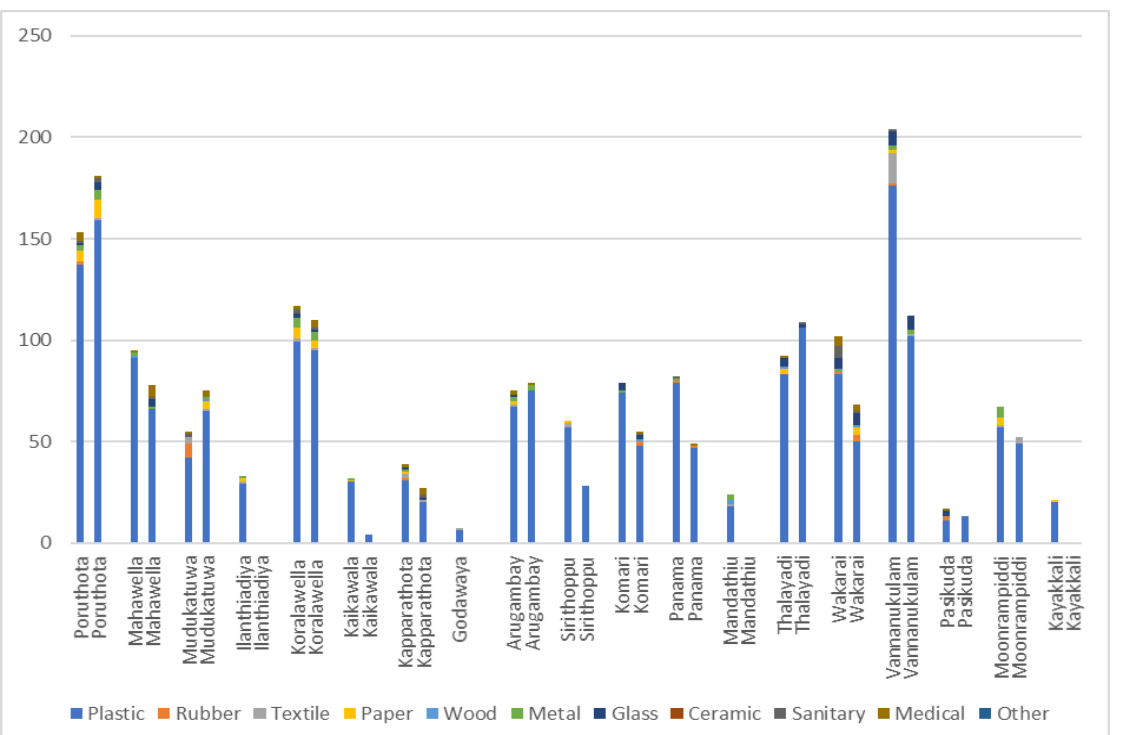


Figure 16: Marine litter composition (following OSPAR protocol) at landing sites around Sri Lanka. First bar of a given location indicates the beach and the second bar the landing site (Adopted by marine litter on landing sites in Sri Lanka: the first survey in Sri Lanka using the OSPAR methodology, Commonwealth Litter Programme, In press)

Additionally, dumping of municipal waste is one major issue for the decline of mangrove ecosystems in Sri Lanka. Several mangrove sites around the Western coast

are used illegally to dump fish/ shrimp/ poultry waste from processing factories which lead to hyper nutrition conditions and changes in water quality.

Nutrient influxes from rivers that drain from basins with intense agriculture, tend to bring in sufficient nutrients for the formation of algal blooms in river mouths and adjacent mangrove areas. This phenomenon has been noticed in Kala Oya where studies revealed a cyanobacteria called *Lyngbya* spp. abundant with the blue-green algae masses floating with water and choking the river banks. *Lyngbya* spp. are known to release biotoxins that can harm fish and other aquatic fauna.

Unfortunately, direct influx of human sewage is still a problem in urban areas where

low-income human populations tend to live in areas adjacent to mangroves. Similarly, tourist hotels also tend to release untreated waste water and pool water into mangrove ecosystems.

How to restore areas affected by pollution?

1. An area earmarked for restoration should be free of influx of pollutants and all possible actions should be taken to manage and prevent the entry of waste. Setting waste traps in waterways is an efficient method. However, the same waste trap can block the lateral movement of species between systems.
2. Take the basin approach. Map the key waste types from the basin, looking into land uses. Work with stakeholders to develop plans. This should be encouraged for all river basins and should be led by relevant government agencies such as MEPA.
3. Educate and empower the communities and other partner agencies. Finances should be allocated in budgets to actions such as
    a) Incentivised removal of waste by selected community members
    b) Waste disposal facility establishment and maintenance
    c) Training on upscaling and recycling of waste
    d) Periodic assessment of soil and water quality to monitor heavy metals/ PAH/ faecal coliform and other parameters related to health of the system
    e) Voluntary group mobilisation to clean the restoration area
4. Clean restoration area after floods.
5. Use plant enclosures to stop garbage choking the new growth

Remember

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

3.6 How to identify mature fruits/ seeds for nurseries?

There are telltale signs that help you to collect fruits. Do not uproot naturally growing plants. Do not pluck immature seeds. Also avoid malformed, predated and diseased fruits. Some tips are given in Table 7.

Table 7**:** Some tips to identify mature fruits of some common mangroves

Species	Source
Avicennia marina	Collect mature fallen fruits with their fruit coat which is pale yellow in colour, during low tide, especially in the morning as soon as they are fallen from the trees to save them from seedling predators (crabs).
Avicennia officinalis	
Bruguiera gymnorhiza	Collect mature propagules from trees and those fallen on the ground.
Bruguiera cylindrica	
Bruguiera sexangula	
Ceriops tagal	Collect mature propagules which have a yellow collar and brownish green hypocotyl.
Heritiera littoralis	Mature fruits from the parent tree or those that have fallen on the floor. Removing the hard seed coat prior to planting will hasten the germination process.
Lumnitzera racemosa	Collect the fallen seeds in the landward areas where they get transported with rising water levels and also from depressions within the mangrove areas.
Lumnitzera littorea	New plantlets can be produced by tissue culture. Collect mature seeds/ fruits from the trees and those fallen to the ground.
Nypa fruticans	Collect from the inflorescences on the trees.
Rhizophora apiculata	Mature propagules, which can be identified by the presence of a pale green ring on the hypocotyl (near the seed/ fruit).
Rhizophora mucronata	
Sonneratia caseolaris	

Sonneratia alba	Seeds in the fruits should be separated by mashing the ripe fruit into a container of water and separating them by straining.
Xylocarpus granatum	Mature fruits (yellow-brown) on the parent trees, fallen or floating, should be collected, seeds should be released by breaking the fruit coat. Seed germination can be accelerated by soaking them in saline water for 2–3 weeks.
Scyphiphora hydrophyllaceae	Mature seeds fallen from the parent trees.
Acanthus ilicifolius	Seeds in mangrove mud can be collected and made to germinate.

3.7 Nursery management

Although planting propagules collected from the wild is less costly, seasonal availability of propagules of mangrove species hampers the reliability of the source of seed material.

The advantage of having a mangrove nursery is that it ensures uninterrupted supply of seedlings for planting. It also enables provision of large numbers of seedlings required to plant in larger areas, even if they are situated far away from the source of seeds/ seedlings. Setting up an efficient nursery demands attention to be paid for a number of aspects (Table 8).

Table 8**:** Aspects to be considered in establishing a mangrove nursery and raising seedlings

Aspects	Description
Selection of sites for nursery establishment	An area close to the shore of the lagoon/ estuary and associated land (close to a creek) where mangrove mud is present and collection of mud from the lagoon/ estuary should be convenient.
	Upper or mid inter-tidal area, with gentle gradient and protection from waves and currents.
	Substratum should ideally be silty-clayey mud Black silty sediment/ soils in the lagoon should be avoided.
	The area needs to be flooded by daily tide and a source of freshwater should be available conveniently.

<table>
<tr><th>Aspects</th><th colspan="2">Description</th></tr>
<tr><td rowspan="3">Preparation of nursery beds</td><td colspan="2">In inter-tidal areas where the wave amplitude is small (e.g., Sri Lanka) frequent inundation of the bed (where the seedlings are kept) with saline water should be augmented by diverting sea/ lagoon water through a channel.</td></tr>
<tr><td colspan="2">Raised beds can be prepared in the supra-tidal areas with facilities to irrigate them with saline water.</td></tr>
<tr><td colspan="2">A net canopy should be installed above the beds to reduce the incident light on the seedlings.</td></tr>
<tr><td rowspan="2">Potting medium to raise seedlings</td><td colspan="2">Lagoon mud has to be scooped and kept piled up for a day.</td></tr>
<tr><td colspan="2">Black polythene bags of 8” x 12” should be filled with the soil leaving about 1” space at the surface to hold water. Holes should be made about 3” above the bottom of the bag to retain water in the root zone.</td></tr>
<tr><td rowspan="4">Nature of mangrove mud (as the potting medium) suitable for mangrove species</td><td>Species</td><td>Potting medium</td></tr>
<tr><td>Sonneratia caseolaris,
S. alba & Lumnitzera racemosa
They form very delicate roots which cannot penetrate sandy or gravelly soil.</td><td>Surface layers of mangrove mud which contains clay & silt
(The filled potting bags should be kept for a couple of days for water to drain and reduce fluidity).</td></tr>
<tr><td>Aegiceras corniculatum,
Heritiera littoralis
Excoecaria agallocha</td><td>lagoon mud (from deeper layers + inland soil (1:1).</td></tr>
<tr><td>Species of Rhizophoraceae, Species of Avicennia, Xylocarpus, Nypa fruticans</td><td>Lagoon/ mangrove mud</td></tr>
<tr><td></td><td>Species</td><td>Transferring Method</td></tr>
<tr><td>Transferring seeds into potting bags</td><td>Sonneratia sp. Lumnitzera racemosa, Scyphiphora hydrophyllacea, Avicennia</td><td>Seeds should be soaked in freshwater for 2-3 days until the first root appears and then the</td></tr>
</table>

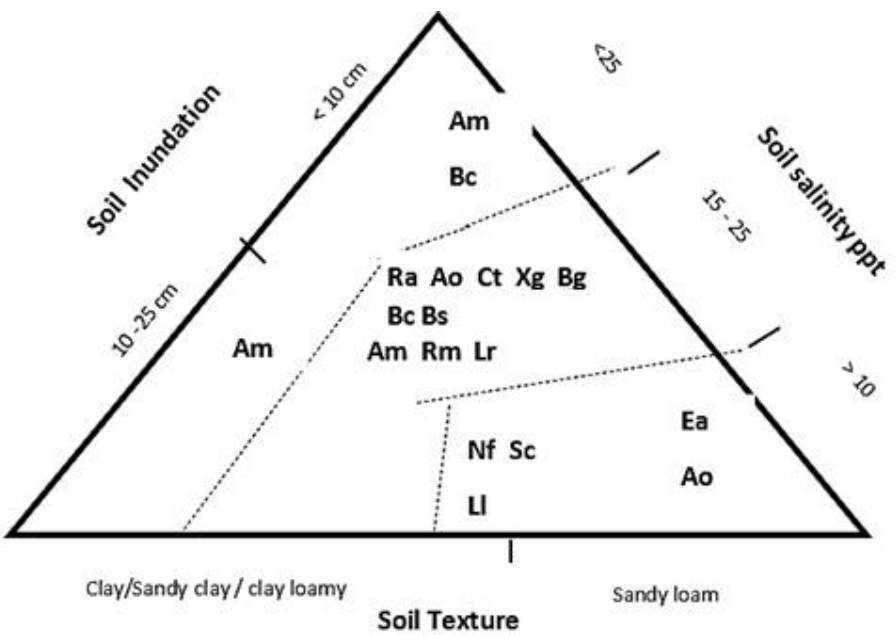
Aspects	Description	
	marina – collect fallen seeds that do not harbor worms.	seedling should be transferred to the potting bag.
	Propagules of species of Rhizophoracea are available throughout the year (in different parts of the country).	Propagules with evidence of diseases, deformities or damage, small or non-uniformly coloured, broken or bruised propagules should be avoided. Propagules should be planted vertically in the potting bags by gently pushing the tapering end of the propagules into the bag with potting medium up to 1/3rd or 1/4th (about 2 inches) of the length of the hypocotyl.
	Avicennia species	Propagules should be placed on the surface of the mud in the potting bag.
Watering regime	Potting bags with propagules should preferably be watered daily (before 10.00 a.m.) with lagoon/ saline water of 20 - 25 ppt salinity. Water should be added until 1 inch water is retained above the potting material.	
	During rainy periods, water gathered in the potting bags should be drained by piercing the bags.	
Shade to provide suitable intensity of sunlight	Light intensity under a natural canopy of mangroves (species of *Avicennia*) has proven to be the ideal condition for the purpose. Shelters should be raised above the bagged propagules with polythene nets that can reduce the intensity of sunlight.	
	Recommended light conditions: Wet & Intermediate climatic zones: 40% reduction in incident light. Dry & arid climatic zones: 60% reduction in incident light.	

Aspects	Description	
Length of nursery care required for mangrove propagules before being transferred to planting sites.	Species	Length of time
	Avicennia marina *A. officinalis*	5 – 6 months (to avoid leaf-eating insect predators).
	Rhizophora mucronata *R. apiculata*	02 months (until 04 leaves & bud are produced) is the best Older (about 1.5 yrs) seedlings are not suitable as they are too tall to withstand the waves/ wind.
	Aegiceras corniculatum	09 months (needs more light than other species).
	Heritiera littoralis	12 months
	Nypa fruticans	09 months (to produce roots in lagoon mud potting medium).
	Bruguiera gymnorhiza *Bruguiera cylindrica* *Bruguiera sexangula* *Ceriops tagal*	04 months (to cope with the predators).
	Xylocarpus granatum	09 months (Leaves are not produced until the seedling grows up to 40 cm but stipules remain).
	Excoecaria agallocha	08 months
Inspection	Thorough daily observation is the key to successful protection.	

It is appropriate to develop a layout for planting seedlings in the sites chosen. This could be done by:

- observing the zonation in natural mangrove areas in the vicinity and mimicking it,
- measuring soil salinity, inundation pattern, texture across the inter-tidal gradient and select species that suit the conditions.

The best species to plant are those that can tolerate the soil salinity, soil texture and inundation pattern characteristic to the site. Therefore, studying these properties is an essential prerequisite for selecting the best suited plant species for the success of the planting programme. The following triangle facilitates selection of best species for a site with known soil texture, salinity and inundation (Figure 17).



Legend

Am – *Avicennia marina* **Ao** – *Avicennia officinalis* **Bg**- *Bruguiera gymnorhiza* **Bc** - *Bruguiera cylindrica* **Bs** – *Bruguiera sexangula* **Ct** – *Ceriops tagal* **Ea** - *Excoecaria agallocha* **Lr** – *Lumnitzera racemosa* **Ll** - *Lumnitzera littorea* **Nf** – *Nypa fruticans* **Sc** – *Sonneratia caseolaris* **Ra** – *Rhizophora apiculata* **Rm** - *Rhozophora mucronata* **Xg** – *Xylocarpus granatum*

Figure 17: Species selection triangle for mangrove planting

Distance between plants depends on the following factors.

- Habit of the plants. *A. marina* trees that produce wider canopies need to be planted about 10 ft apart. Species of Rhizophoraceae family are desirable to be planted either 2 m apart especially on the water-front to manage erosion or 4 m apart in areas away from the water-front.
- Purpose of planting (as erosion barriers in estuaries or wind barriers on the seaward areas of lagoons etc.).

Following good practices are recommended when the seedlings are transferred from nursery to the field.

- Watering of potted seedlings in the nursery should be stopped two days prior to the transportation date.
- Seedlings should be transferred to holes dug in the mud that are 1.5 times larger than the root ball of the nursery-raised seedling.
- Seedlings that need support to stay upright and above the water level should be tied to poles stuck in the mud close to the plant.

Continuous monitoring and intensive care should be given to the planted seedlings for the first 3-4 years as they are vulnerable to environmental stresses during this time. Issues that require attention in order to achieve planting/ restoration success are included in Table 9.

When plants are kept in high densities in nurseries, diseases and pests can always be a problem. Research is essential to overcome such issues.

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Table 9**:** Essential after-care activities

Issue	Remedy
Algal growth	All algae entangled with the transplanted seedlings should be removed by hand during low tide. Smothering the leaves by algae could be prevented by transplanting older (1-1.5 yrs old) taller seedlings.
Siltation	Silt gets deposited on leaves and if the seedlings are completely submerged during high tide, eventually killing them with the action of gastropods that get attracted to silt. Transplanting older seedlings (taller) is the best option to avoid it.
Predation	Seedlings predated by crabs or cattle should be replaced. Planting seedlings/ propagules in the hollow of a piece of bamboo or a PVC pipe may reduce the predator damage.
Cattle grazing	The planted area should be surrounded with a mesh or a barbed wire fence to avoid entry of cattle.
Erosion	Areas such as mudflats that are prone to erosion can initially be consolidated by planting a fast-growing salt tolerant grasses such as *Cynodon* sp, *Porteresia* sp and mangrove seedlings planted subsequently to avoid the transplants being washed away.
Human intervention	Communities in the vicinity should be educated over the importance of mangrove planting. Provisions must be made to secure their participation as vigilantes and protectors.
Polythene and waste accumulation	Periodic cleaning, specially after floods is essential. In restoration sites all efforts should be made to manage waste such as discarded potting bags, water bottles etc. Plan ahead and educate all.

3.8 Working with stakeholders

Local community support is an invaluable resource that can be harnessed for the success of mangrove planting and restoration. Table 10 presents a few options to secure community support for the purpose.

Muthupanthiya community sorting the hypocotyls for nursery.

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Table 10**:** Options available to secure community support for mangrove restoration

Activity	*Modus Operandi* (The way to do it)
Community education on ecological and economic importance of mangroves	Local knowledge about restoration site and mangrove ecology is beneficial for the success of a mangrove restoration effort. Involvement of local communities is cost effective. It is also a mode of empowering them, which creates a sense of ownership in the restoration activity and it encourages them to be vigilant and socially responsible to protect natural and restored mangrove areas.
Mobilisation of local communities for mangrove restoration	Community members, especially the fisher folk can be encouraged to take part in seed/ propagule collection, nursery establishment and maintenance, seedling transportation, planting, after-care operations and protecting plantations/ restoration sites. Female members are more efficient in maintaining nurseries. Participants may be paid a reasonably higher wage than normal to attract members to work in mud.
Use of local community groups	CBOs, Environmental NGO and Fisheries Societies are also potential community groups whose support can be secured for the purpose.
Mangrove restoration through schools	School children and teachers can be made aware of the importance and be encouraged to execute projects through which they can contribute physically to the cause. Schools that volunteer to do so may be rewarded by contributing to improve common facilities of the school.

Constant formal and informal engagement with the community that lives with mangroves is the only way to handover restoration projects to them and to make them champions and guardians. DWC officer from Anawilundawa Sanctuary engaging in a discussion with the community.

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Annexes

Annex 1: Floral biology of mangroves and identification of parts of fruits, seeds and seedlings

From the formation of the flower which produces the fruit, then release of seeds to their dispersal, the biological terms are important to know when it comes to management of nurseries. Also, the format of data sheets kept at nurseries to measure growth and survival should be decided by studying the variations in formation of fruits and seeds in mangroves.

Germination of seeds in most mangroves occur on the parent plant, a phenomenon known as **vivipary**. In such plants dispersal unit is a seeding itself. In addition, germination can be **hypogeal** (cotyledons do not expand and are not exposed) or **epigeal** (cotyledons expanded and exposed). In some mangroves such as *Rhizophora, the* viviparous germination results in an extended hypocotyl frequently referred as the **propagule** (Tomlinson, 1986).

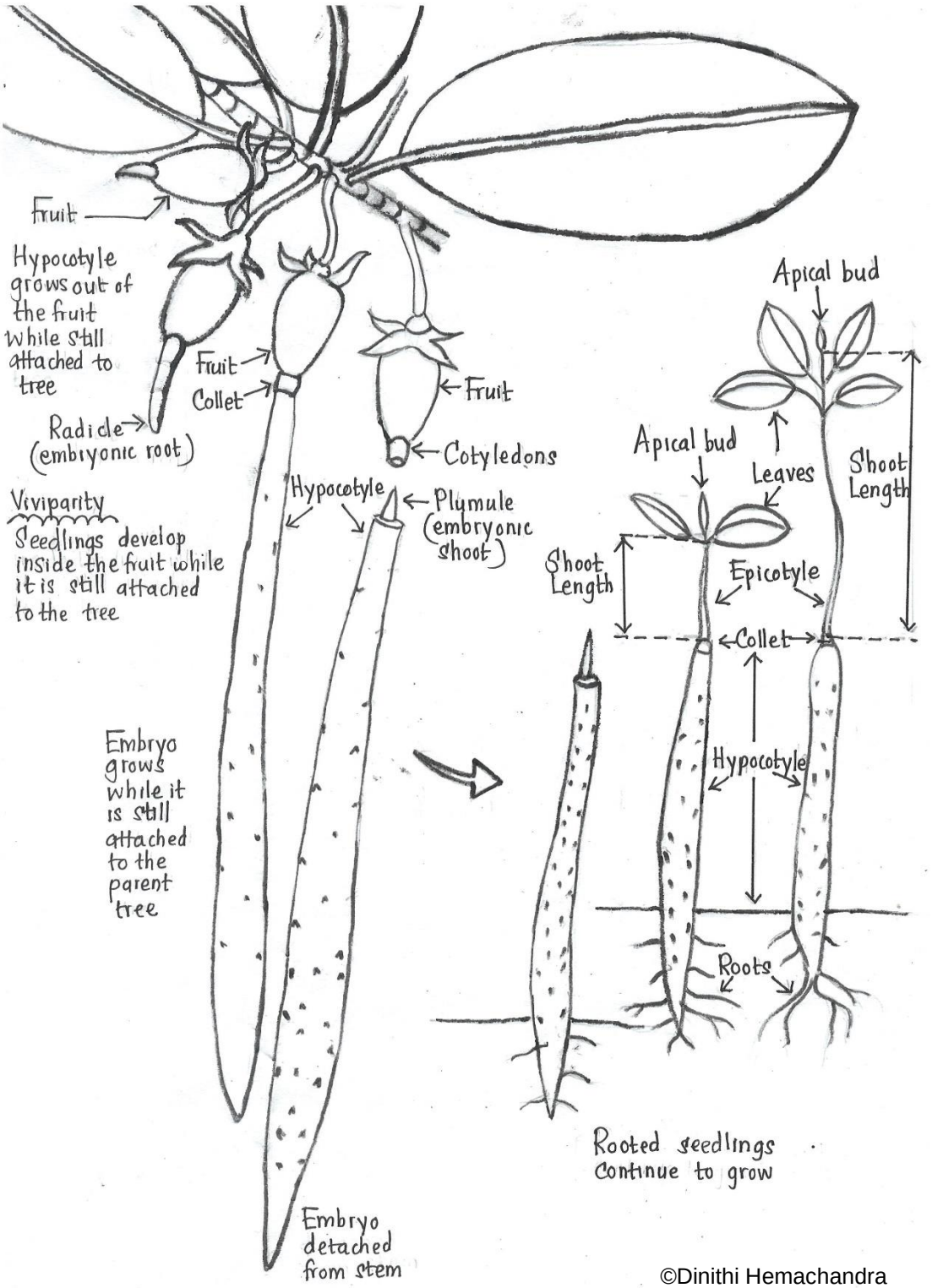

Figure A1: Stages of germination in *Rhizophora* spp.

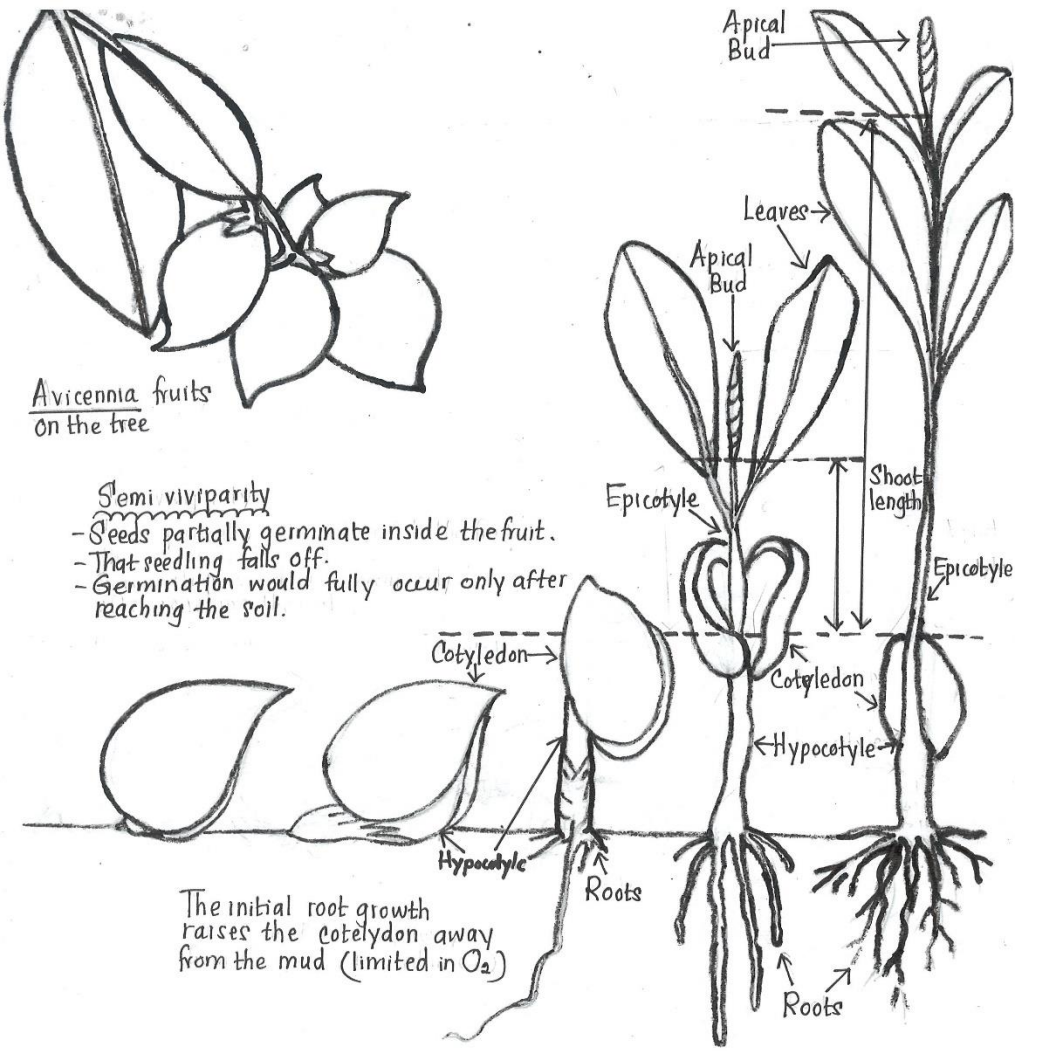

Figure A2: Stages of germination in *Avicennia* spp.

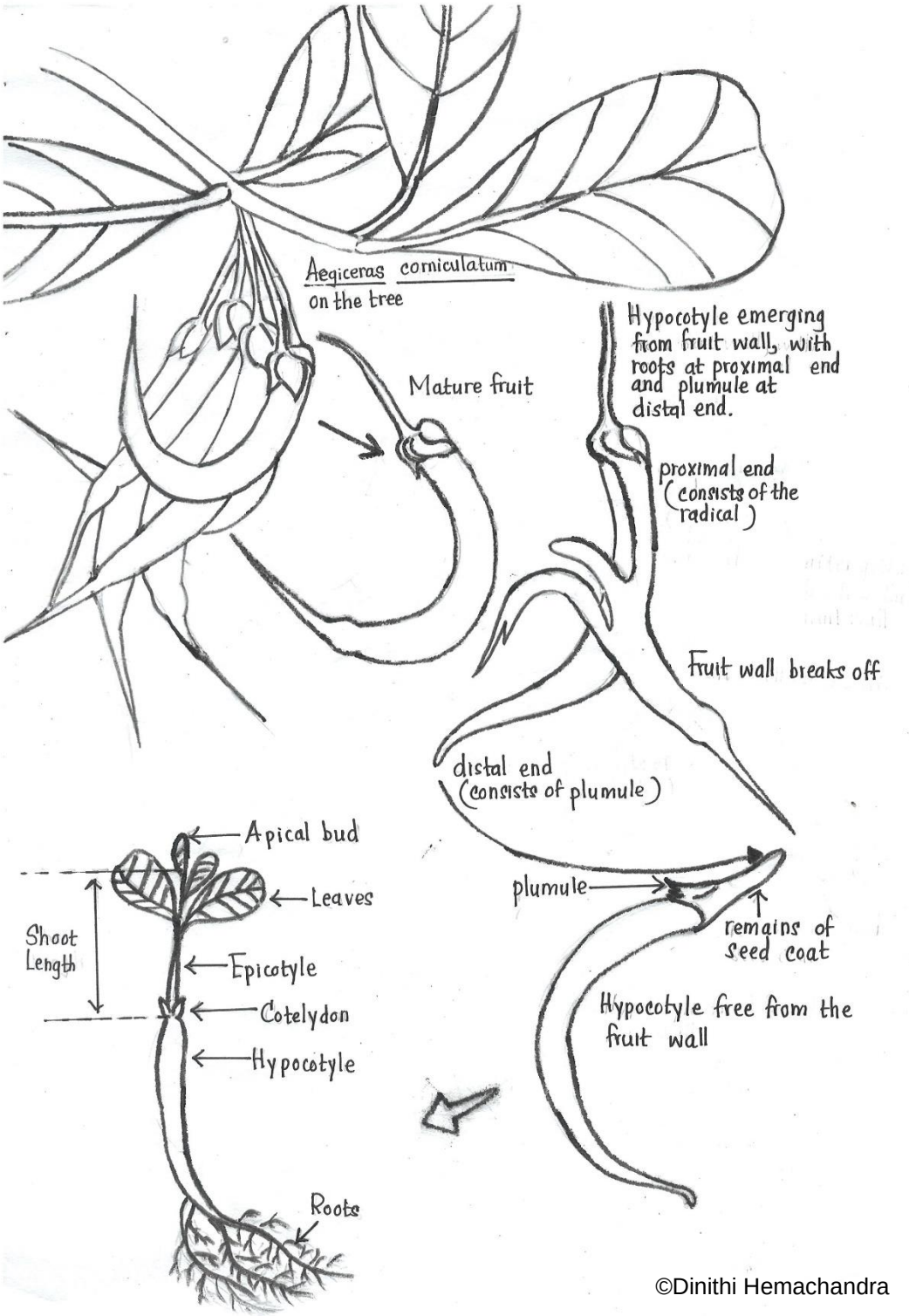

Figure A3: Stages of germination in *Aegiceras corniculatum.*

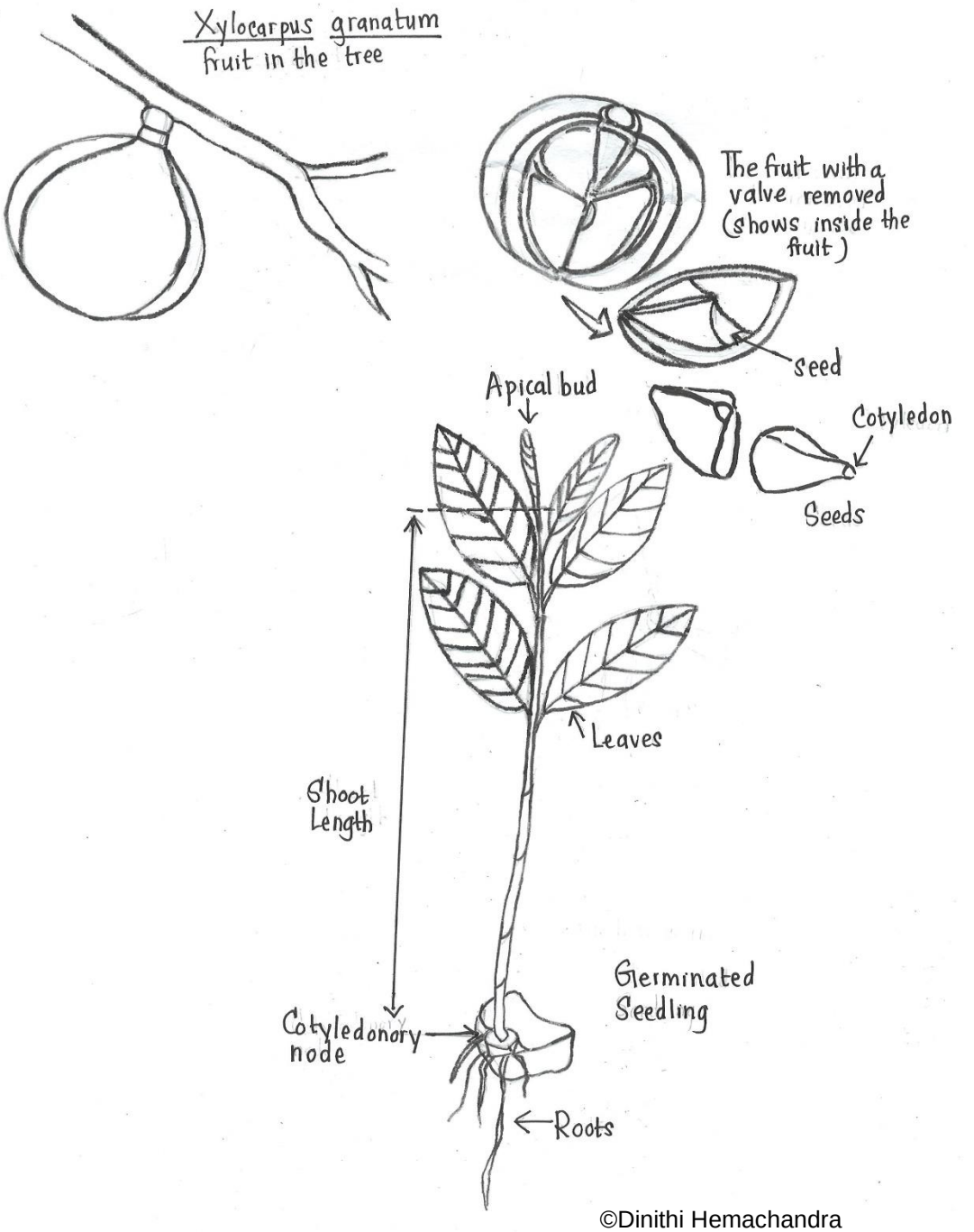

Figure A4: Stages of germination in *Xylocarpus granatum.*

Annex 2: Forms required for restoration initiatives

Collecting data for Form 1A by Forest Department

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Form 1 A: Form for recording floral diversity and composition in area identified for restoration

Form for recording floral diversity and composition in area identified for restoration
Biodiversity Secretariat of Ministry of Environment

Sheet 01 **District: ……..**

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C…….)	**Start : GPS**	**End : GPS**	**Replicate No.**	**Length of the transect**	*Aegicera scorniculatu*	*Avicennia marina*	*Avicennia officinalis*	*Bruguiera cylindrica*	*Bruguiera gymnorhiza*	*Bruguiera sexangula*	*Ceriops decandra*	*Ceriops tagal*	*Excoecaria agallocha*	*Shirakiopsis indica*	*Heritiera littoralis*	*Lumnitzera littorea*	*Lumnitzera racemosa*	*Nypa fruticans*

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Sheet 02

Transcript No. (A/B/C…….)	**Start: GPS**	**End: GPS**	**Replicate No.**	**Length of the transect**	*Shirakiopsis indica*	*Pemphis acidula*	*Sonneratia alba*	*Sonneratia caseolaris*	*Xylocarpus granatum*	*Rhizophora apiculata*	*Rhizophora mucronata*

Sheet 03

Clerodendrum inerme	*Cynometra iripa*	*Derris sp.*	*Derris trifoliata*	*Dolichandrone spathacea*	*Guilandina bonduc*	*Hibiscus tiliceus*	*Hydrophylax maritima*	*Ipomoea pes-caprae*	*Launaea sarmentosa*	*Memecylon umbellatum*	*Phoenix zeylanica*	*Premna latifolia*	*Premna serratifolia*	*Salicornia brachiata*	*Scaevola taccada*	*Senna auriculata*	*Sesuvium portulacastrum*	*Spinifex littoreus*

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Sheet 04

Syzygium cumini	*Terminalia arjuna*	*Terminalia catappa*	*Thespesia populnea*	*Cynometra iripa*	***salt marsh***	*Sesuvium portulacastrum*	*Halosarcia indica*	*Salicornia branchiata*	*Suaeda maritima*	*Suaeda monoica*	*Suaeda vermiculata*	*Cressa cretica*	*Pemphis acidula*	*Avicennia marina*	**Invasive Alien Species** *Annona glabra*	*Dillenia suffruticosa*	*Prosopis juliflora*	*Typha angustifolia*

Tip 1: You can print out these Forms and line (paste) them together as a folded checklist for your field survey.
Tip 2: Keep additional sheets printed out with blank headers, so you can enter any other species you encounter in the field.

How to use this Form?

1. This is the first form to be used in site selection. This form will also enable identification of true of mangroves of the area, native associates, invasive etc. Data should be used in deciding the best combination of plants that should be introduced during restoration. Avoid invasives and species not seen in the area in healthy mangrove patches.
2. Nomenclature to be used (A = area identified for restoration, B= periphery of the area identified for restoration, C= if the periphery does not contain a natural mangrove ecosystem, the nearest mangrove patch)
3. In each strata, lay belt transects of 1m width and varying lengths (10 to 50m). Ideally at least 10% of the area should be covered by belt transects and they should be laid to represent the area.
4. Label the belt transects to indicate the strata (Ex: A1 = first transect of the area identified for restoration).
5. Convert the data into densities as follows.

E.g.:		
Number of mangrove plants found in area of (1 m X 50 m) 50 m^2	=	10
Density per 1 m^2	=	10/50 m^2
	=	0.2 m^{-2}
Density per 1 km^2	=	0.2 m^2 * 10^6
Density per ha	=	(0.2 m^2 * 10^6) /10^2
	=	2000 ha^{-1}

Form 1B: Form for recording faunal diversity and composition in area identified for restoration Biodiversity Secretariat, Ministry of Environment

Form for recording faunal diversity and composition in area identified for restoration
Biodiversity Secretariat, Ministry of Environment

Sheet 01 **District: ……..**

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Mammals													

Sheet 02

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C.....)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Birds													

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Sheet 03

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……..)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Reptile													

Sheet 04 **District: ……..**

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Amphibians													

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Sheet 05

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……..)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Fish													

Sheet 06

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……..)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Bivalves & Gastropods													

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Sheet 07

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……..)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Crabs & Shrimps													

Sheet 08

Date: **Location Name:** **GPS point:** **Photo taken Y/N:** **Name of the data collector:**

Transect No. (A/B/C……..)	Start : GPS	End : GPS	Replicate No.	Length of the transect	Other (……..)													

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How to use this Form?

1. This is the first form to be used in recording fauna species.
2. Nomenclature to be used (A = area identified for restoration, B= periphery of the area identified for restoration, C= if the periphery does not contain a natural mangrove ecosystem, the nearest mangrove patch)
3. In each stratum, use belt transects of 1 m width and varying lengths (10 to 50m) for species like amphibians, fish, reptiles, gastropods etc. Mammals and birds can be recorded using point transects and visual observations. Ideally at least 10% of the area should be covered by belt transects and they should be laid to represent the area.
4. Label the belt transects to indicate the strata (Ex: A1 = first transect of the area identified for restoration).
5. Convert the data into densities if data are collected using transects. Otherwise simply make a check list of species encountered.

e.g.:

Number of faunal group (birds, mammals etc.) found in area of (1 m X 50 m) 50 m^2 = 10

Density per 1 m^2 = 10/50 m^2

= 0.2 m^{-2}

Form 2: Details regarding anthropogenic threats and other data

Details regarding anthropogenic threats and other data

District: …….. Location: …….. GPS coordinates: …….

Strata	Reasons for degradation of mangroves (past)*	Ongoing threats	Suggestions for mitigation
A			
B			
C			
Human settlements in the location identified for restoration(Y/N). If yes provide details			
Land ownership			

How to use this form:

1. Site visits, reference to literature and discussions with communities and officials that have a broad idea about the area should be conducted.
2. Column 2 of this form (*) should be filled if the initial threat/s that resulted in degradation are no longer present (ex: shrimp farming, saltern). In the case of past activities, note the number of years of abandonment.

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Form 3: Form for recording soil and water quality of area identified for restoration

Form for recording soil and water quality of area identified for restoration

Biodiversity Secretariat, Ministry of Environment

District: …….. Location: …….. GPS coordinates: …….

Name of the organisation proposing the restoration: Details of contact person (Mobile: … ……email: ……

Strata	Water			Soil			
	pH	Salinity	Temperature	Salinity	Soil temperature	Depth of aerobic layer	Number of soil cores taken*
A	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	
B	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	

Strata	Water			Soil			
C	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	1. 2. 3. Mean =	

How to use this form:

1.Take at least 3 measurements per strata to determine the mean value of above parameters.
2.Ideal if these measurements could be repeated over dry and wet seasons.
3.Use a soil auger to take soil samples.
4.Soil samples should be duly frozen and should be analysed by an entity with expertise.
5.Method of approved analysis is as follows:

Form 4: Data from nursery

Data from nursery

Location: ……..……..……..……..

Name of nursery: ……..……..……

Year: **……**Month

Name of the organisation raising the nursery:……....

Details of contact person:

Name ……..……....

Mobile: ……email: ……...

Species	Number of seeds/ plants potted (Cumulative Number)	Number of sprouted seedlings (Cumulative Number)	Number of seedlings ready for planting (Cumulative Number)	Number of seedlings Dispatched (Cumulative Number)	Balance (Cumulative Number)
Example *R.apiculata*	10,000	8,000	8,000	2,000	6,000

Form 5: Accelerated Natural Regeneration of Mangroves (ANRM) - Planting Regimes and Protocol

Accelerated Natural Regeneration of Mangroves (ANRM) Planting Regimes and Protocol

Location: ……..……...
Name of nursery: ……..……...
Year: **……..….**Month:…….....
Name of the organisation raising the nursery:…….……
Details of contact person:
Name ……..
Mobile: ……email: ……....
Please refer to general guidelines given in the booklet:

1.Check following boxes before commencement of restoration

No	Detail	Yes/No	Data submitted to BDS Y/N
1.a	Data on (A) area to be restored, (B), peripheral area (C) nearest natural mangrove patch have been collected and analysed? (refer Form 1A)		
1.b	Data on fauna: peripheral and within (Form 1B) Crabs Snails Fish Amphibians Reptiles Birds Mammals		
1.c	Photos of the site - To be kept as evidence to monitor change (Form 1A and B)		
1.d	Soil pH (Form 3)		
1.e	Soil salinity (Form 3)		
1.f	Water salinity (Form 3)		
1.g	Core samples for carbon (at least 3 from each plot) (Form 3)		

No	Detail	Yes/No	Data submitted to BDS Y/N
1.h	GIS/KMZ map with all details marked regarding plots and their sizes and human habitation (Form 2)		
1.i	Data regarding vegetation in the area identified for ANRM that can support managing nurseries (Form 1A)		
1.j	Reasons for mangrove degradation (saltern, shrimp farm, land development for other, human settlement, grazing etc.) (Form 2)		
1.k	Land ownership verified (Form 2)		

2. Restoration plan for the identified area. Pls provide a map, decisions taken regarding water circulation, plots, protection, species to be planted, plant densities in each zone.

Points to be considered	Proposed plan	Budget is estimated and funds are available (Y/N)
1.Total area to be restored is mapped (Please provide a GIS map with coordinates)	(Please attach)	
2.Any plots within the identified area are decided * If you plan to create sub plots in your restoration area, please mark it in the map		
3.If improved water circulation is identified, the method of implementation agreed upon		
4.Planting regime and species selected (please provide for each plot)		
5.Site protection plan developed and agreed		

Points to be considered	Proposed plan	Budget is estimated and funds are available (Y/N)
upon * Examples include community surveillance, fencing, hiring labour as watcher men		
6.Post-planting activities identified		
7.Other		

3. Details of planting

Plot number	Plot size (ha)	Species to be planted in the plot	Planting density per ha for each species	Planting design

Plot number	Plot size (ha)	Species to be planted in the plot	Planting density per ha for each species	Planting design

4. Dates of activities

Plot number	Activity (site clearance/ water channeling, planting, replanting, awareness, data collection for for given forms, meetings etc.)	Date	Notes

Authorization

Director
BDS
Ministry of Environment

Approval:

…….. ……..
Conservator General of Forest Department of Wildlife Conservation

Form 6: Baseline data regarding the seedlings used for restoration

Baseline data regarding the seedlings used for restoration

Ministry of Environment

Name of nursery …….. Date ……

Species: …… Age of plants ……

Growing media …….. Other details ……

Selected 10 random plants from each plot

Plot …… Plot ……..

Plant number	Total height (cm)	Height up to last node (cm)	No of sets of leaves	Girth of stem at 1 inch above soil (cm)		Plant number	Total height (cm)	Height up to last node (cm)	No of sets of leaves	Girth of stem at 1 inch above soil (cm)
1						1				
2						2				
3						3				
4						4				
5						5				
6						6				
7						7				
8						8				
9						9				
10						10				

Number of plants uprooted for carbon measurements …… (**Please label and pack separately for each plot**)

Annex 3: Key to identify Mangroves of Sri Lanka

1 A) Palm-like plant, Leaves with parallel veins …… *Nypa fruticans*
B) Plants do not resemble palms, leaves with netlike veins …….. *2*

2 A) Stilt and prop roots present ……. 3
B) Stilt and prop roots absent……..... 4

3 A) Flowers with stalks (peduncle) present…….. *Rhizophora mucronata*
B) Peduncle absent ……..……. *Rhizophora apiculata*

4 A) Pneumatophores present…….. 5
B) Pneumatophores are absent…….. 8

5 A) Pencil like pneumatophores present ……..... 6
B) Pencil like pneumatophores absent……..... 7

6 A) Leaf tips rounded ……..…. *Avicennia officinalis*
B) Leaf tips pointed ……. *Avicennia marina*

7 A) Flowers with white stamens present……..……. *Sonneratia alba*
B) Flowers with pink stamens ……..…….. *Sonneratia caseolaris*

8 A) Plants with knee roots……..…… 9
B) Plants without knee roots……..…….. 10

9 A) Flowers and fruits with a red calix present……. *Bruguiera gymnorhiza*
B) Flowers and fruits with a red calyx absent……...……10

10 A) Bunch of flowers/ propagules on one stalk…..……..… *Bruguiera cylindrica*
B) Single flower/ propagule on one stalk …..…….. ……*Bruguiera sexangula*

11. A) Ribbon roots are present……..……..……..... 12
B) Ribbon roots are absent…….……..……. 13

12. A) A keel present on the fruit…… *Heritiera littoralis*
B) Keel absent on the spherical fruit…… *Xylocarpus granatum*

13. A) Propagules are present…..…….....…… 14
B) Propagules are absent…….. 17

14. A) Propagules with long and straight hypocotyls present……..…… …. 15
B) Propagules with long and straight propagules absent……. *Aegiceras corniculatum*

15. A) Propagules with hanging/ drooping hypocotyls present ……. *Ceriops tagal*
B) Propagules with hanging/ drooping hypocotyls absent …… *Ceriops decandra*

16. A) Latex present in the leaf and bark……. 17
B) Latex absent in the leaf and bark……..…….…… 18

17. A) Thorny trunks are present……..……. *Shirakiopsis indica*
B) Thorny trunks are absent…….…… *Excoecaria agallocha*

18. A) Leaves are larger than 3cm……...……. 19
B) Leaves are not larger than 3cm…… *Pemphis acidula*

19. A) White flowers are present……...……. 20
B) White flowers are absent/ crimson red flowers present…… *Lumnitzera littorea*

20. A) Flowers with a pink tinge/ colouration and short stalk… *Scyphiphora hydrophylacea*
B) Flowers without a pink tinge and long stalk…… *Lumnitzera racemosa*

Acknowledgements

Participants for the process of preparing and validating the National Guidelines for the Restoration of Mangrove Ecosystems of Sri Lanka.

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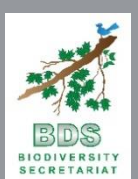

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