MARINE ECOSYSTEMS

METHODOLOGICAL GUIDE TO **MANGROVE RESTORATION**

FONDS FRANÇAIS POUR L'ENVIRONNEMENT MONDIAL

INITIATIVE MANGROVES DU FONDS FRANÇAIS POUR L'ENVIRONNEMENT MONDIAL

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MARINE ECOSYSTEMS

METHODOLOGICAL GUIDE TO MANGROVE RESTORATION

CONTENTS

PREAMBLE

The large number of mangrove conservation or restoration initiatives currently underway reflects a genuine enthusiasm for this emblematic ecosystem of intertropical coastal zones.

While it is justified by the multiple functions performed by these specialised brackish water forests at both global (carbon sequestration) and local (reducing climate change impacts, supporting local economy, etc.) levels, this enthusiasm is not always aligned on the extent of their degradation, which on average has improved significantly over the last 20 years (with major contrasts depending on the country).

Moreover, the results of these numerous projects have sometimes been limited, reflecting the weakness of the initial diagnoses and the inadequacy of the methodologies implemented.

The French Facility for Global Environment (FFEM), like other sponsors, has supported numerous projects around the world as part of its strategy on the resilience of aquatic ecosystems, dedicated to the protection, management and restoration of mangroves. To improve their efficiency and learn from these various programs, the FFEM has also supported a cross-cutting capitalisation initiative, the FFEM Mangrove Initiative (https://initiative-mangroves-ffem.com/), which has brought together practitioners, experts and researchers to discuss the experiences of these restoration projects.

The present guide has been developed within the framework of this platform, which is rich in numerous shared experiences both geographically and in terms of the diversity of its members profiles, which include geographers, sociologists, engineers, ecologists and botanists, etc.

It aims to provide support for project developers and other practitioners, to ensure a greater efficiency of restorations.

Janique Etienne
Project Manager
"Management of coastal and open sea
FFEM"

1

CHAPTER 1

WHY RESTORE MANGROVES ?

Authors: Catherine GABRIÉ and Julien ANDRIEU

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.1 MANGROVES

Mangroves are evergreen forests found in intertidal sedimentary environments at the landsea interface. They are found in tropical and subtropical latitudes. Present along the coastline of 123 countries, mangroves develop along sheltered coasts, in shallow lagoons, estuaries or deltas. The term "mangrove" is used to describe both the ecosystem and its constituent plant species, the mangroves trees. There are two main biogeographical areas distinguishable in terms of the number and type of mangrove species: western mangroves (Atlantic coasts of the American and African continents) and eastern mangroves (Indo-Pacific coasts), which are the most diverse.

In addition to the mangrove forest sensu stricto, the mangrove socio-ecological system is now considered more broadly, as including different environments forming a continuum from the mainland to the sea. It includes grasslands and salt-rich soils (known as « tan » in Senegal), mangrove forests, mudflats, tidal channels, sandbanks and the area from the mouth to the seafront. Added to this are the elements of the mangrove landscape built and managed by human populations (rice fields, aquaculture ponds, etc.) and all the stakeholders involved in governance, at the various levels of social organisation.

The latest FAO report (FAO, 2023 and http://www.globalmangrovewatch.org/) estimates the total area of mangroves in the world in 2020 at 14.8 million hectares (147,359 km²), of which almost 44% (6.48 million hectares) are situated in South and South-East Asia.

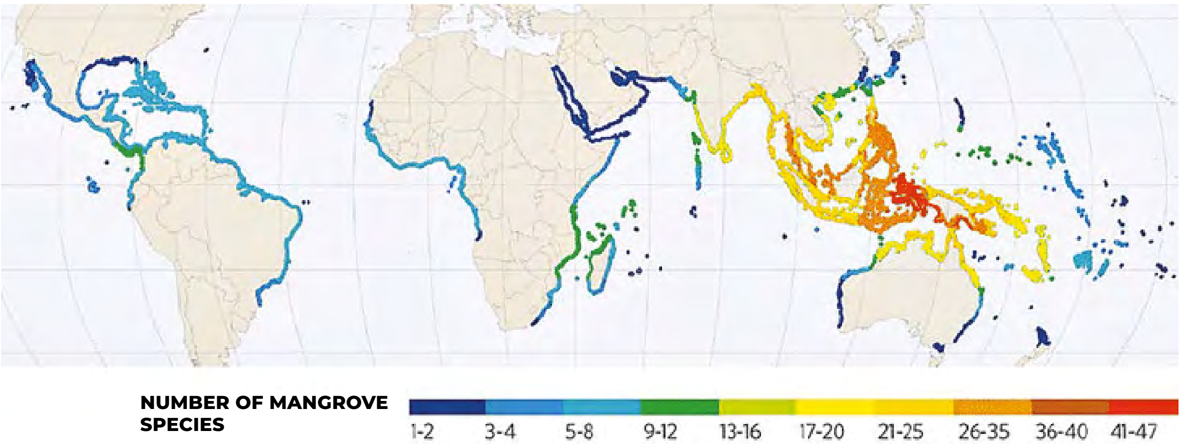

Figure 1: Map of mangroves in the world and number of species by region (source: Deltares 2014)

.2 ECOLOGY

Estimates of the number of "genuine"Mangrove species vary from 50 to over 70. The species are distinguished by unique morphological and physiological adaptations, which enable them to grow in saline and anoxic environments, such as their roots or leaves, which eliminate excess through by excretion. Mangroves are remarkable for the richness of their root systems. The genera *Laguncularia, Avicennia, Sonneratia* and *Conocarpus* have pneumatophores*; *Rhizophora* species have adventitious and aerial roots. The root system serves not only for anchorage and nutrition, but also for system respiration, and differs depending on environmental conditions (Tomlinson, 2016; Agraz Hernández et al, 2006).

The distribution of the different physiognomic types of mangrove and the different species that make them up is mainly conditioned by (i) water salinity, especially interstitial salinity, and (ii) hydro-periodicity in intertidal zones, controlled by tidal cycles and micro-topography. Mangroves, which are located in the tidal range, adapt to the tidal cycle, the periodicity of flooding and their exposure to air. This aspect is crucial for their distribution, zonation and ecological succession (Hogarth, 2015; Agraz Hernández et al, 2011).

The zonation of mangroves can be seen as a mosaic that varies according to the physical, biological and chemical interactions between plant, substrate and water in a given area. Each mangrove species tolerates a certain range of salinity. The distribution of species therefore follows a gradient of salinity and frequency of immersion by the tides, from the sea to inner lands. In addition, a few centimetres of topographical difference will determine the frequency of each species and, by changing scale, their distribution over a given area (estuary, delta, etc.).

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Most mangrove propagules are great travellers: for weeks or even months, they float and disperse, carried along by tidal currents, and are able to colonise distant coastlines that are favourable to their establishment, sometimes several hundred kilometres from their place of origin.

Mangroves are highly dynamic ecosystems, colonising new sedimentary zones or retreating rapidly following natural events (sediment displacement, typhoons, tsunamis) or human activities that lead directly or indirectly to their degradation. They are also resilient and capable of regenerating after such disturbances, but sometimes lose their structure and function.

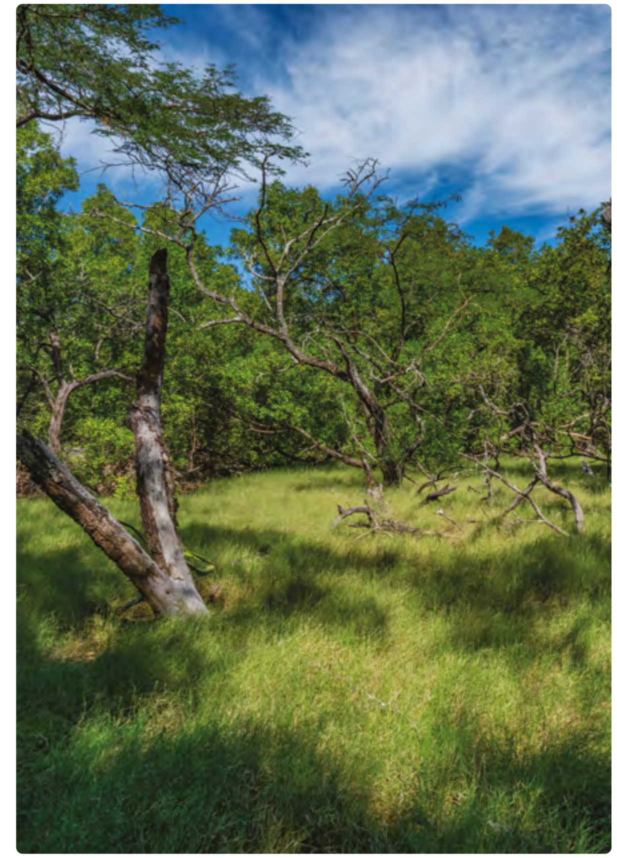
If we take into account the major biogeographical regions, the diversity of hydrosystems (deltas, estuaries, bays, lagoons), the diversity of tidal ranges and the diversity of modes of governance, we realise that each mangrove is unique.

TO FIND OUT MORE

Mangrove**: **a forest in the sea. Edited by François Fromard, Emma Michaud, Martine Hossaert-McKey, Institute of Ecology (INEE) of the CNRS.

Mangroves: educational pack. Océanopolis (https://initiative-mangroves-ffem.com/wpcontent/uploads/2020/03/DOSSIER-MANGROVESCALAMEO.pdf)

Pneumatophores: aerial root outgrowth enabling tree to breathe



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TYPES OF MANGROVES
(following Lugo & Snedaker, 1974)

Fluvial mangrove (riparian), located on the banks of rivers and in deltaic channels. It is the most developed because of its location in optimal environmental conditions. The salinity is estuarine and nutrients are abundant.

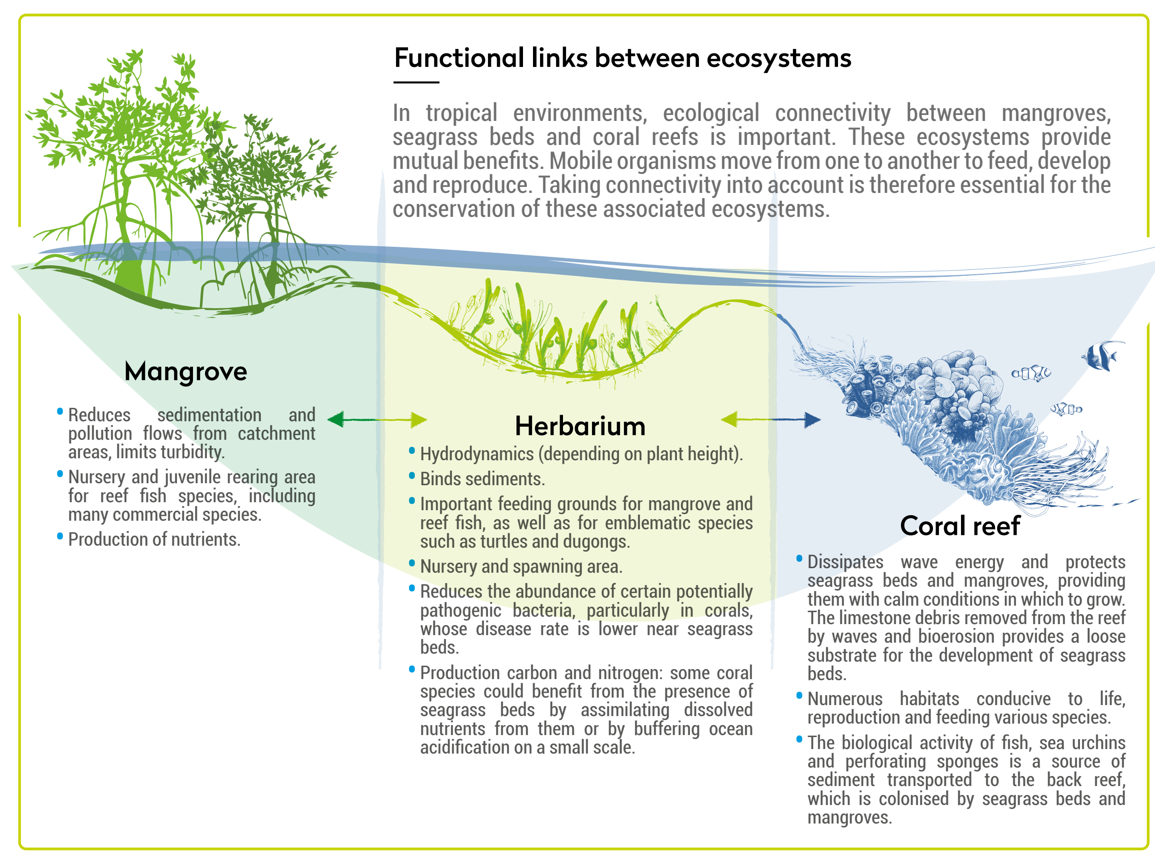
Coastal mangrove, located on the shores of lagoons, estuaries and bays. The extent of the forest varies according to geomorphology and hydrology.

Basin mangrove, located behind coastal or river mangroves, it is periodically flooded with less frequency.

Submerged mangrove, generally monospecific of the genus *Rhizophora sp.*, it is constantly affected by the ebb and flow of the tides. It corresponds to islands in tidal channels (estuaries) and coastal lagoons.

Shrub mangrove, characterised by weak structural development, due to its location in areas of intense evaporation in conditions of hypersaline sediments.

Figure 2. Close links between ecosystems (source: Ifrecor 2020)



.3

BIOLOGICAL AND CULTURAL DIVERSITIES, SERVICES PROVIDED

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Mangrove forests are among the world's most productive ecosystems and contain an exceptional biological diversity. Vital for millions of people and for the planet, they provide coastal communities with means of subsistence. To some extent, they protect coastlines against natural disasters and store carbon, thereby mitigating the impacts of climate change.

In addition to their diversity in terms of flora, mangroves and their associated environments constitute a wide range of habitats. They shelter, feed and protect many species: crustaceans, molluscs, fish and birds for the most common, yet also mammals (tigers, monkeys, etc.), snakes, turtles, crocodiles, etc. They are areas of nurseries and growth for juveniles of many species, including coral reef and seagrass species that are often found in close proximity.

They are also an essential place to live for more than 120 million people, who live there permanently or temporarily, following the rhythm of the tides and depending on their resources (wood, fish and shellfish, salt, honey) for their livelihood. The multiplicity of values and uses associated with mangroves underpins their adaptation to environmental and social change.

The socio-cultural dimension is also essential: they are inhabited, used and controlled through customary rules by the local populations, and often have a sacred dimension (appendices and see also chapter 4 on mangrove development).

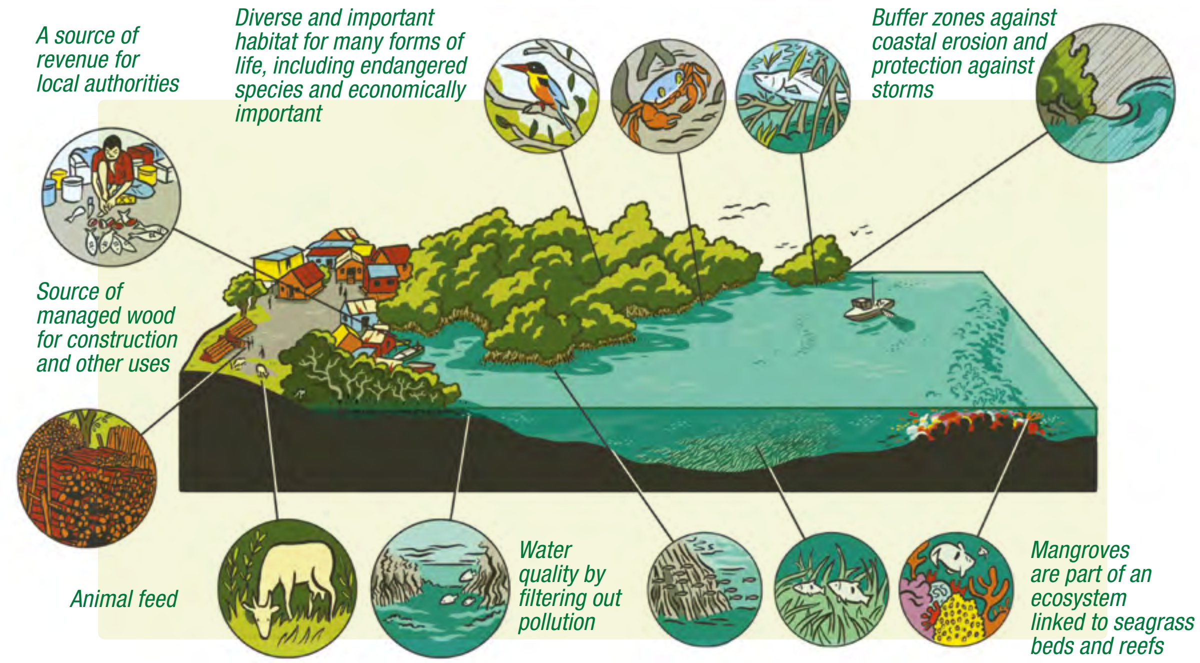

Figure 3. The importance of mangroves for people and nature (source Scriberia in Del Ben, 2022)

They also play a particularly important role for the most vulnerable populations, such as women, who often have no access to land and are therefore totally dependent on mangroves.

Research in Mayotte has shown that waves energy is mitigated by more than 90% in vegetated areas, compared with 35% in areas devoid of mangroves (Jeanson et al, 2018)

THE IMPORTANCE OF MANGROVES IN MITIGATING THE EFFECTS OF CLIMATE CHANGE

MANGROVE RESTORATION AND BLUE CARBON (COMTE ET AL, 2023)

"Many public and private organisations in the North invest in blue carbon projects, mainly in the South, to offset their greenhouse gas emissions. These projects are designed by "project developers" in accordance with international standards. These projects can deliver carbon credits after an assessment of the quantity of carbon stored or emissions avoided.

However, this assessment is often based on methods and inventories that lack rigour and reliability. The valuation of these credits on the voluntary carbon market is opaque and highly variable, ranging from $6 to $30 per tonne of CO2eq. These credits are then sold on international markets and certified by third parties. In short, blue carbon markets involve a variety of intermediaries from the Global North - investors, project developers, auditors and certifiers - with a financial and sometimes short-term vision. These stakeholders can be far removed from the needs, complexity and long-term resilience of blue carbon ecosystems, as well as the Indigenous Peoples and local communities associated with them".

These investments lead to financing restoration projects which, all too often, are not based on indepth socio-ecological diagnoses and are not co-constructed with local communities, often leading to failure.

Almost half of human carbon dioxide emissions are captured by natural environments, significantly reducing global warming.

Coastal wetlands, mangroves, salt marshes and seagrass beds are the ecosystems that store the most carbon (blue carbon). They only cover 0.1% of our planet's surface, mangroves store up to 10 times more carbon per hectare than terrestrial forests, making them essential in the fight against climate change.

While mangroves, like forests, produce plant matter that fixes carbon, the key difference is that bacteria decompose the litter very slowly, due to the presence of saltwater and low level of oxygen. Soils gradually accumulate large amounts of plant fragments, becoming highly carbon-rich.

The destruction of these ecosystems not only halts carbon storage, but also releases into the atmosphere the carbon that had been incorporated into the soil.

FAO, 2023

Mangroves are among the most carbon-rich ecosystems on the planet. They store around 6.23 gigatons of carbon worldwide in their biomass and soils, where it will remain for centuries if these soils are not disturbed (Leal and Spalding, eds., 2022).

IFREMER (POLSENAERE P., 2020)

We know that salt marshes, mangroves and seagrass beds store carbon 10 to 20 times more than temperate or boreal forests. When forests sequester less than 10 g of CO_2 per square metre per year, coastal ecosystems retain 100 to 200 g. According to figures from the International Union for Conservation of Nature (IUCN), we know for example that every year, almost 2% of mangroves disappear, contributing to the release of 120 million tons of CO_2 into the atmosphere.

https://www.fondationbiodiversite.fr/sciencedurable-les-ecosystemes-coasts-wellsof-blue-carbon/

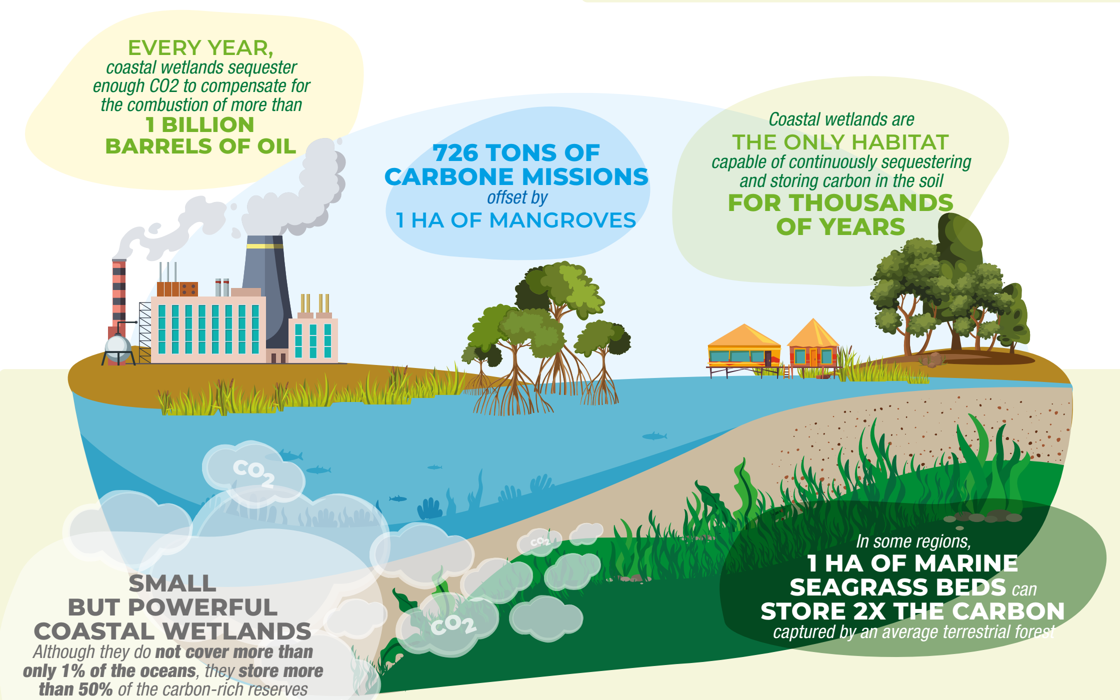

Figure 4: Importance of coastal blue carbon (following The Nature Conservancy Oceanwealth.org)

.4 SITUATION OF MANGROVES IN THE WORLD

The surface of mangroves in the world has decreased from 19 million hectares in 1980 (FAO, 2007) to 14.8 million ha in 2020 (FAO, 2023), a loss of more than 20%, and although the figures are often uncertain and the situation varies from region to region, the overall decline in mangroves is clear. If we distinguish between periods, the rate of net loss has slowed considerably (FAO, 2007 and 2023): approximately 185,000 ha were lost each year in the 1980s, 118,500 in 1990-2000; this figure fell to 18,200 ha/year in 2000-2010 and 10,200 ha/year in 2010-2020.

Net losses have decreased and are increasingly offset by natural expansion or restoration (393,000 ha gained between 2000 and 2020 according to the FAO, 82% of which is natural expansion and attributable to restoration, for a loss of 677 000 ha on the same period, which amounts to a net loss of 284 000 ha. The origins of this mangrove retreat in the world are: "the development of aquaculture (26.7% of the total loss) and natural retreat, often linked to climatic hazards (25.9%). Conversion to oil palm and rice cultivation accounted for 16.6% of mangrove loss and conversion to other forms of agriculture and undefined uses" (FAO, 2023).

"The dynamic nature of mangroves is also highlighted to by independent research on the global evolution of tidal wetlands, which has examined changes over time in mangroves, mudflats and tidal marshes. In many cases, apparent losses in one particular ecosystem are actually transitions to another ecosystem." Global Mangrove Alliance (GMA), 2023.

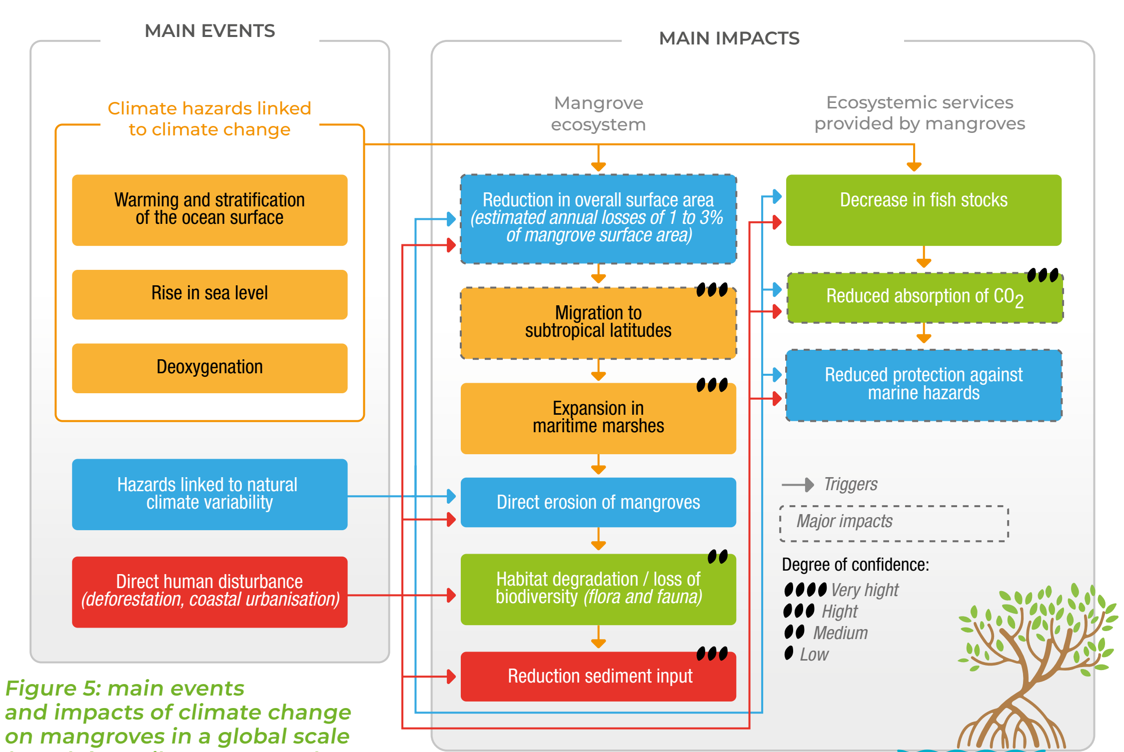

Figure 5: main events and impacts of climate change on mangroves in a global scale (Fauché Brasil, 2020 - Based on IPCC 2020 data)

CARBON STOCK IN THE MANGROVE FORESTS OF OUIDAH (BENIN), CUAJINIQUIL AND TERRABA SIERPE (COSTA RICA)

Chavez Barrera, 2024 and Chavez Barrera et al, in press

The carbon stock varies significantly according to the state of the forest, with an average of 312.096 Mg C/ha in forests in good condition and 32.178 Mg C/ha in degraded forests (undergoing restoration) in the areas studied in Costa Rica and Benin.

- In Benin, a significantly higher carbon stock was observed in the forests in good condition(118.088 ± 22.314 Mg C/ha), compared with the degraded site, with a difference of 72.551%. This disparity is attributed to the invasion of Paspalum vaginatum in certain areas, which suffer from poor water quality and fragmentation. In both sites, the soil carbon stock is considerably higher (between 85.606% and 99.303%) than the carbon fixed in the plant biomass.
- In the wetland area of Térraba Sierpe in the Province of Puntarenas, the mature forest showed the highest carbon stock (312,096 Mg C/ha). Tree biomass accounted for the largest portion of carbon stored, at 67.036%, compared with soil organic carbon. In comparison, mangrove areas colonised by Acrostichum aureum showed a 31.44% reduction in carbon stock.
- In Cuajiniquil, Costa Rica, the reference mangrove had a carbon stock of 192.96 Mg C/ha, which was 84.146% higher than that of the degraded mangrove due to changes in land use, topographical elevation and high salinity caused by salt production, an activity that ceased 60 years ago.

Measuring soil carbon in Costa Rica

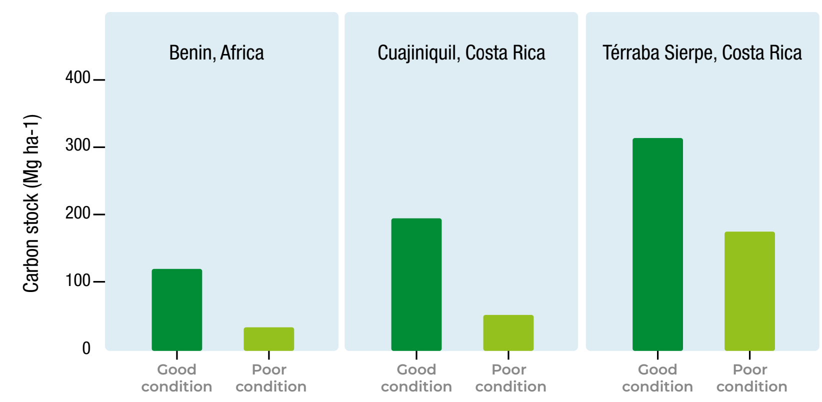

Figure 6. Average carbon stocks in mangroves in good condition compared with degraded areas in Benin, Africa, and the United States. Cuajiniquil and Terraba Sierpe, Costa Rica. The calculation is based on the sum of the carbon in the above-ground and below-ground biomass, as well as soil organic carbon measured in 50 cm deep soil cores. Edited from Chavez Barrera (2024) and Chavez Barrera et al. (in press).

.5 THE RESTORATION OF MANGROVES

Faced with this situation, and in order to limit losses, the practice of restoring mangroves has become widespread, leading to a variety of projects that have multiplied over the last few decades: restoration projects and/or projects dedicated to limiting pressure by creating marine protected areas, banning uses and "raising awareness" among local people of the importance of conserving mangroves for many benefits they provide. These projects have met with varying degrees of success, both from the point of view of biodiversity and the well-being of local communities, despite the many existing guides, which are difficult, if not impossible, to implement on the ground because they do not consider the specific nature of local contexts and the real involvement of local stakeholders.

In terms of active restoration, Macera's (2024) bibliographical work on the success of restoration projects (study of 198 restoration sites around the world) shows that two types of method are used: replanting, which accounts for 87% of the bibliography studied, and rehabilitation, which aims to support the natural regeneration of the damaged area, representing 13% of the works studied.

RESILIENT ECOSYSTEMS

While mangrove ecosystems are currently experiencing a loss on a global scale (0.04% per year), the same is not always true on a local scale. The Senegalese mangrove has been increasing significantly since the 1990s. A study (Andrieu et al, 2020), based on a spatial analysis of mangrove gains (3,600 ha between 2000 and 2015) using remote sensing data and botanical field data (47 sites), showed that, following natural mortality in the 1980s and 1990s, spontaneous regeneration accounted for 96% of the expansion, with the remaining 4% being the result of reforestation. This study thus reveals that the mangrove ecosystem has shown resilience in the face of variations in rainfall and salinity, providing a better understanding of the potential impacts of climate change on mangroves and their ability to recover from drought-induced mortality.

This work, like that of Del Ben (2022), shows that, although rare projects are successful, replanting is more often than not doomed to failure: more than a quarter of the reported projects indicate that propagules' survival rates between 0 to 10% only. In addition to natural events (typhoons and other storms) and human disturbance, poor choices regarding restoration protocols are often to blame: poor location of the replanting site, species replanted, unsuitable age of propagules and site given the tidal immersion conditions.

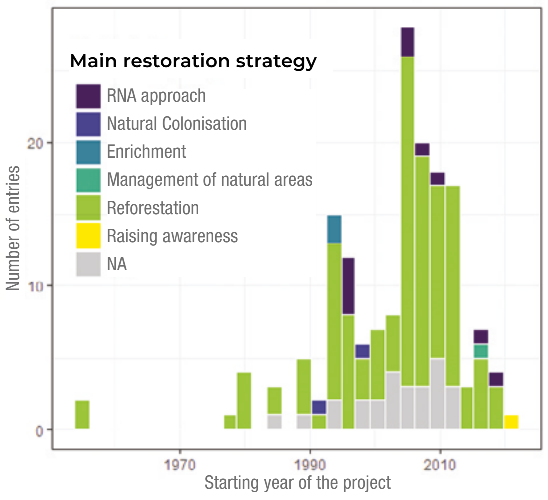

Figure 7. Main restoration strategies according to the literature review (Del Ben, 2022)

Insufficient knowledge and information on the functionality of mangroves can lead to the inability to eliminate stress factors from the sites to be rehabilitated. Monitoring of plantations is inadequate, rare or non-existent. Communities and other stakeholders are not sufficiently involved.

In projects that are often more recent, rehabilitation aims to encourage natural recolonisation by restoring the hydrology and topography of the mangrove. This rehabilitation is often accompanied by replanting to encourage faster recovery. It takes around 3 to 5 years to see the positive effects of a an ecosystemic rehabilitation.

However, projects generally last less than 5 years and there is no long-term monitoring after the end of the project. Information on the success of rehabilitation projects is therefore scarce and the results less well documented, but some experiments in Mexico, Costa Rica (Agraz Hernàndez), India (Gosh et al., 2020) and Thailand (Macera et al., 2023), for example, are successful (see box on page 18).

DEFINITIONS AND CONCEPTS (MACERA, 2024)

Restoration: the action of returning an ecosystem to its original state, as far as possible, or to its historical or natural evolutionary trajectory (if known).

Rehabilitation: the re-establishment of ecological conditions and processes in a degraded ecosystem or its habitat, in order to initiate a trajectory towards the re-establishment of a state close to the previous state (recognising that complete restoration may be impossible in short or medium term). Rehabilitation can take various forms: modulating the physico-chemical parameters of the environment, reducing or even halting anthropic pressures by various means, raising awareness among local communities and other stakeholders of the need for sustainable use of the environment, or taking measures to manage the environment (marine protected areas).

Reforestation: renewal of forest cover following the loss of forested areas, whether as a result of habitat degradation by man (e.g. forest extraction, land use change) or by natural processes.

Afforestation: planting trees to repopulate an area that has long been deforested, or that has never been forested (greenfacts.org).

Replanting: planting propagules or seedlings from another area in order to artificially increase the plant cover, which may or may not be a former mangrove (afforestation).

Natural recovery: process of restoring an ecosystem to its previous state without human intervention.

Photos of restoration work in Cuajiniquil (Costa Rica) ©Google Earth

.6 ENVIRONMENTAL POLICY AND RESTORATION FRAMEWORK

Since the 1st international convention on environment, signed in Ramsar in 1971 and dedicated to the recognition of wetlands as being of (international importance), mangroves have been the subject of numerous agreements and schemes aimed at conserving them, including Ramsar, the Convention Biological Diversity (CBD), CITES, CIMES, Unesco, Regional Seas...

INTERNATIONAL FRAMEWORK

The diversity of international frameworks and the diversity of governance models lead to a diversity of restoration methods.

- **The Convention on Biological Diversity (CBD)** is a legally binding international treaty with three main objectives:
  - conservation of biological diversity,
  - the sustainable use of biological diversity,
  - and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources.
- The mission of the **Ramsar Convention** is "The conservation and wise use of wetlands through local, regional and national actions and international cooperation, as a contribution to the wordwide realization of sustainable development. Several resolutions about mangroves have been adopted by the Convention on Wetlands, such as: in 2018 "Promoting the conservation, restoration and sustainable management of blue carbon coastal ecosystems" or in 2022 "Proposal for the establishment of an International Mangrove Centre (a Ramsar Regional Initiative)".
- **The United Nations Decade on Ecosystem Restoration 2021-2030** focuses on balancing ecological, social and development priorities in landscapes where different forms of land use interact, with the aim of fostering long term resilience.

NATIONAL FRAMEWORK

The different countries govern their mangroves in very different ways. On the one hand, not all countries have the same levels of commitment to protecting natural environments or the same strategies for achieving this. In addition, mangroves, by virtue of their position at the interface between land and sea, are placed under the authority of very different bodies (ministries of the sea, fisheries, forests, wildlife) and are too rarely the subject of dedicated cross-cutting bodies, implementing integrated management coastal zones (ICZM). Added to this are games between public and private players, between national authorities and NGOs, etc.

Thus, considering a restoration project in a country with top-down state management by a single body (forestry authority, for example) is very different from considering it in a country with an influential galaxy NGOs and a state that has set up an ICZM.

However, it is worth noting the implementation of subregional programmes such as the PRCM and the RAMPAO network in West Africa, which cover the mangrove regions of seven countries (Mauritania, Senegal, Gambia, Guinea Bissau, Rep of Guinea, Sierra Leone and Cape Verde), making it possible to coordinate conservation actions at ad hoc scales.

THE EXAMPLE OF KENYA: TOWARDS PARTICIPATORY FOREST MANAGEMENT

Forest management in Kenya has evolved over more than 130 years.

At the end of the 19th century, the use of forests and natural resources was controlled by a council of elders applying a system of traditional rules with no formal policy (Mbuvi 2021).

Then, around 1900, the management and control of resource exploitation passed into the hands of the British colonial government. After 1950, the colonial government introduced the first m anagement m easures for the mangroves of the Lamu archipelago, the largest in the country (66% of Kenya's mangroves). The exploitation of mangroves was based on a quota system (Okello, 2021). It was not until independence, with the establishment of the Kenya Forest Service and the repeal of various forest conservation and management laws since the 2000s supporting decentralisation and the transfer of forest management, that benefits from natural resources and local peoples' participation were guaranteed.

In Kenya, the participation of communities and other stakeholders in forest management is implemented through Participatory Forest Management (PFM). This new approach could lead to better management of resources, as it encourages local participation, ownership and participation.

Kenya now has more than 250 CFAs. Their role includes the protection, conservation and management of public forests, including mangrove forests. However, there are currently gaps in community's involvement in the creation and implementation of mangrove management plans and policies for the restoration and protection of these forests (Ahmed et al 2023).

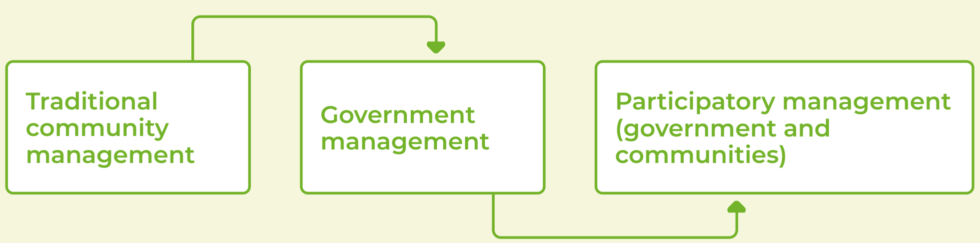

Figure 8. Evolution of forest management in Kenya. Adapted from Mbuvi 2021.

THE EXAMPLE OF MEXICO

In Mexico, restoration programmes are governed by a comprehensive legal framework that includes both general provisions and specific instruments for ecosystem restoration. The protection of mangroves, in particular, is supported by various laws and regulations:

NOM-022 is an official Mexican regulation that establishes technical criteria for protecting, preserving and restoring mangroves in Mexico, with the aim of preserving their biodiversity and ecological balance. It defines measures to prevent their degradation and destruction, as well as to promote their restoration in case of negative impacts. It also includes assessment, monitoring, community participation and environmental education actions.

Ley General del Equilibrio Ecológico y la Protección al Ambiente (LGEEPA): this law, one of the main pieces of legislation, sets out the general guidelines for environmental protection in Mexico. In its article 27, it establishes the obligation to protect and restore mangroves, as well as preserving biodiversity and ecosystems.

General law on the sustainable development of forests: this law governs forestry activities and contains specific provisions for the protection and sustainable management of forest resources and associated ecosystems, such as mangroves.

General law on wild species: it aims to protect and conserve wild species and their habitats, including mangroves. It establishes measures for the restoration and conservation of terrestrial and aquatic ecosystems, as well as for the management of threatened species that depend on mangroves.

National Water Law: this law governs the use and conservation of water in Mexico, including provisions for the protection of bodies of water such as lagoons and estuaries associated with mangroves, and for their restoration in case of degradation or pollution.

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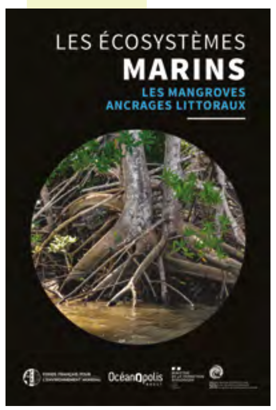
WHY A NEW GUIDE TO MANGROVE RESTORATION?



The many restoration failures around the world can be explained by a lack of global knowledge of this complex ecosystem, the lack of a proper initial diagnosis of the targeted sites and the choice of inappropriate restoration methods adapted to the context. However, many guides exist. The main recent guides are listed in the appendices (References), with details of the subjects they cover (see also the mangrove initiative website https://initiative- mangroves-ffem.com/veillepublications)

With the exception of the guide to tropical wetlands, which is aimed at managers in the French overseas territories, all the other documents are either in English or Spanish. All of them, in varying degrees of detail, set out the various stages required for a successful project. The Mangrove Alliance report (2023) devotes a chapter to blue carbon issues, which are increasingly emerging, given the importance of this ecosystem in storing carbon to mitigate climate change, offset greenhouse gases (GHGs) and in the carbon quota market framework. Finally, the latest Mangrove Alliance report looks at how local knowledge can be taken into account in mangrove conservation and management (GMA, 2023).

This guide is intended for practitioners in Frenchspeaking countries (particularly West Africa and the Indian Ocean). It is based on the experience of mangrove restoration projects financed by the FFEM between 2017 and 2024 in Costa Rica, Benin, West Africa and the Philippines (table 2).

PROJECT	OBJECTIVES	GEOGRAPHY	PREVISION DATES BEGINNING/END	RELEVANT SURFACE
Costa-Rica/ Benin	Restoring, conserving and sustainably managing mangroves to combat global warming	Costa Rica and Benin	01/08/2017 31/08/2024	CR: 58 ha on 3 sites Benin: 30 ha
Philippines	Strengthening coastal resilience disaster risk reduction and climate change adaptation in small island territories by integrating green and grey infrastructures	Municipality of Concepción	2015-2019	20 ha on 5 sites
West	Monitoring coastal risks and soft solutions in Benin, Senegal and Togo	Benin mouth of the Mono river	01/11/2018 31/12/2022	

Table 1. FFEM mangrove restoration projects

Mangroves © DR

Beyond the technical aspects of mangrove rehabilitation, this guide emphasises the importance of developing mangroves for the benefit of local populations, whether this involves developing natural resources (wood, molluscs, shellfish, honey, .) or intangible, natural and cultural heritage, in order to ensure the communities' appropriation and commitment to rehabilitation and protection.

As recommended by the Community Based Ecological Mangrove Restoration (CBEMR) method, it also stresses the importance of co-constructing all stages of the process (objectives, diagnosis, implementation, evaluation) with mangrove stakeholders for successful restorations, i.e. ensuring co-benefits between the various sustainable development objectives (mitigating climate change, preserving biological diversity, reducing inequalities, reducing poverty, etc.).

FLUCTUATING VALUES

Estimates of mangroves surface area, the number of true and associated mangroves species, CO2 storage and blue carbon vary widely in the literature and are often imprecise. Figures are frequently reproduced from one report to another. In this document, we rely on data from the latest FAO report (2023), but these figures should be interpreted with caution.

While mapping mangroves at a given date, and scale is now a task mastered by many data producers, ensuring comparability between two dates is more challenging, and doing so consistently at the global scale is even more complex. Major efforts have been made to produce large global datasets; however, although such datasets are broadly valid, they are often inaccurate in exceptional or context-specific cases.

For example, inverse estuaries in Senegal are hydrologically and ecologically atypical; Casamance (and the regions further south) are also atypical, with a landscape mosaic of mangrove forests and mangrove rice fields. Global Mangrove Watch used to produce most of the statistics in the latest FAO report is therefore particularly inaccurate for these two deltas, which are atypical on a global scale, and the errors in the data for Casamance probably have a major impact on the statistics for West and Central Africa.

It is therefore advisable to consult both these reports and (peer-reviewed) publications mapping the area in question, compare the data and take the time to have a scientific team produce an analysis if the figures diverge too widely.

2

CHAPTER 2

HOW TO PLAN A RESTORATION PROJECT?

Authors: Claudia AGRAZ HERNANDEZ, Julien ANDRIEU and Juliana PROSPERI

.1

A GLOBAL PERSPECTIVE ON MANGROVES AT THE SCALE OF THE SITE TO BE RESTORED

The question of the interest and feasibility of mangrove restoration arises at different scales; spatial and temporal, at which the phenomena is observed being of major importance.

On the scale of a country or region, it is interesting for decision-makers and sponsors to have an overall view of the status of mangroves and degraded areas requiring restoration, and thus avoid senseless projects. In countries where mangroves are well conserved on a national scale, degraded areas may exist locally. In countries where mangroves are disappearing through conversion to shrimp farms, firewood collection or other activities, it is still possible to observe an effective protected area that maintains mangroves, or even restore them. It is therefore interesting to examine the question of sites on several scales.

On a national scale, we will look at the main features of the country's mangroves: the distribution and surface area of mangrove forests, the types of mangroves t h a t exist (coastal, estuary, river mangroves, etc.), structural characteristics, the way zones are spread over, the state of these mangroves in the country a n d the surface area increasing or decreasing in these areas?

What is the legal status of these mangroves, and what about land tenure? Are they protected? Partly? Not at all?... A literature and cartographic review of coastal areas will provide some answers to these questions; Global Mangrove Watch also provides an interesting tool for country-level analysis, which of all past and current restoration projects is useful at this scale.

On the basis of this global vision, we can then identify a set of potential sites to be examined on an even finer scale, depending on the ecological issues, hydrosedimentary dynamics, degradation factors and socioeconomic issues, in particular concerning the needs and expectations of local communities and the history of past restoration work. These potential sites could then be the subject of more detailed investigations: have they already benefited from a diagnosis, have they undergone recent changes, what are the causes and factors of these changes? Which communities are in demand?

Once the area of intervention has been selected, restoration must be based on a sound knowledge of the environmental and socio-economic situation. The sequence of activities to be planned is as follows:

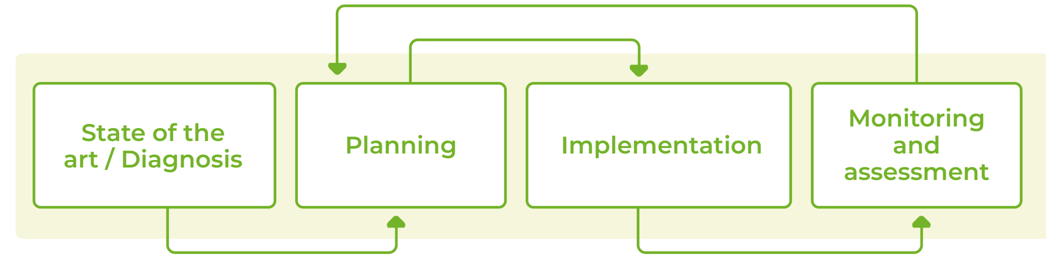


Figure 9.
Sequence of activities for the mangrove restoration

Environmental and social diagnosis

- **Understand the relationship between communities and the mangrove** (activities, uses, values), their expectations and their needs, to set objectives and co-construct a restoration programme that is understood and accepted by the population. Their participation is essential to the success of any restoration initiative;
- **Develop a spatio-temporal analysis of changes in environmental conditions** that may have affected the structure and function of the ecosystem, due to natural events (e.g. hurricanes, typhoons) and/or anthropogenic impacts (logging, aquaculture, etc.), or invasions, such as that of the defoliator caterpillar (Hyblaea puera) in Madagascar. Remote sensing will be a very valuable tool at this stage and beyond, and we will also be drawing from the knowledge of the communities involved;
- **Study the feasibility of restoration, based on the defined objectives,** by analysing the current environmental conditions of the ecosystem to be restored. These conditions should be assessed and compared with those of a reference forest in order to determine the extent and intensity of changes in hydrological functioning and in the physicochemical parameters of soil and water. This ecological diagnosis makes it possible to understand the state of the mangrove, identify the causes of degradation and plan appropriate restoration.

Planning the restoration

The diagnosis enables restoration techniques and methods to be defined and adapted to the specific situation of each site to be restored. Training local communities enables them to play an active part in the restoration.

Implementing restoration

Application of restoration techniques and methods involving the local population.

Monitoring and evaluation

Ongoing monitoring, beyond the life of the project, will enable to assess restoration success and the level of ecosystem recovery, and to adapt the strategy accordingly. This involves continuous monitoring of the physicochemical parameters of soil and interstitial water at restored and reference sites, to determine the extent of environmental recovery, as well as monitoring the morphophysiological variables of vegetation established through reforestation and/or natural regeneration.

AND AT THE END OF THE DIAGNOSIS, SOMETIMES YOU MUST LEARN TO SAY NO!

The results of the diagnosis are used to determine the feasibility of restoration, and to decide whether or not to continue with restoration activities. If feasibility is low, there is still time to choose another site, change the method or change objective.

When considering a restoration project, many questions arise. One is not necessarily familiar with local conditions, other projects or the wishes of the local community regarding their environment. If there are too many red flags in the diagnosis, if the causes of degradation cannot be eliminated, you have to accept the idea of giving up. There are other methods and other places that fit restoration better!

.2 TAKING INTO CONSIDERATION LOCAL KNOWLEDGE AND COMMUNITIES EXPECTATIONS

While the choice of sites to restore is often made by NGOs, funded by donors, sponsored by local or national government departments, a crucial aspect that is often overlooked is the involvement of local communities. Any conservation or restoration effort in a given area will be more successful if it answers a need from local communities and has the support and understanding of the people living in or near this ecosystem. The choice of restoration will therefore have to be based on the needs and expectations expressed by the communities.

Fishing among mangroves in the Saloum delta, Senegal © Cormier-Salem, IRD

2.1 I CONSIDERATION OF LOCAL KNOWLEDGE

Western scientific knowledge is not the only knowledge that can be mobilised to diagnose an environment (for example, to diagnose the potential restoration of a mangrove). Local communities and indigenous populations possess invaluable local knowledge that can be used to successfully carry out an intervention in the environment in which they interact. To go a step further, a large proportion of mangrove restoration work is carried out by external parties (international sponsors, government and regional intermediaries potentially detached from the reality of local communities, foreign or urban consultancies) who use concepts that are different from those used by local communities (and not just for linguistic reasons).

- **Ask the local community without preconceived ideas** about their knowledge of mangroves, the history of the site and its evolution, and their practices. While many environments have been degraded by human activities in the last few decades, this does not mean that the site being diagnosed has necessarily followed this trajectory. However, in the time available for a diagnosis, you will have few tools with which to go back a long way in time and find out about the previous state of the mangrove as well as the factors behind these changes. Asking local communities could provide crucial information.
- Allow time for **debate** whenever **points** of views of external scientific players and those of local communities diverge. Also, don't rush into convincing. Even if scientific tools are sometimes more robust than local knowledge, there is a risk that unresolved differences may reverberate throughout the project if this issue is not openly discussed. Be tactful and show respect when challenging people's knowledge. Who knows, you may also reconsider your own understanding of the site.
- Entrust local communities with all the expertise that can be delegated to them. A **continuum of tasks** is an ideal objective. If certain technical tasks will be carried out solely by external scientists, others may be carried out jointly, and some operations may be completely delegated.
- Think about the choices you make (or those that will result from your diagnosis) in terms of **environmental justice for all categories**, especially the most marginalised who are less likely to express themselves and therefore be excluded by the choices made with the more influential categories. Ask yourself about power relations between men and women, between generations, the existence of caste systems, discrimination on the basis of origin (indigenous people VS migrants), ethnicity, skin colour, etc. If the local community is dominated by one category, look for a way to question the other categories, not to result in unfair choices. It is often the category dependent on mangroves.
- Provide full access to data to local communities, from the earliest stages of diagnosis. Respect the Nagoya Protocol. They are the holders of important knowledge and deserve access to your knowledge too.

> Many respondents tend to provide answers they believe are expected. If you are associated with environmental protection, you run the risk of eliciting a biased narrative that portrays the past negatively and overstates future intentions. Take the time go beyond these initial statements.

2.2 I CONSIDERATION OF COMMUNITIES NEEDS AND EXPECTATIONS

The mangroves we are seeking to restore are socio-ecological systems. The society that lives around its mangroves (that lives off its mangroves) and the ecosystems (the mangrove forest, the channels, the mudflats) are closely linked by a complex web of interactions.

The state of this system, at the time when restoration is considered, is the result of these interactions (rarely of a few events completely external to the socio-ecological system). So, if restoration is considered, this means that at least one of these society-mangrove interactions is affected, and that restoration will therefore also have impact on the local communities.

Environmental governance is globalised. The objectives set by the main environmental stakeholders stem from this governance. Restoration projects re-mobilise them locally. If local communities' expectations regarding this precise interaction between society and mangroves are taken into account too late, or that it is not even considered (decision-makers may, for example, pursue a policy focused solely on ecological objectives), the local community will very likely not support the project. It then has two options: to adopt a coercive governance that changes practices in the name of ecological governance, or to review this governance in the light of local communities' expectations.

Care must be taken not to confuse "raising awareness of the expected benefits of the planned restoration" with "engaging in dialogue with local communities about their expectations". While the former is regularly and appropriately carried out, the latter is only rarely implemented. More concerning for the success of restoration, it is sometimes assumed that the former is sufficient to replace the latter ("there's no point in asking them what kind of relationship they want with the mangrove; it is better to explain why they should not touch it").

Very early on in the project, we recommend that social sciences specialists carry out a survey of communities expectations in terms of mangrove governance, to design an inclusive project from its earliest stage that not only restores the mangroves but also allows local people to decide what links them to the mangroves.

THE NEED TO TAKE ACCOUNT OF THE LOCAL CONTEXT: THE EXAMPLE OF A PROJECT IN THE PHILIPPINES

The French Facility for Global Environment has financed a project to strengthen the resilience of coastal populations in a region of the Philippines frequently affected by meteorological hazards (municipality of Concepción, province of Iloilo). To this end, an exploratory project aimed to test a combination of "grey" infrastructure (breakwaters, sediment traps) and "green" infrastructure (mangrove reforestation) combined with projects offering additional sources of income. Fishermen often live on the seafront and park their boats opposite their homes after fishing. If a mangrove area is to protect housing, it must occupy the beachfront opposite the houses. However, on the one hand, a good ecological, hydrological and sediment diagnosis would have shown that this habitat is not optimal (waves and sandy substrate). On the other hand, a social analysis of the local population would have revealed that, while there was a strong desire for grey infrastructure compatible with boat parking, the planting of mangroves in front of fishermen's houses was not desired, or even wanted. As a result, many local residents continued to drive over the reforestation and park their boats opposite their homes as soon as the project was completed.

© J. Andrieu

An unwanted restoration for local populations should not be planned. Holding public meetings to remind people of the importance of mangroves is generally not enough to change a community's wishes regarding its practices and uses. This is all the more true in a context of diverse interests, "the local community" in the singular being made up of different categories with different opinions, actually, and different interests. It is therefore often appropriate to seek compromises between desires and reality, between what is necessary, feasible and acceptable.

- Since the restoration considered is seen as necessary by a number of stakeholders, it is becoming essential to co-build a diagnosis between all of them.
- Since the project must be feasible to succeed, it is important to identify the objective conditions required for intervention."Since a project must be acceptable, it must on the one hand meet the needs and desires of the communities and on the other hand not come up against any stumbling block (touching an economic issue, contradiction with a religious belief, etc.).
- Since a project must be socially acceptable, it should both address the needs and aspirations of local communities and avoid potential obstacles (such as economic constraints or conflicts, with religious beliefs).

This study phase on local communities will also inform members of the role they can play in participating in the diagnosis and in implementing the restoration.

2.3 I COMMITMENT TO COMMUNITIES INVOLVEMENT

Beyond community acceptance of the restoration initiative and their contribution to environmental knowledge, restoration efforts cannot be implemented without their active involvement. Activities such as digging canals and establishing nurseries require substantial labor and can provide significant income for participants and their families within the framework of the project.

2.3 CONTRIBUTION OF REMOTE SENSING

Satellite imagery can add the following elements to the diagnoses of a mangrove, for which restoration is considered:

- A map of the current extent of the mangrove and its evolution on time;
- Species zonation patterns;
- Information on the causes of degradation, pollution and sediment dynamics.

A QUICK REMINDER ON IMAGE TYPES AND THEIR CHARACTERISTICS

Images can be taken from a drone, a plane or a satellite. They can be simple photographs or so-called multispectral measurements (we measure radiation in wavelengths other than visible colours to learn more). Many users attach great importance to spatial resolution (a sensor with a large number of detectors produces images with a high number of pixels). The higher the platform flies, the larger the ground area represented by each pixel. A high-quality camera mounted on a low-flying drone can capture a mangrove leaf with several thousand pixels (which is of limited use unless one is counting insects), whereas a mediumresolution satellite image has pixels measuring 30m on each side making it impossible to count individual mangrove seedlings or to determine how many are still alive one year after planting.

However, only the latter type of satellite imagery provide information on the state of plant cover in the mid-1980s. The images used to map past dynamics differ from those used to count seedlings. Some are freely available, while others require purchase (which we will not discuss here). Some images are easy to interpret visually, whereas others demand training and specialized software. Navigating these options is not straightforward!

© C. Agraz Hernández

3.1 | A MAP OF MANGROVE EXTENT TODAY

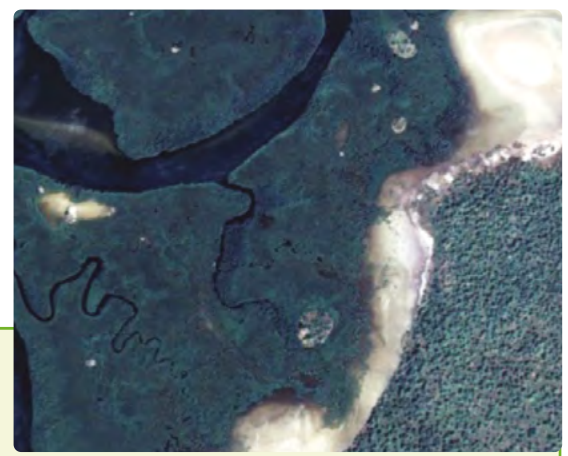
Knowing the exact distribution of mangroves today is an important first stage of the diagnosis. For most sites, it is a relatively simple operation. There are two (free) options available to the diagnostic operator:

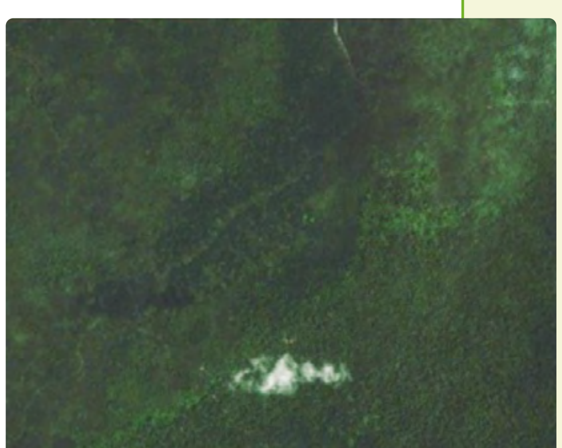
- Visual interpretation on Google Earth and manual digitalization in a geographic information system. Care must be taken to distinguish mangroves from other adjacent wetland and forest vegetation in humid climates (easier in dry climates). More rarely, there is a risk of confusion between low, open mangroves and other subtidal environments (seagrass beds) if the image is of poor quality (and at low tide).

ADVICE

Use two or three images that are close in time and whose weather and tides (or season) vary to ensure a robust interpretation.

- The other option is to analyse a multispectral satellite image. LANDSAT (30m) and Sentinel-2 (10m) images are free, and it takes a competent remote sensing operator a few hours to produce a mangrove map (see Andrieu and Mering, 2009, for a method that is fairly easy to apply).





Above on the left, a very open, very low mangrove in an arid, hyperhaline environment (Indus Delta, India). Mangroves can be distinguished from mudflats by their darker colour and granular texture.
Above on the right, a mangrove in a fairly dry climate (Saloum delta, Senegal). The mangrove (in the north-west) is slightly darker than the savannah (in the south-east). The texture here differs from that of the savannah with trees spaced far apart.
Below on the left, a mangrove in a very humid equatorial climate (Malaysia), where the mangrove (in the north-west) is difficult to distinguish from the mainland forest (in the south-east).

Illustration of the distinction of a mangrove on Google Earth in 3 or 4 different climates

The restoration project raises some important questions:

- How important is it to know the current extent of mangroves?
- Is a fine and very local cartography of the site enough?
- Do we need to know the extent of mangroves in the surrounding area?

Knowing the regional state of mangroves is important (see paragraph 1), as is the identification of reference sites and sites suitable for propagule collection. A good diagnosis will therefore combine these two scales.

3.2 | MAPPING CHANGES IN THE MANGROVE SWAMP GOING BACK SEVERAL DECADES AT BEST

A number of questions must guide the restoration project, and remote sensing can provide answers: Why is restoration necessary? What is degraded? Is it local or regional? How long has it been degraded for? Can we try to identify the factors behind the degradation?

A diachronic mapping of the mangrove over the last three or four decades using LANDSAT imagery over a small region (an area of several square kilometres) will show whether the mangrove at this scale has decreased or increased in area, remained stable with offsetting changes (roughly as many areas of gain as areas of loss) or been truly stable (with very few detectable changes).

Going further, this mapping can indicate where changes have taken place, which greatly helps to understand the factors behind them.

It is generally possible to determine the subsequent land use or land cover of areas where mangroves have disappeared, including open water due to erosion, enclosed flooded areas converted to shrimp ponds, mudflats resulting from natural or logging-related deforestation and built-up areas, etc. Progressive dynamics must also be analysed as they are more numerous than they may initially appear: it is possible to assess whether sedimentation promotes mangrove expansion, whether abandoned aquaculture sites undergo natural regeneration, whether restoration initiatives are effective, and whether natural processes, such as fluctuations in rainfall drive changes in mangrove extent. All these factors need to be considered in a proper diagnosis.

From the 1950s to the late of the 1960s, Senegal knew a markedly humid period, followed as soon in 1969 by a prolonged and severe drought. However, the mangrove were protected from wave action by the Sangomar sand spit . The following year, this barrier breached, and as a result, mangroves were exposed to wave conditions that were unfavorable to their stability. Part of the fine sediments was eroded while other sediments were redistributed to different areas.

By comparing the image on the right with the 2020 image, one can better understand some of the changes observed in the central part of the scene. It is also possible to observe between 1986 to 2020, a marked increase in vegetation density and greenness. Indeed, the dry period ended in 1998, and the return of relatively wet conditions has greatly favored mangrove recovery, as mangroves have the capacity to regenerate when environmental conditions improve.

Illustration of the dynamics of the Saloum mangrove and their interpretation for a restoration diagnosis ©Google Earth

3.3 | A VIEW OF SPECIES ZONING

Satellite imagery provides a simplified overview of species zonation, which can help refine and support the diagnosis. Image analysis is more complex and detailed mapping is not necessary for all restoration projects. However, it can be useful to verify, for example, whether the selected species is appropriate for the identified zonation pattern, by allowing observation at a broader spatial scale than that provided by botanical field surveys.

© M.M. Chavarría Díaz

3.4 | WHAT ELSE DO WE SEE USING IMAGING?

An overview of sedimentary dynamics

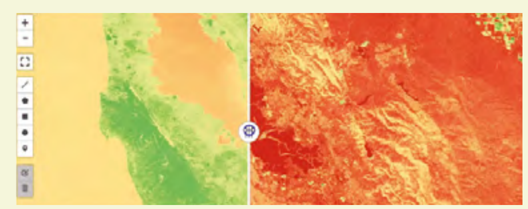
Satellite imagery is particularly useful for understanding sediment dynamics, especially in mangrove systems protected from wave action by dynamic sand spits. For a proper diagnosis, it is important to see whether water mouths open and close, whether it is regular (seasons) or irregular (cyclone). This information can help explain changes in the state of the mangrove that has been diagnosed.

An idea of the sources of pollution

©Google Earth

In the same spirit, it is important to take a close look at the surroundings of the mangrove that has been diagnosed, particularly upstream: is it possible to identify sources of pollution upstream of the mangrove? (sea farms, factories, large towns); are there any dams present that could cause hydro-ecological fragmentation? (separating fresh water upstream from sea water downstream is harmful to mangrove ecosystems).

NDVI IS A USEFUL TOOL, YET TRICKY TO USE



Mangroves, like all chlorophyllous plants, are very green and photosynthese intensively under the best conditions, but they are less green and slow down their photosynthesis under ecological stress. Multispectral satellite imagery makes it possible to measure, for the same pixel and with perfect simultaneity, the signal in the red band and in a wavelength called "near infrared", which is reflected by photosynthesising plants. These two measurements are combined to produce an index (NDVI Normalised Difference Vegetation Index) that can provide information about the health of the vegetation cover. We can therefore, in theory, compare NDVI values between two diagnosed mangrove areasor across two different time periods. However, not all variations in NDVI are meaningful. Reliable interpretation for diagnostic purposes requires a substantial dataset, which entails acquiring a sufficient number of satellite images over time.

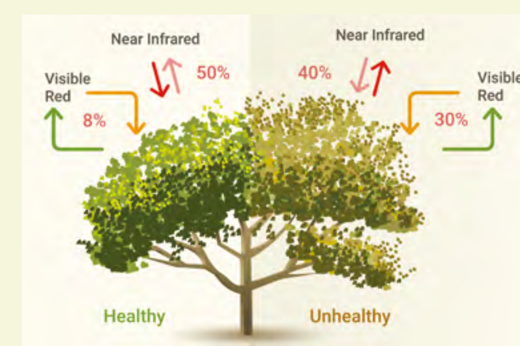


Figure 10. Source diagram: Bikesh Bade, tutorial All you need to know about NDVI

.4 ECOLOGICAL DIAGNOSIS OF THE FIELD

The zonation of mangrove species depends on a combination of chemical and physical factors, arising from site-specific conditions shaped by tidal frequency, amplitude and period, precipitation, fresh water input, evaporation rates and temperature. These factors influence the salinity, pH, redox potential (oxidationreduction potential) and nutrient availability in the sediment pore water thereby shaping the distribution of mangrove species. Their survival is constrained by their tolerance to these environmental parameters.

While restoring the original structure and function of the ecosystem is challenging, it is possible to create favorable conditions that accelerate the natural regeneration of a degraded mangrove forest.

Carrying out a detailed environmental diagnosis at the site level, prior to restoration, is essential to understanding the causes of degradation and to designing restoration and conservation strategies tailored to local conditions.

These strategies are diverse, and may involve simple protective measures to reduce the activities that cause degradation, but most often they involve restoring the hydrology of the site. Diagnosis enables the most appropriate techniques to be defined for restoring the hydrology by recreating conditions conducive to the development of plant communities, supporting natural recolonisation or reforestation, if necessary.

Diagnosis makes it possible to compare and adjust the physico-chemical parameters in the areas to be restored in relation to reference areas where the mangrove is in good condition. Once wanted intervals are obtained for the various parameters the reforestation plan can be considered.

The distribution of the different mangrove physiognomic types and the different species that compose them is mainly conditioned by hydrology, in particular hydroperiod, microtopographic distribution and interstitial salinity (Flores Verdugo et al., 2007).

A complete diagnosis must include:

- the behaviour of **the hydroperiod** (water level in the mangrove),
- **microtopographic distribution:** both microtopography and hydroperiod establish the unique physical and chemical conditions that influence ecosystem's type, structure and function,
- numerous **physico-chemical parameters** such as salinity, nutrients in interstitial water, redox potential and pH values, as all these factors regulate the mangrove habitat.

In addition, the structure of the forest, the vegetation's characteristics, the dominance and presence of species and the identification of bio-indicators must also be considered.

These parameters are measured regularly at the reference site and at the site to be restored, which will be studied before, during and after restoration.

Finally, it is important to identify the activities and uses of the forest, as well as all the pressures which, from afar (catchment areas) or close by, are sources of ecosystem degradation. Because if the area to be restored is subject to any kind of stress or constraint, it is essential, in order to guarantee the success of the restoration, to identify and when possible, to eliminate or reduce the causes of this stress.

Physiognomic type	Border	Arbusive	Halophilic plain	Marsh
Forest structure	Density : 2,050 trees/ha - 22.3 m²/ha	49,000 trees/ha 6.12 m²/ha	-	-
Forest width	<30 m	5 - 25 m	15 - 20 m	<6 > 50 m

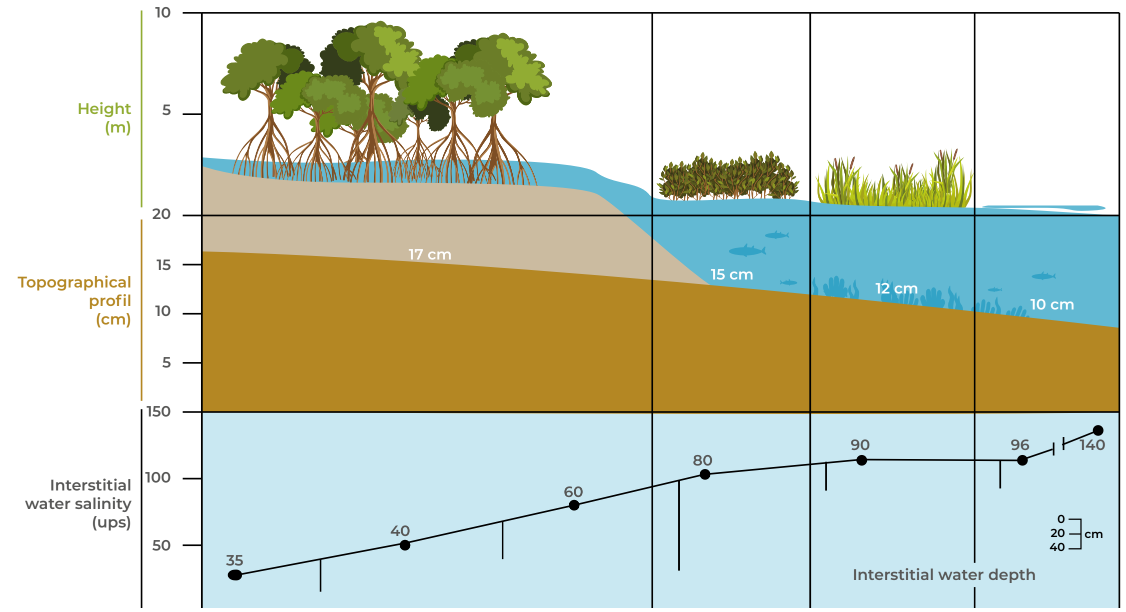
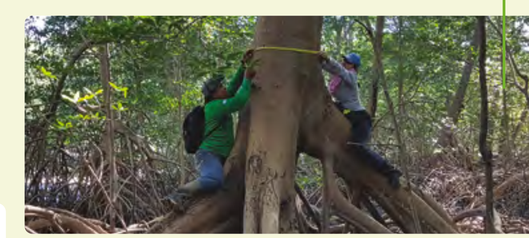


Figure 11. Vegetation profile of a mangrove forest in the Boca Cegada system, Nayarit, Mexico (Agraz Hernández, 1999).

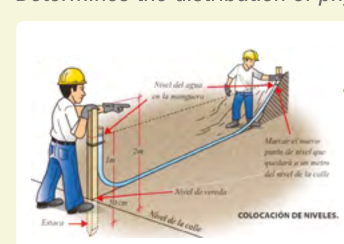
1- A reference site
To return to the structure of the reference forest

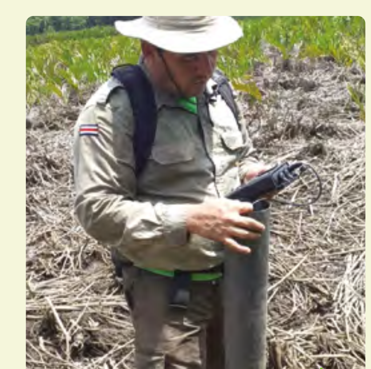
2- Study of the physiognomy of the forest (zoning) Density, height, frequency of mangrove species...



3- Study of the hydroperiod
(Frequency, height and duration of flooding) Regulates many parameters and conditions the establishment of different species.

4- Analysis of microtopography
Determines the distribution of physiognomic types





5- Physical and chemical analysis of pore water
(Salinity, pH, nutrients, redox potential) Regulates the mangrove habitat

Figure 12. Main stages of environmental diagnosis

4.1 | STATE OF THE ART

The diagnosis will begin with a state of the art based on an analysis of existing documentation and maps: historical analysis, vegetation cover (spatial analysis of existing maps), fauna and flora including invasive species, climate (rainfall and temperature), hydrology, evolution of human activities (historical and current uses), governance and management methods.

4.2 | CHOOSING THE SITES

A prospective visit will be conducted to carry out an initial reconnaissance of the site, identify the distribution and extent of the forests, assess their structural characteristics, and identify degraded areas and the presence of dead trees in order to determine potential restoration sites and define the reference forest(s).

Choosing (a) reference site(s)

It is essential to select a mangrove forest in good ecological condition, with propagules of mangrove species that are native to the region in order to :

1. Be able to compare its environmental conditions with those of the restoration site. These elements will serve as a reference to determine the species to be reintroduced, define the tolerance intervals (minimum and maximum) of the various parameters to be reached after the hydrological rehabilitation actions, the optimum time for collecting propagules and the most favourable period for reforestation, if necessary,
2. and; collect material (propagules of native species) for restoration.

The comparison of physico-chemical parameters of interstitial water between sites is needed to define the type of ecological restoration to be carried out and help define the restoration "design".

Aerial image showing the reference site and the site to be restored in Cuajiniquil, Costa Rica. Credits Google Earth year 2013: M. en C. Felipe Chavarria Díaz y M. en C. María Marta Chavarria Díaz (Latitude: 10o55'15.22 "N; Longitude: 85o42'55.99 "W).

The aim of restoration is therefore to recover, at the site to be restored, the environmental parameters as close as possible to the reference site and within the tolerance range of the species to be replanted, in order to ensure the recovery of hydrological behaviour and the survival of the replanted vegetation and/ or established by natural regeneration.

In this reference forest or in this area selected solely for the collection of propagules, vegetation profiles should be drawn up and the physical, chemical and biological parameters should be monitored (in accordance with the methodology described for the environmental diagnosis).

4.3 | MANGROVE PHYSIOGNOMIC TYPES (FACIES)

Measurement of the trunk diameter basal area's study © C. Agraz Hernández

Physico-chemical variations in the water and soil and differences in flooding, from sea to land, lead to a zonation of the mangrove, with a succession of plant formations in distinct "strips" (physiognomic types or facies).

The physiognomic types of mangrove forests are determined by an analysis of the forest structure based on the calculation of forest attributes (density, height, trunk diameter). These attributes present variations due to the great spatial heterogeneity of environmental parameters in mangroves.

It is common for physiognomic types to change along topographical gradients, from sea to land, as a result of variations in flood levels, residence times of water (hydro period), salinity concentration and oxygen availability in the interstitial water (water that flows between the spaces of the particles making up the soil).

The physiognomy of mangrove forests along the vegetation profile from the water's edge to the interior of the forest is studied during a prospective course in order to define the organisation of these attributes and the dominance of species. In each physiognomic type, at least two quadrats of 100 m2 (10x10) or 50 m^2 are established, parallel or perpendicular to the coast, depending on the width of the forest. Each quadrat is marked with a ribbon, and the four cardinal points of each quadrat are geo-referenced.

Claudia Agraz Hernández ©DR

The first quadrats are installed at the transition between sea and land (coastline, estuary, bay, etc.). The second set is established in the next zone, where the height and density of the forest change, excluding the transition zone between forest types, and so on.

For each quadrat, all the tree species are counted and identified, and the height is determined with a graduated telescopic ruler, while the diameter is measured at 1.30 m from the ground with a dendrometric tape. For species with aerial roots, the diameter is measured 30 cm above the last aerial root.

When the density of individuals is very high, it is advised to reduce the size of the quadrat, for example in shrubby forests.

Forest attributes are calculated for each quadrat and the average is established based on the two quadrats per community, as indicated below:

- **Absolute density:** average number of individuals of a specie per sampling zone;
- **Relative density:** absolute density of the specie compared with the total absolute densities of all species;
- **Frequency:** percentage of sampling units in which the specie is present in relation to the total number of units used;
- **Height:** average height of the individuals of the species;
- **Basal area:** One divides the diameter (in cm) by two to obtain the radius (r). The surface area is then calculated (pi (3.1416) xr2 in cm2). Calculating the average basal area of each mangrove species gives the mean basal area per species in cm2 (ABP). The mean basal area of each species (ABP) is multiplied by the absolute density of that species, thus indicating the basal area per hectare for each species. The value is then divided by 10,000 to obtain the basal area per hectare in m2/ hectare. The sum of the basal areas per hectare for the different species gives the total basal area;
- **Dominance:** The total basal area of a species relative to the total basal area of all species in the stand;
- **Importance Value Index (IVI):** characterises the importance of a specie compared to others (= relative density + relative dominance + relative frequency).

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4.4 I IDENTIFICATION OF BIO-INDICATOR SPECIES

Several animal or plant bioindicators, observable with the naked eye, can provide information on the condition of the mangrove. Here are just a few of them:

- **Pneumatophores:** their dried-out tips indicate changes in the hydroperiod behaviour;
- **Changes in the dominance of one specie**, or balding foliage in others: could be the result of a change in the physico-chemical parameters of the interstitial water;
- **Increase in halophytes** associated with mangrove species (*Sesuvium, Salicornia*, etc.) may indicate :
  - changes in the environmental conditions that favour the growth of halophytic plants, such as variations in water or soil salinity. In some cases, this may reflect a degradation of the mangrove's ecosystem, an important approach in the study of their ecosystem,
  - a natural process of ecological succession or greater plant diversity in the ecosystem, which could be the result of the recovery of environmental conditions through the implementation of restoration actions.
- **The increase of fungi and insects' presence** is attributed to the environmental changes that are causing the degradation of the ecosystem. The increase in the presence of certain wood-eating insects and saprophytic fungi in the area is due to the presence of stressed trees undergoing senescence (Macías et al., 2023).
- **Reduction or absence of crabs**, their density may vary due to lack of oxygen dissolved in the interstitial water

Site colonised by (A) Salicornia and (B) Sesuvium portulacastrum (A)© J. Prosperi, (B)© M. Chavarria

4.5 I IDENTIFYING INVASIVE SPECIES

The impact of invasive plants on coastal and marine ecosystems is significant, as they can alter biogeochemical cycles, modify habitats and affect key breeding and feeding areas for birds and turtles (Alonso & Castro-Díez, 2015).

There are numerous papers mentioning invasion events and invasive species in mangroves around the world, including both accidentally introduced alien species and native species that have become invasive due to habitat modifications (Biswas et al., 2018). For example, the fern *Acrostichum aureum* has become invasive in several countries, including Malaysia, Australia, India and several Central and South American countries such as Puerto Rico, Brazil, Panama, Mexico and Costa Rica, highlighting the need to address this issue in order to protect the integrity of mangroves and coastal ecosystems.

In Africa, human activities such as salt production, wood cutting for construction, fuel or aquaculture, and wastewater input have deteriorated mangroves's habitat. As a result, the invasive grass species *Paspalum vaginatum*, initially introduced to feed cattle and used on golf courses, has invaded these ecosystems. This invasion is further fragmenting and degrading mangroves, affecting their composition, structure and functioning. Addressing these threats is essential to preserve the biodiversity and ecosystem services provided by mangroves.

Colonisation by Paspalum vaginatum Ouidah, in Africa ©DR

Colonisation of banks by the fern Acrostichum aureum (forefront). © A. Rosenfeld

MIKOKO, THE MANGROVES' KNOWLEDGE EXCHANGE PORTAL
https://portal.mikoko.co.ke/

The Mikoko project, an integrated capacity-building initiative for the restoration and conservation of mangroves in Kenya, is built around a strategic cross-cutting tool: the Mangrove Knowledge Exchange Portal (Mikoko Portal). This digital platform collects and freely shares relevant data and knowledge on the mangrove environment, with a particular focus on biodiversity (geo-referenced animal and plant data, cartographic data, field observations, a plant identification tool, among others), thereby providing a reliable and sustainable tool for mangrove management in Kenya.
The Mikoko Portal consists of various modules, including an educational tool for plant identification dedicated to non-specialists (no botanical knowledge required) and offers multi-entry access. Users can explore and become familiar with more than 50 mangrove species from the Indo-Pacific coasts, the most diverse in the world! Although the portal focuses on Kenya, these modules - especially this one - are tools that can be used by anyone.

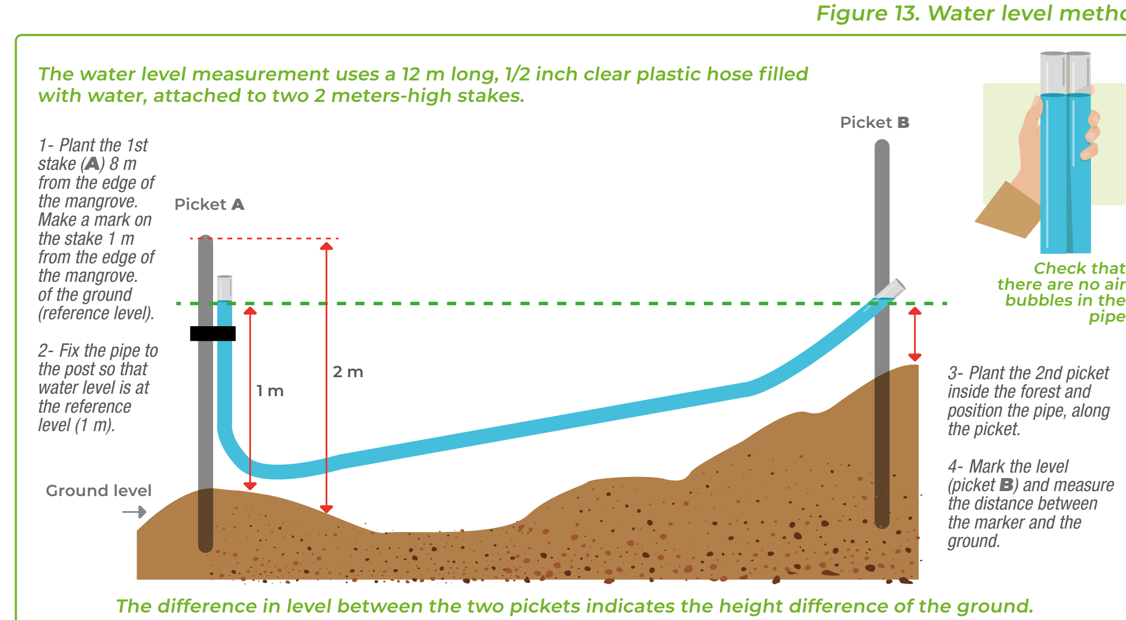
4.6 I ANALYSIS OF THE TOPOGRAPHY OF THE SITE

Microtopographic variations determine the distribution of mangrove physiognomic types, as well as the presence or absence of species that can establish in areas potentially suitable for reforestation.

These variations can be used to identify wether excavation or, conversly, land filling is needed to restore the appropriate topographical level. In mangroves, a difference of just 3 cm in the micro-relief of the soil, combined with 60 to 80 ups of salinity in interstitial water, can distinguish a mangrove forest from a monospecific thicket of *Avicennia germinans* (Agraz Hernández, 1999).

To determine microtopographic distribution, two methods can be used, depending on the size of the area to be restored (over or under 20 ha):

Figure 13. Water level method



ups: practical unit of salinity (approximately equivalent to 1mg/g of salt)

Restoration site < 20 ha

The traditional method using a level cylinder is a topographical technique for determining height differences in the field. A 12-metre transparent pipe is filled with water and connected between two points in the field approximately 8 m apart (Figure 13).

This procedure is repeated along the vegetation profile, recording the start and end of each physiognomic type, as well as the presence of adult species and seedlings.

Topography is measured both in the reference area and in the restoration area in order to define, through comparison, the areas suitable for reforestation and the species to be planted.

In the event of detection :

- Subsidence, when the ground level is lower than the natural distribution of mangrove species, sediments removed during the digging of artificial canals will be used to fill and level the area,
- Elevated ground: When the ground level is too high, excavations will be carried out to allow proper water.

© J. Reyes Castellanos

Figure 19. Determining topographic level using RTK methodology in Benin (photo above) and distribution microtopography of a degraded mangrove forest at a site in Cuajiniquil, Costa Rica, 2018 (photo page p47).

Restoration site > 20 ha

The RTK (Real-Time Kinematic) method is an advanced positioning technique used to obtain precise ground level differences for the area of interest in real time. It relies on high-precision GPS receivers and base stations, which transmit differential corrections to the RTK receiver in the field.

The process begins with the installation of a base station at a known, stable point in the area. Next, an RTK receiver (antenna) is deployed in the area to be mapped. This receiver calculates the position of the ground in real time with centimetre-level accuracy, using differential corrections received via satellites from the base station. The RTK receiver also measures elevation using GNSS signals, providing a threedimensional representation of the field.

As the RTK receiver moves around the area of interest, it continuously records position and height data, which is stored in a storage unit or transmitted in real time to a data processing device.

Once the survey is complete, the data is processed using specialised softwares to create a digital field model, which includes details of the elevation, slope and other topographical aspects of the mapped area. When applying the RTK method in mangrove ecosystems, the data is corrected compared to average sea level.

RTK (REAL TIME KINEMATIC)

Is a surveying technique that uses navigators' phase measurements from GPS, GLONASS and/or Galileo. Using a single reference station, it provides real-time corrections to achieve sub-metric accuracy.

© A. Rosenfeld

Figure 14. Map of the microtopography of the area to be restored using the RTK method (Cuajiniquil)

4.7 I ANALYSIS OF THE HYDROPERIOD

The hydroperiod corresponds to the frequency, height and duration of flooding in the different areas of the mangrove. This flooding is the result of a combination of factors, such as the effects of the tide, river inputs, runoff and fluctuations in the groundwater. The behaviour of this physical parameter is also influenced by microtopography.

The hydroperiod determines the physico-chemical conditions of the interstitial water and the soil, which conditions the structure of the mangrove and the installation of species in the areas; it also makes it possible to determine the areas suitable for the reforestation project (Flores Verdugo et al., 2007). If the site's hydrological regime has been modified, it is essential to establish the parameters needed to define the most favourable rehabilitation techniques.

Rapid quantification of flood levels

Hydrodynamic and tidal models are essential tools for predicting changes in the amplitude of flooding in mangrove ecosystems.

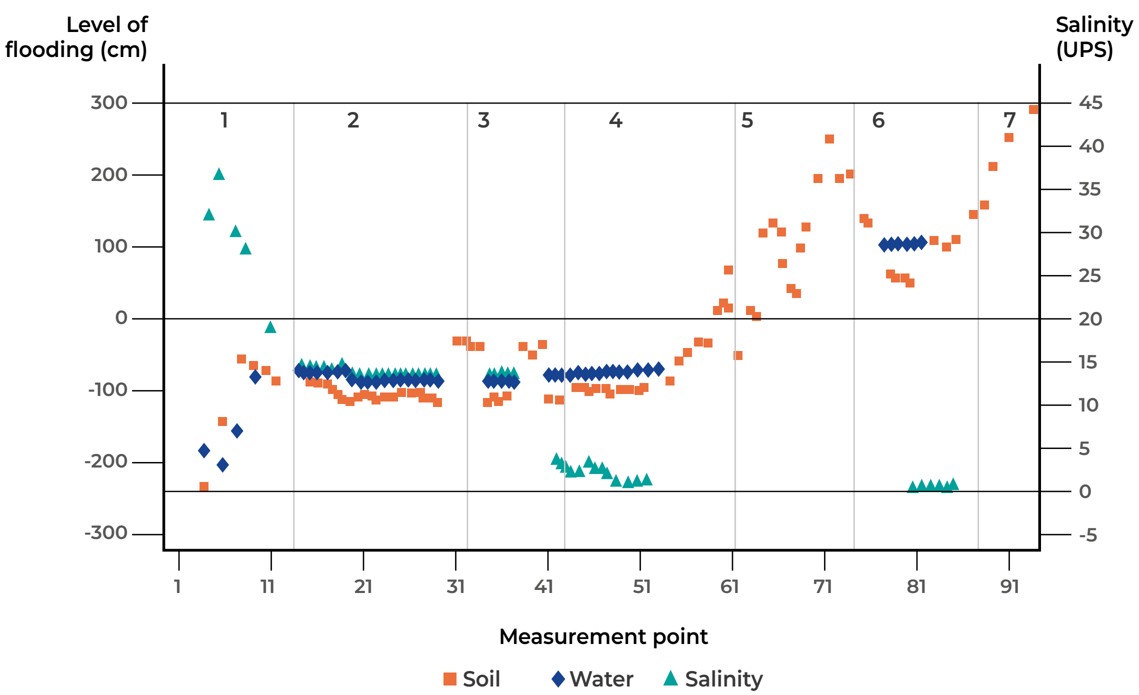
Twenty-four-hour-temporary inundation zones are delineated during low tide, high tide and the period of highest tides within the different mangrove plant formations (or physiognomic types), as determined from the analysis of forest structure. This is done using the tide tables specific to the site and taking into account the time of day. This determination is carried out during the microtopography assessment (see topography assessment method).

The method is as follows: several milestones are set up along the vegetation profile, from the seashore to the land; the first is placed outside the mangrove, in the water, and another at the start of the forest, 10 metres after the lower limit. The third milestone is located 10 meters from the second, until all the different physiognomic types are covered.

Once the markers have been installed, the flood amplitude is measured simultaneously on each, using a tape measure, by measuring the distance between the ground and the maximum water level (tidal amplitude) at the time of the highest and lowest tides.

SOIL AND SEDIMENT QUALITY (I. SAKHO)

The water content of the soil and the physical and chemical quality of the pore water are controlled by the texture of the substrate. The granulometric study of the following three fractions (sand, silts and clay, on soil samples taken at different depths in the first 20 to 30 centimetres) i s t herefore crucial for analysing the factors of failure or success in a mangrove restoration project. These in situ samples and laboratorybased textural analyses can be combined with macroscopic field observations, particularly based on soil color. In Joal (Senegal), a high mortality rate was observed at a site where the soil had a reddish-brown appearance characteristic of soils rich in iron oxide and alumina.



	(1) Forest of Rhizophora sp.	(2) Forest of Avicennia sp. Laguncularia sp.	(3) Tular wetland	(4) Popal wetland	(5) Flood zone	(6) Interdunal lake	(7) Flood vegetation
Vegetation	*Rhizophora mangle*	*Avicennia germinans, laguncularia racemosa*	*Typhia domingensis*	*Sagittaria lancifolia, Pontederia sagittata*	*Echinochloa pyramidalis*	*Pistla stratlotes*	*Annona globra, Pachira aquatica, Ginoria nudiflora*
Redox potential during the dry season (mV)	116.8 ± 13.8	425.7 ± 4.3	311.7 ± 31.7	238.0 ± 21.7	456.6 ± 8.6	430.3 ± 24.9	483.7 ± 13.4

Figure 15. Topographical and vegetation profile along a wetland to the north of the Mancha lagoon, Veracruz, Mexico. Water level, soil level and salinity are shown along the different communities in the transect. The redox potential was measured at a time when the interdune lagoon was completely dry (Flores Verdugo et al., 2007).

4.8 I ANALYSIS OF INTERSTITIAL WATER QUALITY

Salinity, pH, potential and temperature

In situ studies of the physico-chemical parameters of interstitial water, temperature, pH, salinity and redox potential, are carried out throughout the year, at a minimum frequency of twice a season. These measurements are taken from piezometers, two for each physiognomic type.

The piezometers consist of a PVC (polyvinyl chloride) pipe 10 cm in diameter and 1.5 metres long. Holes 1 cm in diameter are drilled in the last 30 cm of each tube, corresponding to the area with the greatest amount tree root biomass, allowing pore water to penetrate inside the tube (Flores-Verdugo et al., 2007).

© C. Agraz Hernández

Figure 16. Installation of PVC pipes in reforestation sub-plots for collecting water samples and measuring physico-chemical parameters in situ, in accordance with Agraz Hernández et al. (2007). © C. Agraz Hernández

At the reference site

In the reference forest, the piezometer must be installed at the depth where the maximum root biomass is observed, along the vegetation profiles. This step is crucial for recording the ranges of physico-chemical parameters of the pore water in a healthy mangrove, as these data will be compared with measurements from the area to be restored to guide restoration strategies.

At the restoration site

The restoration site should be divided into 100 m x 100 m plots, which will be clearly delimited. If the range of environmental parameters is very wide, it is advisable to reduce the plot size to 60 m x 60 m to create more precise measurement units.

Installation of piezometers

Piezometers must be installed at the depth where the root system is most developed (approximately 50 cm below the sediment surface), and the location of each tube must be geo-referenced (Agraz Hernández et al., 2011; Agraz Hernández et al., 2022). The tubes are positioned according to topographical level, taking into account soil characteristics, flood levels, and the biological indicatorsmost relevant for tracing the site's history.

At least eight tubes per hectare should be installed in each plot, although this number may vary depending on topographic heterogeneity, variability in chemical parameters, and the presence of natural channels.

Each piezometer is drained and interstitial water is sampled to determine the physicochemical parameters (pH, redox potential, salinity, temperature and nutrients) using a multiparameter probe. These analyses are conducted monthly in both the reference forest and the restoration site.

Salinity concentrations and redox potential values of the water are classified according to Cronk and Siobhan Fennessy (2001), Agraz Hernàndez et al. (2007a), Chan Keb (2007).

Analyzing these parameters allows the identification of environmental stress conditions affecting mangroves on the restoration site and enables adjustments to the design of the proposed hydrological rehabilitation model.

Determination of salinity, redox potential, pH and pore water temperature in an Avicennia germinans forest at a site in Central America.
© C. Agraz Hernández

Pore water analysis (Cuajiniquil, Costa Rica) @ A. Rosenfeld

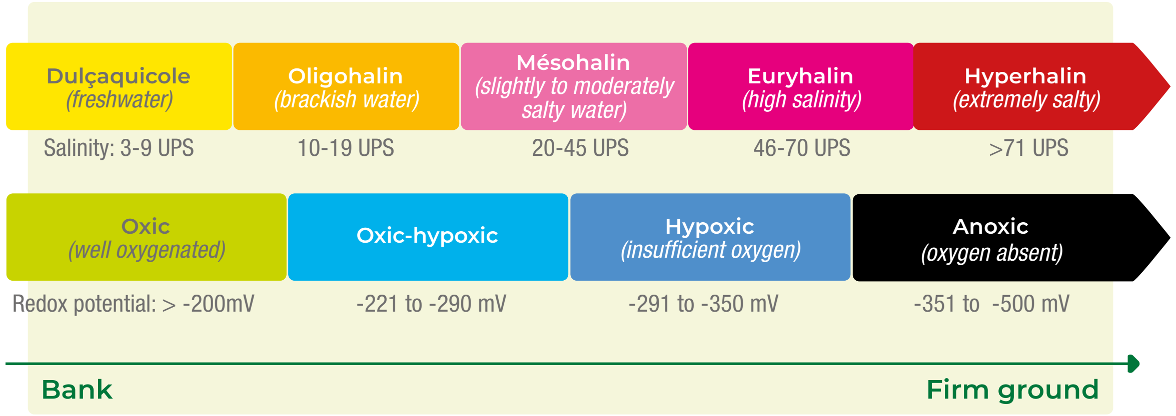


Figure 17. Changes in salinity and redox potential along a vegetation profile

Nutrients

The analysis of nutrients in pore water is considered a critical indicator of ecosystem health, because of its influence on plant growth, biological productivity and water quality.

In addition, it reveals the long-term negative effects of eutrophication, caused by the constant input of wastewater on plants, a priority piece of information to be taken into account in habitat quality recovery programmes.

In restoration field, this analysis makes it possible to identify the availability of nutrients for propagules from natural regeneration and planted species, as well as for other mangrove organisms.

Samples will be collected from each piezometer. Two samples will be collected in 50 ml polypropylene, washed beforehand according to the criteria of Gasshoff and Johansesen (1973), and Koroleff (1983). A drop of phenol will be added to one of the bottles to reduce bacterial activity. Samples should be transported on ice during field work and stored at - 4°C in the laboratory until processed. It is recommended to analyse the oxidised nitrogen compounds (nitrates and nitrites), as well as phosphates and nutrients linked to plant nutrition. In addition, it is important to analyse reduced nitrogen compounds (ammonium) because they are linked to reduced interstitial water conditions, phosphates to water quality and sulphates to the seawater's entry.

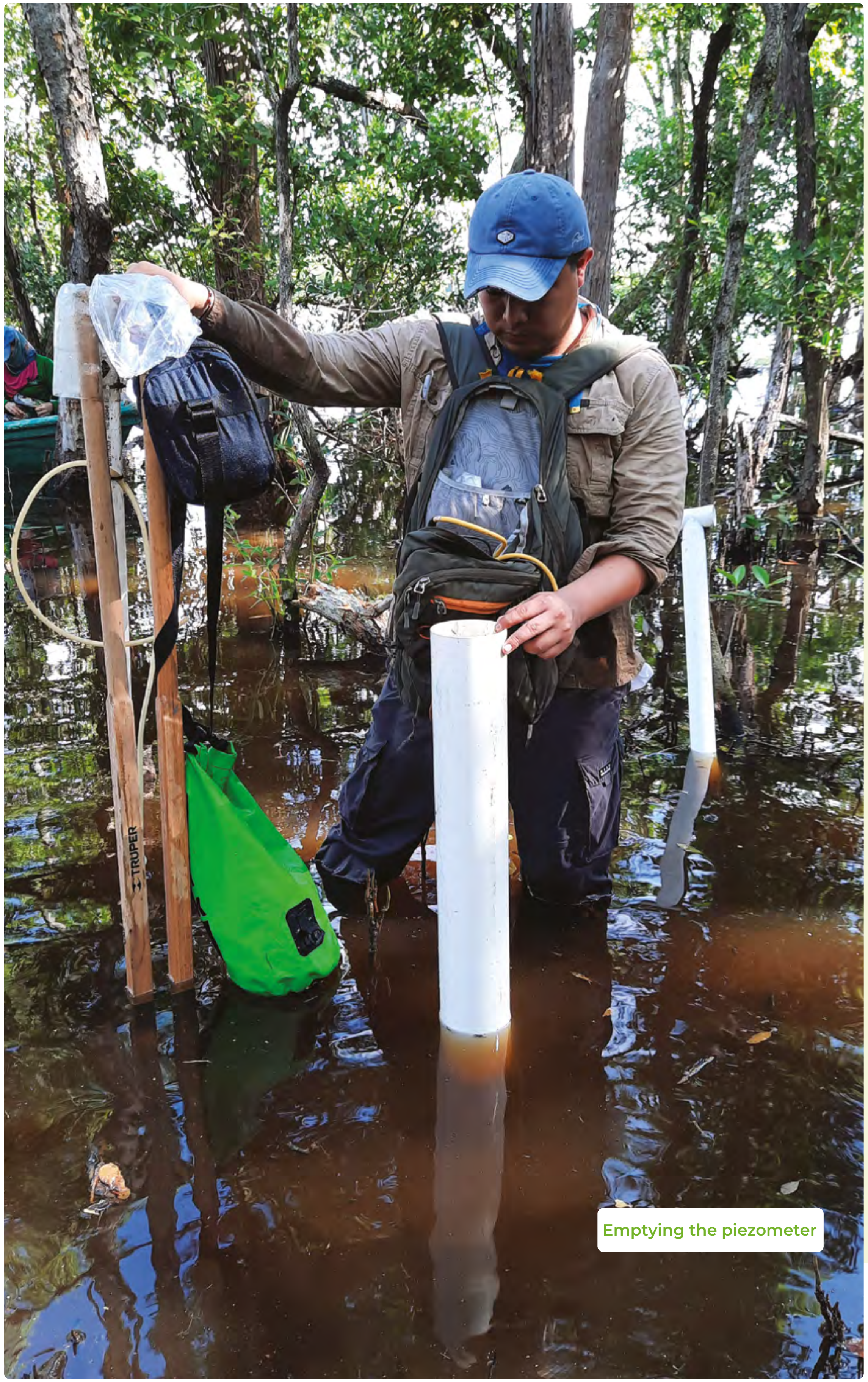


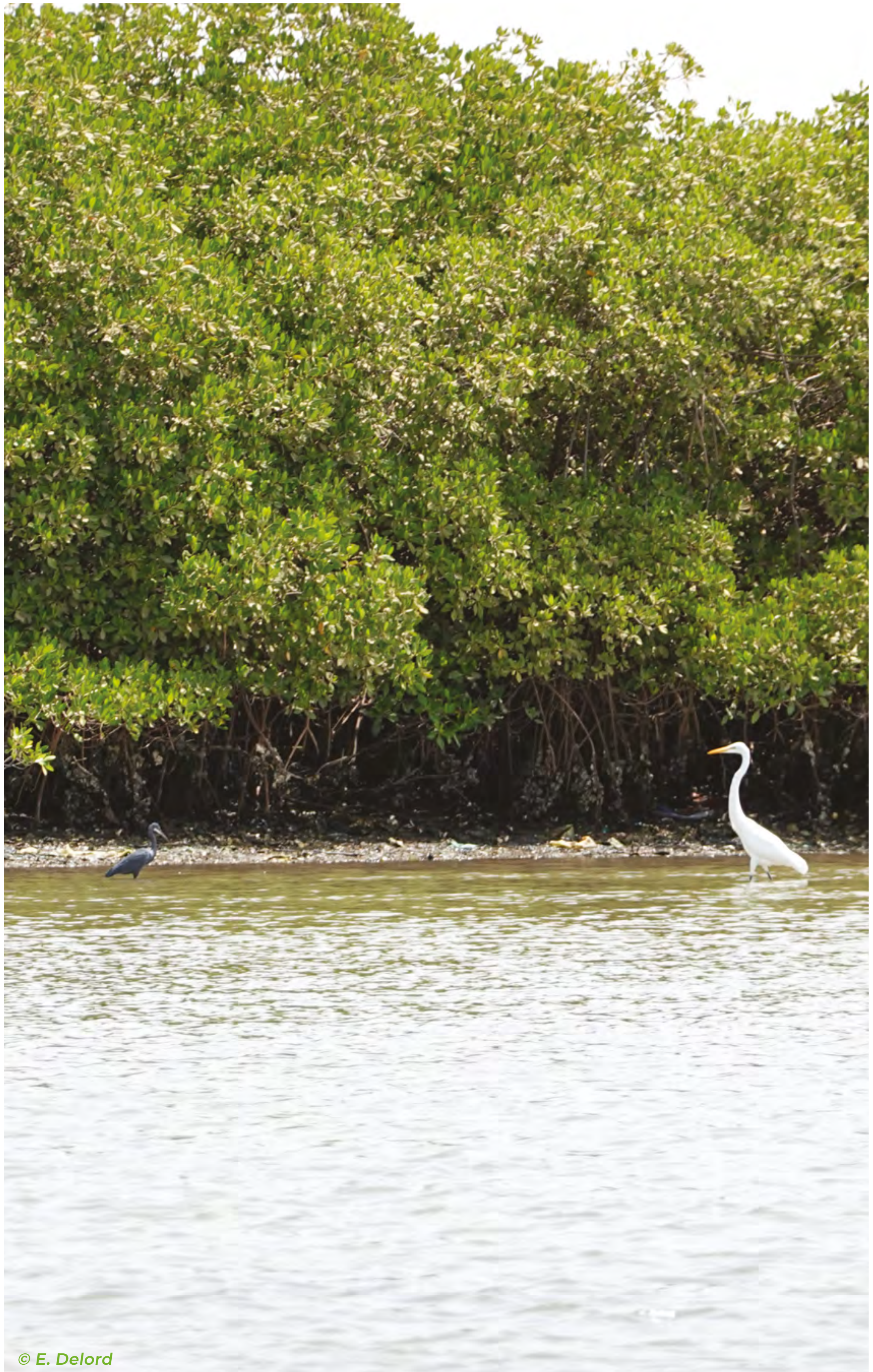
Figure 18. Field and laboratory procedure for the analysis of nutrients in mangrove pore water© C. Agraz Hernández

3

CHAPTER 3

A RAPID ASSESSMENT OF THE STATE OF MANGROVES

Author: Lisa MACERA



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3.1 THE RAM MANGROVE METHOD

The RAM-Mangrove method makes it possible to estimate the state of mangrove ecosystems quickly, affordably and within the reach of managers. This method provides an overall rating of the state of the ecosystem using both ecological and socio-economic indicators. Derived from the MERCI-Cor method, developed specifically for coral reefs by IFRECOR since 2016 (Pinault, Pioch and Pascal, 2017), the MANRAM (Mangrove Rapid Assessment Method) developed in 2019 (Pinault, IFRECOR internal report) and the RAM-Mangrove method (Macera et al., 2024) are dedicated to mangrove ecosystems. This section presents the method's content and operation, followed by its fields of application. Finally, the inherent limitations of this type of approach are presented.

Faced with constraints of time, budget and skills, managers require tools that are both effective and simple to use (Mechin et al., 2023). Nevertheless, it is imperative that these tools succeed in capturing an adequate complexity of the socio-ecological system at hand. The methods currently used to assess the state of mangroves, often based on a single indicator or a limited number of indicators, are proving insufficient to capture the inherent complexity in a socio-ecological system as rich as that of mangroves. Hence the importance of an integrated, multi-criteria approach, designed to best embrace this complexity, aligned with the recommendations of many authors (Borja et al., 2009; Faridah-Hanum et al., 2019). The overall characterisation of the ecosystem's structure, an assessment of its state and the identification of environmental pressures are fundamental components of any environmental management approach.

Faced with this lack of suitable tools, rapid ecosystem assessment methods emerged in the United States in the 1990s (Pioch et al., 2015). They are called RAM for "Rapid Assessment Method" because they are inexpensive, fast and require accessible scientific expertise. Today, these methods are widely tested, and numerous guides have been published to provide a framework for their development (Dorney et al., 2018; Sutula et al., 2006).

RAM

RAMs (rapid assement methods) are used in many fields such as medicine, geology and agroecology, they are now widely recognised in the scientific community.

More specifically, the RAM-Mangrove method is based on the UMAM method created by the State of Florida to assess the state of Florida's wetlands and coastal zones as part of their development (more information available here: https://flrules.org/gateway/ChapterHome.asp?Chapter=62-345).

IFRECOR - ifrecor.fr/eviter-reduire-compenser-restaurer-mercicor/

1.1 I INDICATORS AND RATING SYSTEM

To assess the state of mangroves, a rating system based on environmental indicators has been developed. This system allows the calculation of an overall score that reflects the general state of the ecosystem. This score is obtained by averaging the scores of 15 ecological and socio-economic indicators.

These 15 indicators are grouped into five categories representing the main aspects of the ecosystem: the landscape context, the mangroves, the soil, the associated biodiversity and the society-mangrove relationship. The indicators are presented in the table below:

CATEGORY	INDICATOR
1 Landscape context	1. Connectivity
2 Mangroves trees	2. Specific richness
	3. Cover rate
	4. Population dynamics
	5. Height of the canopy
	6. Mortality rate
	7. Vitality
3 The soil	8. Substrate texture
	9. Pore water salinity
	10. Sediment dynamics
5 Associated biodiversity	11. Abundance of crabs
	12. Associated flora and fauna
6 The relationship between society and mangroves	13. Variety of uses by local communities
	14. Level of protection of the zone
	15. Macro-waste pollution

Table 2. Indicators of the main socio-ecological aspects

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Each indicator is given a score from 0 to 3, based on a precise description of each class of score (0, 1, 2 and 3). As an example, let's consider category no. 2 "Mangrove Trees", which includes indicator no. 7 "Vitality".
This indicator is used to assess the presence of diseases, parasites or other factors that could cause damage to mangrove trees and ultimately to the ecosystem. Descriptions of the 4 levels of scores are shown in Figure 19. Details on the scores for all indicators can be found in the appendix to this book.

Figure 19. Detailed scores for the "vitality" indicator

1.2 I OPERATING PROCEDURES FOR SCORING

Depending on the indicator under consideration, the data can be obtained either through a field's sampling, a literature review or spatial image analysis methods (Andrieu, 2018). For example, if a fauna and flora inventory has recently been carried out in the area, the associated fauna and flora indicator can be easily filled in. The rate of cover can be easily determined using spatial analysis methods such as high-resolution remote sensing. However, for most indicators, a field's sampling is absolutely essential. In order to minimise the bias associated with sampling , we have developed a standardised sampling protocol.

The sampling protocol detailed below was carried out specifically for the mangroves of Senegal (Saloum delta). The method requires a recalibration of the protocol to adapt to the specific features of each new territory.

The basic spatial arrangement of the field protocol consists of a linear land-sea transect. Ideally, where possible, this is preferable to the traditional quadrat. This is because mangroves show strong zonation of certain parameters along the tidal range. Linear transect sampling takes better account of this ecological reality. The length of this transect can be adapted depending on the difficulty of access to the area, ideally the entire canopy should be crossed, and if not possible, we recommend a minimum length of around 50 metres, in the form of a series of small transects evenly distributed along the channel to the mainland. It is important to note that a field's sampling is always carried out at low tide.

Sampling varies according to the size of the area of interest. For areas with less than 100 metres of coastline, we consider that these areas are homogeneous. All our indicators, and a single transect is therefore sufficient to describe them.

For areas with more than 100 metres of coastline, we recommend sampling 5 transects, evenly distributed, for every 2 km of coastline (Figure 3).

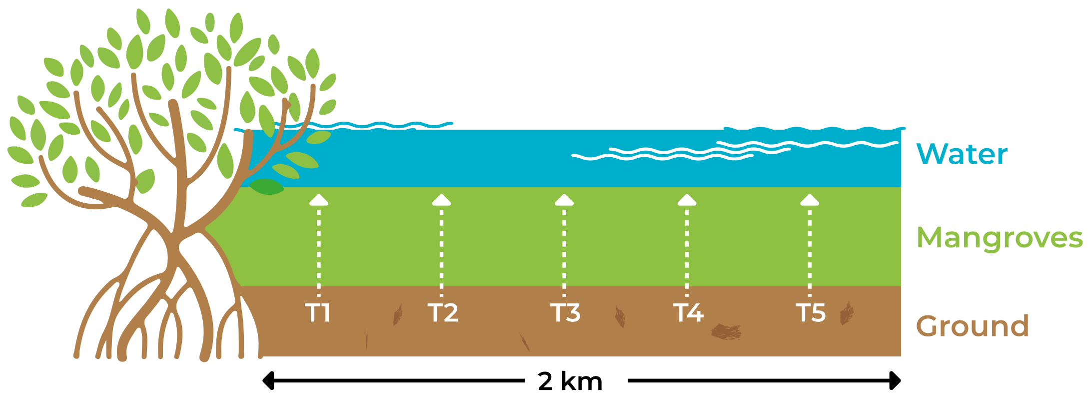

Figure 20. Sampling protocol for the RAM Mangrove method for a 2km stretch of coastline.

1.3 | OPERATING PROCEDURES FOR SCORING

By averaging all the scores, we obtain an overall score which is an indicator of the state of the environment. But how should this indicator be interpreted? To answer this question, let's take an example. The assessment of a mangrove area in the Saloum delta in Senegal carried out in 2023, for which the scores obtained are presented below (see Table 3).

CATEGORY	INDICATOR	AVERAGE SCORE FOR ALL TRANSECTS
1 Landscape context	1. Connectivity	2.4
2 Mangrove Trees	2. Specific richness	2.1
	3. Cover rate	2.6
	4. Population dynamics	2.8
	5. Height of canopy	1.4
	6. Mortality rate	2.8
	7. Vitality	2.6
3 The ground	8. Substrate texture	2.9
	9. Pore water salinity	3
	10. Sediment dynamics	2.8
5 Associated biodiversity	11. Abundance of crabs	2.5
	12. Associated flora and fauna	2
6 The relationship between society and mangroves	13. Variety of uses by local communities	2.7
	14. Level of protection of the zone	2
	15. Macro-waste pollution	2
AVERAGE SCORE		2.44

Tableau 3. Scoring the mangrove zone of the Saloum study in Senegal

Mangrove restoration in Senegal ©E. Delord

The overall score for the area of interest is 2.44/3. This corresponds to a very good state of the socioecological system, which has been very little altered and is able to perform most of its ecological and/or socio-economic functions. This rating is confirmed by the monitoring carried out by the University of Senegal (Awa Rane Ndoye, Issa Sakho Université Cheikh Anta Diop of Dakar, com. pers.), which confirms excellent environmental quality, considered a benchmark..

To help users interpret the results of the overall indicator, they can refer to the table below:

NOTE	DESCRIPTION
0-0,75	A completely altered state due to human activities and/or natural events, where the changes are so significant that there is an almost total conversion of the ecosystem, which can no longer fullfil its ecological and socio-economic functions
0,75-1,5	An altered state due to human activities and/or natural events. There is a partial conversion of the ecosystem, which can no longer perform the majority of its ecological and socio-economic functions, although some are maintained
1,5-2,25	A good state but slightly altered due to human activities and/or natural events. The ecosystem can perform most of its ecological and socio-economic functions, but some have been lost or will certainly be in the near future
2,25-3	Very good and unaltered condition. The ecosystem can fulfil all its ecological and socio-economic functions in a sustainable way and may have exceptional features making the site an area of high ecological and/or socio-economic interest

Table 4. Interpretation of results by score category

This note gives developers and managers a better understanding of the environmental status of sites and the strong or weak issues associated with them.

.2 FIELDS OF APPLICATION OF THE METHOD

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This method has a multitude of applications in various types of projects:

- **Mangrove restoration projects:** this is used to carry out an initial diagnosis of the area targeted for restoration. This provides an overall understanding of the ecosystem and identifies the main degradation factors. In the case of several potential sites, it helps identify the areas presenting the greatest challenges and choose the most appropriate site, in addition to other sources of information. Once the restoration measures have been implemented, this method can also be used to monitor the state of the environment and assess the impact of the restoration measures. The tool only makes sense if it is used in the same way as an initial status tool (t-1 vs. t+1) before the project and then after restoration as an assessment tool.
- **Coastal development projects:** An initial assessment of the area targeted by the project is used by the project manager as a reference for the associated impact study. This diagnosis also forms the basis for determining any compensation measures required. This approach, already used in the MERCI- COR method, can also be transposed to the RAM-Mangrove method. After the development project, the method should be used to monitor the state of the mangroves and estimate the ecological losses caused by the project.
- **Research projects:** By applying this method to the same site over a long term, it is possible to understand the temporal evolution of the site and the responses of the ecosystem to the pressures it is subjected to. This provides valuable information for research projects in ecology and environmental conservation.

.3 LIMITS OF THE METHOD

To use this tool properly, it is crucial to be aware of its potential biases and limitations. Firstly, the method is based on a semi-quantitative scoring system, which introduces a potential bias and variability in the assessment process depending on who is performing the method. To compensate for this, the scoring system presents a high level of details in order to guide the user as much as possible. Secondly, the method provides an instant assessment of the state of mangroves, in terms of both ecological and social aspects, at a specific point in time. It does not fully capture the temporal variability and long-term ecological dynamics of mangrove ecosystems, particularly in a context of rapid climate change. Finally, this method is very recent and, like all decision-support tools, will become more robust through shared experience and repeated use.

Apart from these limitations, which are intrinsic to the tool, it should also be noted that, in general, assessing the ecological status of mangroves using field indicators is challenging due to issues related to:

- **Accessibility:** Mangroves are typically located in coastal areas characterized by complex and dynamic ecosystems. Their muddy, marshy and intertidal environments, often make them difficult to traverse on foot or with conventional vehicles;
- **The influence of tides:** Fluctuating water levels due to tides temporarily prevent access to the sites;
- **Dense vegetation:** Mangroves are characterised by dense vegetation, including stilt roots, pneumatophores and entangled shrubs. These features can make it difficult to penetrate the forest and access specific study sites.
- **Remote locations:** Many mangroves are located in remote or isolated areas, often far from urban centres or research facilities. Limited infrastructure, inadequate transport and long distance can trigger logistical problems and increase the cost and time required for fieldwork.

To overcome these difficulties, researchers often use specialised techniques such as remote sensing (coupled with GIS). In addition, collaboration with local stakeholders, including government agencies, research institutions or community organisations familiar with the area, can help overcome logistical barriers to accessing mangrove ecosystems.

In conclusion, this approach represents the first method for a rapid assessment of the state of mangroves that is accessible to managers. It enables an integrated assessment of the socio-ecological system, while considering the constraints of managers in terms of time, budget and skills.

4

CHAPTER 4

IMPLEMENTING THE RESTORATION PROJECT

Authors: Claudia AGRAZ HERNANDEZ, Julien ANDRIEU and Juliana PROSPERI

.1 INTRODUCTION

Senegal © Awa Rane Ndoye

The main objective is to place the degraded site on a recovery trajectory compared to the reference system, to restore the structure and function of the ecosystem in short to medium term.

The restoration of mangrove forests can take different forms and includes different complementary and often successive phases:

- Passive restoration aims to mitigate, or ideally eliminate the causes of degradation and to protect mangroves by strengthening protection policies, creating marine protected areas and/or working with stakeholders involved in degrading activities to reduce or eliminate the factors responsible for this degradation;
- Active restoration, guided by the elements of the diagnosis, is based on engineering interventions responding essentially to three fundamental trends: hydrological rehabilitation to encourage natural regeneration, reforestation and/or, in most cases, a combination of the two. Removing obstacles to water circulation can sometimes be sufficient.

Before any major intervention, it should be assessed whether favouring natural regeneration would be sufficient and, if necessary, supported by facilitating hydrological circulation.
Natural regeneration occurs when the mangrove shows signs of colonisation through the arrival of propagules and seeds of mangrove species.

.2 PASSIVE APPROACHES: MITIGATING THE CAUSES OF DETERIORATION

This guide is not intended to be exhaustive or detailed on passive techniques, particularly regarding combating deterioration, which varies greatly from one site to another, and from one source of deterioration to another, but it does seem important to provide an overview.

2.1 I IMPROVING ENVIRONMENTAL POLICIES

Protecting and restoring these ecosystems requires political will and genuine commitment, backed up by solid research and data. Only a holistic, multidisciplinary approach can meet the challenge of conserving and restoring mangroves on a global scale.

Strengthening or updating environmental regulations can have a positive impact on the environment, leading, for example, to the restoration of mangroves. Today, some countries in South and South-East Asia have a large number of aquaculture ponds. Some of these countries have fairly lax policies in terms of controlling the discharge of effluent from these ponds into the mangroves. Such pollution (particularly with antibiotics) leads to a deterioration in biodiversity. In such a case, the restoration to be considered is not active: it is not a question of trying to re-implant, in water that is still polluted, the marine organisms that have been decimated. The restoration approach to be considered is primarly passive, focusing on engaging decision-makers to strengthen effluent regulations. The expectation is that, once these measures are implemented, water quality will improve and biodiversity will be resilient enough to restore biocenoses similar to those affected by pollution. Environmental policy should therefore target (sometimes major) economic actors, and awareness-raising efforts (see below) should be directed at both policy-makers and businesses.

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PLEASE NOTE:

We need to address the right problem, which requires a precise diagnosis of the factors contributing to the degradation of the mangrove's environment. Unfortunately, it is often difficult to challenge the large agri-food companies that benefit from lax pollution regulations. In some cases, the problem originates far upstream, as some mangroves drain very large catchment areas (Amazon, Gange-Brahmaputra,Niger).

Mangroves are closely dependent on river and sediment inputs. Improving environmental policy on a catchment scale for a mangrove may include rethinking, on this scale, an irrigation system or a dam system upstream. But this will most likely raise questions about conflicts of interest. The river contract approach in France is of interest.

2.2 | CREATING A PROTECTION ZONE AND/OR MANAGEMENT MEASURES

Study of the mangrove (in Senegal) © DR

One particular example of the improvement of environmental policies is the creation of a protected area. "Protected" is a generic term that covers a range of tools with different objectives and modes of governance. It is a tool that has both the strength and the weakness of being local and territorial. It is highly effective when it comes to protecting an environment locally against a factor of degradation that we wish to prohibit (often a specific use). However, on the one hand, banning certain uses requires careful consideration, negotiation and sometimes compensation. On the other hand, restricting some of the forest uses of local communities through the creation of a new protected area is not a suitable option if the main issue is pollution carried by the river.

Once again, it is essential diagnose the factors and stakeholders involved in the degradation.

If the chosen tool is appropriate, additional questions arise during the second phase of the diagnosis: where (and why here)? What size should it be? What zoning should be applied?

- A very small protected area (even a strictly protected one) surrounded by a degraded environment is rarely effective, especially in highly connected environments. A small marine protected area located in a polluted and a densely populated ocean will have little effect. The creation of a protected area must be based on ecological connectivity (with other similar or different environments). It must also be based on the notion of ecological solidarity. In other words, protected areas should be considered as part of a network.
- The combination of small strictly protected reserve zones, surrounded by areas where uses are regulated (but permitted if sustainable) has proven effective (Man and Biosphere Programme).
- All the desired management measures, coconstructed and labelled to ensure the cobenefits of sustainable management for nature and society, are always welcome.

2.3 | RAISING AWARENESS ABOUT UNSUSTAINABLE PRACTICES

If a practice is unsustainable, it may be appropriate to initiate discussions with the local community whose activities may be contributing to environmental degradation. However, it is important to avoid preconceived assumptions about local communities, which are sometimes too quickly blamed. Have scientific studies assessed the extent of the degradation? Have these studies identified the factors and actors responsible for it and demonstrated that a particular local practice use is unsustainable? In such case, awareness-raising is a tool that should be mobilised.

Before initiating discussions with the concerned community, it is necessary to first examine the rationale and origin of this practice (economic, cultural, or political). An information campaign can then be developed to demonstrate that this practice is harmful to the mangrove. However, it is preferable to build this demonstration together with members of the local community to ensure that the appropriate language and concepts are used.

Finally, we need to give time for ideas to infuse, consider contradiction, and work together on the field. We need to engage in dialogue, not impose ideas on communities. You also have to bear in mind that:

- "awareness" campaigns alone cannot ensure changes in practices,
- many communities will listen, show they are respectful and welcoming by acquiescing to the messages, but this attitude does not mean that they will easily change their way of life.

For these reasons, conflict resolution and collaborative management tools such as "serious games", participative scenarios and Multi-Agent System models are remarkable tools for co-construction.

Mangrove education in Cuajiniquil (Costa Rica©M.M. Chavarría Díaz

.3
ACTIVE APPROACH: RESTORATION TECHNIQUES


Training local teams to implement restoration (left: Terraba Sierpe; right: Benin) © C. Agraz Hernández and J. Reyes Castellanos

3.1 I RESTORATION DESIGN AND CHOICE OF RESTORATION TECHNIQUES BASED ON DIAGNOSIS FINDINGS

A comparative analysis of the restoration area and the reference forest, during the diagnostic phase, enables the extent and intensity of environmental changes to be identified, corrective measures to be planned accordingly and appropriate species to be selected for planting:

- Analysis of the hydroperiod helps to understand changes in hydrological behaviour and enables the layout to be designed to define the number, direction and connection of channels to promote the dilution of salts in the soil and pore water, as well as the oxidation of water and the availability of nutrients in it.
- The study of the topographical distribution supports the decision-making process for corrective ground level techniques (excavation or backfilling).
- Comparative physico-chemical analyses indicate the minimum and maximum values for each environmental parameter that predominates in the reference area. This comparison makes it easier to correct the parameters in the area to be restored, by selecting the most appropriate techniques.

DEGRADATION SCENARIO	IMPLICATIONS FOR RESTORATION
Deforestation without modification of the hydrological scheme	Determining and correcting the topography; Determining the physical and chemical conditions pore water; Reforestation; Protection of reforested areas.
Deforestation with modification of the hydrological regime	Building a network of artificial canals; Correcting the topographical level; Reforestation.
Changes in hydrological behaviour	Building a network of artificial canals; Correcting the topographical level; Monitoring the physicochemical parameters of pore water and biological variables in reforestation.
Changes in topography	Increase in topographic level due to subsidence or erosion; Decrease in topographic level due to accretion.
Salinisation and anoxia	Building a network of artificial canals; Correcting the topographical level.
Eutrophication due to agricultural and urban wastewater discharges	Mitigation of input sources (environmental management and education programmes); Reforestation with species with greater phytoremediation capacity (e.g. Laguncularia racemosa); Correction of hydroperiodic behaviour (water passages).
Invasion of species	Removal of invasive vegetation; Correction of ground level; Restoring hydrological behaviour.
Road and motorway construction	Installation of nozzles to allow the passage of wildlife, ensure the free passage of sediment and prevent impediments to the passage of water. As many nozzles as necessary should be considered to restore hydrological behaviour and sediment dynamics.

Table 5. Degradation scenarios for mangrove sites and implications for ecological restoration (after diagnosis and monitoring of the physico-chemical parameters of pore water and biological variables in reforestation in all cases)

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Digging canals in Ouidah, Benin© C. Agraz Hernández

3.2 I HYDROLOGICAL REHABILITATION

Hydrological rehabilitation requires building (and sometimes destroying) artificial channels, bridges, dredging channels, building artificial lagoons combined with artificial channels, or a combination of all these measures, to rehabilitate the dynamics water circulation. The aim is to reduce anoxic conditions, as well as high concentrations of salts in sediments and the residence time of water. This is a fundamental aspect, as hydrological behaviour tends to guarantee the successful restoration of mangrove structure and function, with lower longterm costs.

The hydrological rehabilitation strategy is based on the diagnostic elements. For example:

1. **High salinity, low oxidation reduction potential and high residence time of pore water:** need to improve water circulation by building channels or implementing draining systems to reduce salinity, improve oxygenation conditions and favor nutrients' availability.

(ASSISTED) NATURAL REGENERATION

If there is a mangrove forest in a good healthand with a good availability of propagules next to the restoration area, it is considered that hydrological rehabilitation is sufficient to re-establish the mangrove. This will induce natural colonisation, without the need for reforestation, although the re-establishment of natural cover will be slower.

2. **Presence of sulphides and anoxia:** measures to improve oxygenation of the water, such as creating channels to increase the exchange between seawater and freshwater, reducing anoxia and elements that inhibit enzymatic and photosynthetic processes.

3. **Long residence time of water:** If water remains in an area for an extend period, it can contribute to the accumulation of sediments and nutrients, as well as the development of anoxic conditions. In such cases, measures should to be taken to improve water circulation such as constructing channels or installing drainage systems to accelarate the outflow of water from the area.

When to intervene: Restoration work should preferably be carried out during the driest months, when mangrove areas are less affected by tides and rainfall, facilitating sediment excavation. This timing allows the rainy season to promote the flushing of the area, reductions in salinity and redox potential, and a decrease in water residence time. Restoration strategies and techniques, such as the construction of canals, embankments, bridges and artificial ponds, will be implemented manually with the assistance of local community members.

Elimination of the obstacles to water circulation

The construction of certain infrastructures can prevent or slow down the circulation of water and jeopardise the functioning of a mangrove. There are various types of infrastructure: aquaculture ponds, dykes, anti-salt dams, low walls and roads, to name but a few. In some cases, and depending on the size of the infrastructure, breaches can be dug with shovels and pickaxes to remove the obstacles to water circulation.

It is important to note that culverts (nozzles) should not be used as a hydrological rehabilitation strategy, since they require maintenance as they become silted up with time and restrict the movement of wildlife. On the other hand, it is advisable to build small bridges to allow water to circulate.

Generally speaking, the priority is to recover hydrological behaviour.

Draining of natural channels

The rehabilitation of existing canals (dredging, desilting) is recommended, as they indicate the behaviour of currents in the hydrological system, as shown by the shape of the canals that follow estuaries, meanders or natural channels, which can be identified by photographic analysis using drones in particular and checking the field.
The mouths of canals must be directed towards areas protected from strong winds and waves to prevent them from obstructing, flooding or silting up the reforestation area.

The natural hydrological movement can be optimised or reinforced by new interconnected artificial channels to increase the rate of recovery of sedimentary conditions.

Draining a channel © C. Agraz Hernández

Creating a network of channels

The hydrological rehabilitation strategy consists in building a network of interconnected channels with each other, with the sea and the freshwater source, either in a straight line or with curves similar to those of natural estuaries.

To establish hydrological rehabilitation strategies, it is necessary to define a main channel according to the topographic distribution, soil type, location of natural watercourses and the environmental stress to be mitigated.

In order to establish hydrological connectivity, the main channel will be linked to several secondary and tertiary channels, in addition to the natural channels. The heterogeneity of the soil must thus be considered, as well as the freshwater supply, the behaviour of the local tide and the littoral current, if present. To prevent sedimentation over time, the number and dimensions of the channels


Digging canals in Costa Rica © M.M. Chavarría Díaz and C. Agraz Hernández

are determined according to the scale of the site to be restored, the concentration of salinity and the degree of anoxia.

The distribution of channels must take into account the slopes of the water outlet (simulation of low tide "ebb", with a response of dilution of salts, greater oxygenation of sediments and pore water) and inlet (high tide "flow", entry volume of the lagoon water and seawater depending on tidal influence).

It is essential to take into account the direction and intensity of the winds depending on the season.

Shape and dimensions
They depend on the configuration and size of the site. For example, in the restoration projects in Costa Rica (7 ha) and Benin (30 ha), the central or main canal, which must be the widest, was at least 2 m wide and 1.5 m deep. The secondary and tertiary side canals were at least 1 m wide and 1.5 m deep. However, in a much larger restoration of 517 ha in Mexico, a channel 5 m wide, 2 m deep and 4,400 m long was dug, connecting main channels 2 m wide and 1.5 m deep, which in turn connected to secondary and tertiary channels 1 m wide and 1.5 m deep.

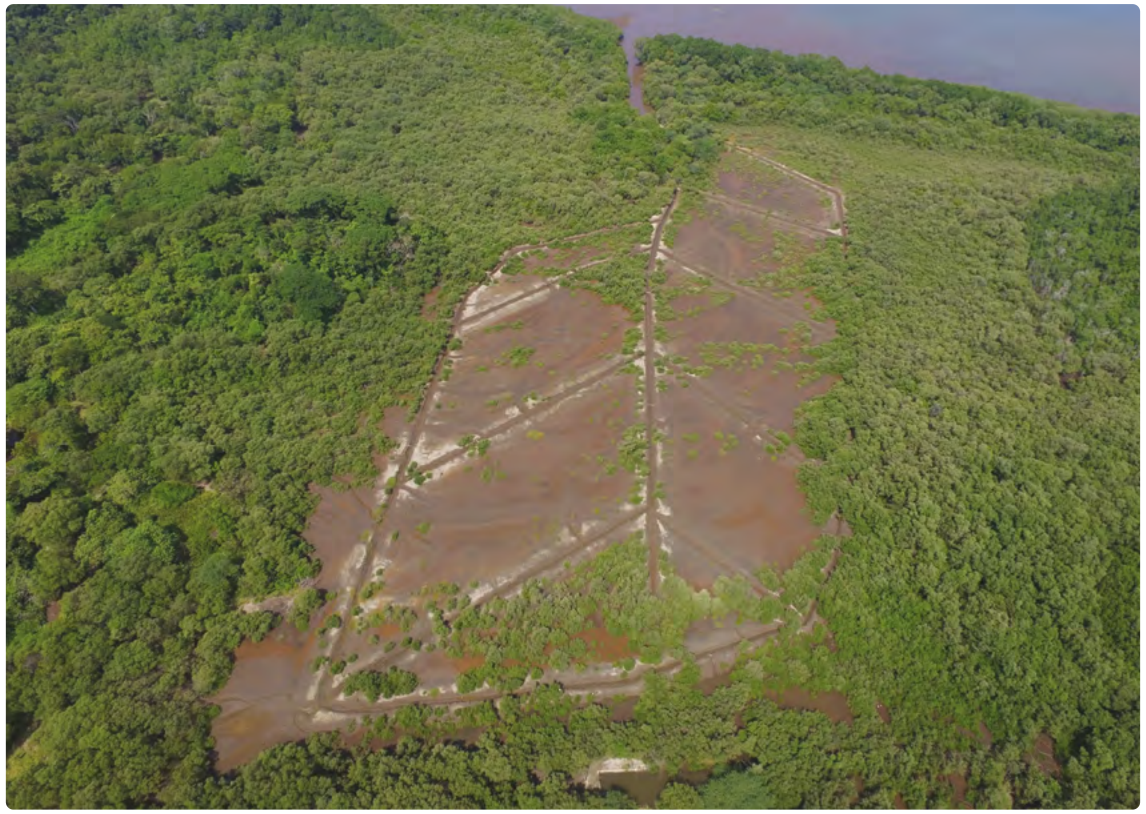
This is why it is essential to determine the hydroperiod prior to rehabilitation in order to define the direction of the channels. The amplitude and frequency of these water masses (the ebb and flow) control the entry and exit of sediments, preventing the long-term silting up of canals and lagoons. This is recommended in the case of karstic soils.

© J. Reyes Castellanos

Maintenance of artificial canals

It is essential to clean artificial canals at least every 3 years or during a hydrometeorological event, to prevent silting caused by natural events.

The permanence and health of the plantation depend on maintaining these conditions.



Network of canals at Cuajiniquil (Costa Rica) ©M.M. Chavarría Díaz

3.3 | MICRO-TOPOGRAPHIC LEVEL RECOVERY

The appropriate topographical level is restored by excavating areas that are too high or, on the contrary, by filling in areas that are too low compared to the level of the reference zone, using the sediment discharged during the construction of the canals.

Elimination of opportunistic/invasive species

Wetlands are particularly vulnerable to invasive species. These species grow rapidly, forming dense colonies and accumulating large amounts of dead organic matter. They generally modify the structure of the habitat by increasing the topographical level through the development of their root system and their capacity to retain sediment; they thus modify the hydro-period behaviour as well as the physico-chemical characteristics of the pore water beyond the tolerance ranges of native mangrove species.

They modify the nutrients' cycle and productivity, and can even alter food networks. Opportunistic and invasive species can enter in competition with mangrove seedlings, not only for nutrients and space, but also for light, thus reducing the number of native species.



Manual removal of Paspalum vaginatum in Benin (top left) and A. aureum in Costa Rica
© C. Agraz Hernández

In scenarios of severe environmental disturbance, high soil productivity, hydroperiod behaviour and sediment dynamics, as well as salinity concentration and hypoxic conditions, facilitate invasions and also accelerate the growth of invasive species in terms of numbers and biomass.

On the contrary, the re-establishment of good hydrological conditions generates physicochemical intervals that are intolerant to invasive plants (e.g. *Paspalum vaginatum* in Africa or *Acrostichum aureum* in Costa Rica), but tolerant respectively to the species *Rhizopora racemosa* in Africa and R. racemosa, *R. mangle* or *Pelliciera rhizophorae* in Costa Rica.

A topographical analysis of the sites enables to assess the extent of the changes caused by invasive species in comparison with the original topography. As invasive species are eradicated, usually manually, hydrology, sediment dynamics and, consequently, topography are gradually restored.

Once the hydrosedimentary processes have stabilised, reforestation is carried out. It must be carried out intensively to prevent the recolonisation of invasive species, allowing native species to recover their habitat and re-establish biodiversity.

.4 REFORESTATION

This guide sets out the principles for implementing different types of reforestation, taking into account the election criteria for mangrove species. The aim is to crease the survival of the plant cover once the restoration ork is complete. Some criteria based on scientific:

- to salinity,
- size of the zone,
- type and density of planting/reforestation,
- seed collection (depending on the phenology and health of the springs),
- creation of nurseries,
- monitoring of nurseries.

The right time for reforestation is dictated by the physico-chemical conditions of the pore water on the restoration site, after the construction of the artificial channels, which must approach the conditions of the reference site.

Species selection

Species should be selected according to site conditions (see "Physical and chemical analyses" section). The predominant species in the reference forest and adjacent forests must also be considered into account. It is necessary to compare the ranges of physical and chemical parameters of the pore water and the micro-topographical distribution between the reference site and the restoration site after hydrological rehabilitation. When these conditions are similar, the appropriate species to introduce can be defined. This ensures a natural colonisation and a genetic flow in the restored population (McKee et al., 2007).

Size of the area to be reforested

It is essential to determine whether the area is large enough to allow seeds to disperse and ecological connectivity between habitats (Lewis, 2005).
The size of the area to be reforested is highly variable, depending on the restoration techniques and the restoration of connectivity.


Flowers and fruit of Avicennia marina.
© J. Prosperi

Pilot restorations have been developed in Costa Rica and Benin in view of developing innovative techniques adapted to different degradation situations. In our pilot sites, the reforested area in Costa Rica (Terraba S ierpe) was 6 hectares, and in Benin (Ouidah) it covered 30 hectares. Largescale restoration can then be considered, as in the case of the restorations carried out in Mexico in the state of Campeche, where the surface areas can range from 1,800 to 3,000 hectares.

4.1 | SEEDINGS/PROPAGULES/SMALL PLANTS COLLECTION

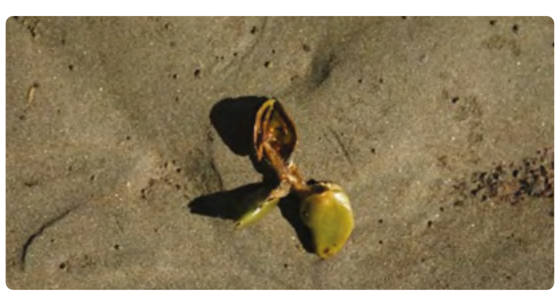
On the basis of the environmental diagnosis and the phenology of the species of mangrove forests in good condition adjacent to the site to be restored, the time of year for collecting and the quantity of propagules available should be determined.

It is essential to harvest only mature propagules. Correct collection involves climbing trees and shaking branches so that only mature propagules fall, ready for planting.
This avoids cutting green propagules unnecessarily. If it is not possible to climb the tree and it is necessary to collect them by other means, it is essential to choose propagules/fruits with the following characteristics:

- **Colour:** in *Rhizophora* the colour of the abscission collar (where the seedling detaches from the fruit) is a good indicator of maturity, red in *R. apiculata*, yellow in *R. mucronata* and greenish in *R. stylosa*; brown scaly fruits that burst at maturity in *Conocarpus* and yellowish green fruit in *Avicennia marina*;
- **Size:** if collecting from branches, select the largest propagules. In *Rhizophora* in particular, the fruit detaches easily. According to Rabinowitz (1978), the size of the propagules determines their viability; the larger, the more viable they are;
- **Consistency:** a firm propagule is a sign of maturity and good health;
- **Other factors:** Propagules damaged by insects, crustaceans or other organisms should be excluded.

Propagules storage

Rhizophora and Laguncularia propagules can be stored in humid conditions for up to 20 days. During this period, the propagules retain their viability. For *Avicennia* species, it has been shown that they are more prone to decomposition over short periods due to their nutritional properties, which makes them more difficult to preserve, with observed mortality rates ranging from 10% to 70%. It is therefore difficult to determine a particular method or effective storage period that does not compromise the Fruit viability of propagules.



Germination of Avicennia germinans. © J. Prosperi

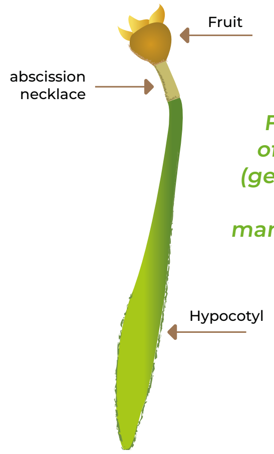


Figure 20. Representation of a Rhizophora propagule (germinated fruit). Modified from "La restauration de mangrove, guide technique", web, 2018".

Extraction of young seedlings

The method used is a crucial factor in the survival of forest transplants. It is suggested that, when extracting seedlings, extraction diameter should be half the total height of the seedling and the depth should be the same as the height of the seedling.

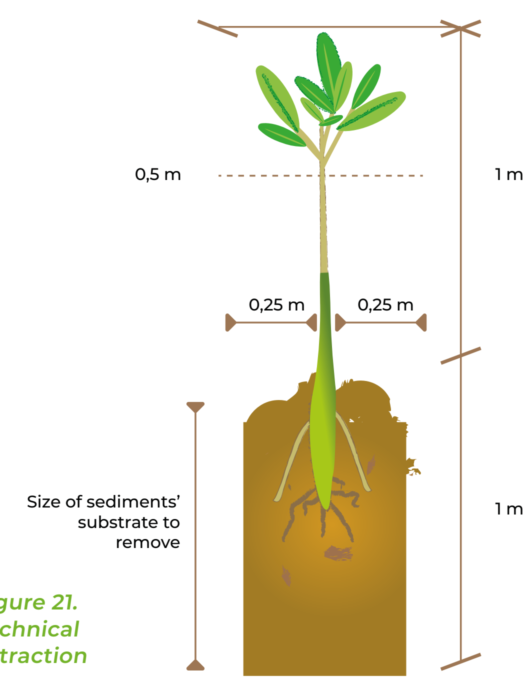


Figure 21. Technical extraction

4.2 | TYPES OF REFORESTATION

For all types of reforestation, see the "Environmental diagnosis" section for information on species selection, seed collection and reforestation.

Direct sowing (*in situ*): this can be done using mature propagules taken directly from the tree or freshly fallen. Direct by "voleo for *Laguncularia*, *Avicennia* and *Conocarpus*. In *Rhizophora*, the propagules are planted vertically to a maximum depth of 1/4 of the total length of the propagule. This is done when there are enough healthy, mature propagules to carry out reforestation.

Seedlings from adjacent forests: When there are not enough healthy propagules or not in sufficient quantity, the plants are taken from a mangrove forest previously diagnosed as a site in good condition, where 50% of the seedlings can be harvested. In general, it is estimated that between 10% and 30% of undergrowth seedlings survive to become mature trees in a mature forest. So extraction does not alter the natural regeneration of this forest.

Transplanting seedlings from a plant nursery: This option involves establishing a storage site (temporary or permanent) for propagules and seedlings in order to provide plant material for reforestation work. This option can have a positive impact on the survival rate of plantations. It can also be necessary for large-scale, long-term reforestation.

4.3 | REFORESTATION DENSITY

Senegal © Awa Rane Ndoye

The criteria for defining reforestation density per hectare will depend on the physiognomic type of the reference forest. The aim will be to achieve a density similar to that of the reference forest when the planted trees reach maturity. One must consider the number of propagules required, the size of the area to be reforested, the spacing between plants, depending on the prevailing environmental characteristics and the time at which reforestation is to be carried out.

Below is a proposal defining the number of seedlings to be planted on a given area (1 ha) according to the criteria of Agraz Hernandez et al. (2007).

4.4 | NURSERIES

Creation of plant nurseries

The creation of mangrove nurseries answers to the need to produce plants with homogeneous characteristics in terms of vigour and health. Plants produced under these conditions tend to have low stress levels, high resistance rates and high growth rates, while guaranteeing the availability of material throughout the year at the lowest possible cost.

This is all the more important as the reproduction periods differ from one mangrove species to another. For example, *Rhizophora mangle* and *Rhizophora harrisonii* are the only species to reproduce throughout the year, whereas *Avicennia germinas*, *Avicennia bicolor*, *Laguncularia racemosa* and *Conocarpus erectus* only reproduce during the summer and the rainy season (depending on the region), when the salinity of the interstitial water decreases as a result of dilution by rainfall.

Nursery at Laguna de Términos, Mexico
© Juan Osti Saenz

Another and no less important aspect of the use of mangrove nurseries is the provision of socio-economic benefits through training and employment for coastal communities ("mangrove farmers"). This is important given the decline in fisheries due to multiple anthropogenic impacts and natural events.

The physical and chemical parameters considered to be priorities for the establishment of a mangrove seedling nursery are: the availability of fresh and brackish water (a river or estuary or the sea, lagoons or drinking water must be nearby), topography of the land (this will depend on the type of nursery to be established, whether it is in situ, on mainland, temporary or permanent), the wind speed and direction during the year and the distance from external pests. Climatic conditions of the site are also important, to avoid poor quality propagules.

Planting technique (plant nursery or in situ): planting depth varies according to the morphology and size of each species. With Rhizophora, we recommend planting to a depth of 5-7 cm, introducing the propagule. For Avicennia, the appropriate depth is 3 to 4 cm and for Laguncularia, 0.5 cm.

Nursery in Asia
@ Julien Andrieu

SUBSTRATE FOR THE PRODUCTION OF NURSERY PLANTS

Fertilisers are substances of natural or synthetic origin that are added to the substrate or plant to provide the nutrients required for optimal development. Pesticides are another important element, as they can be organic (biological production) or synthetic. Organic pesticides present no or minimal risk to the environment due to their decomposition, so their residuality is very low. They provide effective control and low concentrations of the product are required.

They are compatible with integrated pest management systems because of their selectivity (Fanjul L. et al., 2006). Organic pesticides include growth regulators for pests and pathogenic micro-organisms: fermentation products or plant and microbial derivatives, pheromones and semio-chemicals, live microbes such as fungi and myco- and entomopathogenic bacteria, stimulators of plant growth and even beneficial nematodes, oils, soaps, sulphur and also synthetic products with innovative chemistries. The way in which a product is formulated or applied can also bring a pesticide into the category of organic products (Fanjul L. et al. 2006). It is therefore recommended to use a mixture of organic products as a substrate for transitional and permanent nurseries.

It is advisable to use some kind of black, virgin polyethylene boxes to prevent the root system from being damaged by sunrays. The recommended dimensions for these boxes are 50 cm long and 30 cm wide, with a volume of 230 ml and internal guides to direct the root system downwards. The plants should remain in the nursery for a maximum of four months. It is important to reuse the bags, and when they are no longer functional, hand them over to the authorities for an appropriate final destination.

Monitoring nurseries and young plants

In order to establish the success of the reforestation, it is necessary to identify and quantify survival, growth, causes of mortality and the number of leaves produced. Attacks on seedlings by pests or herbivores should also be recorded. Seedlings should be monitored on the field on a monthly basis.

Transplantation of forest seedlings with temporary stays in the nursery: seedlings extracted from the forest have a temporary stay in the nursery before being transplanted. This allows the root systems, damaged during extraction, to be restored and the health of the seedlings to improve. This is reflected in their survival, thereby reducing the stressful phase associated with transplanting to reforestation plots.

Transplanting trees: transplanting small trees of *R. mangle*, *A. germinans* and *L. racemosa*, over a year old and between 25 cm to 60 cm tall, at a distance of 5 m from each other, can guarantee a 65% survival rate, using the extraction technique described in this section. It is important to inject a root system replenisher at low tide *(in situ)* every week for two months before transplanting to the restoration site. To this end, organic products containing natural nutrients, proteins, carbohydrates, humic acids and rhizobacteria that promote vigorous, healthy plant growth are generally effective. Agraz Hernández et al (2004) reported significant benefits from the use of this type of product in addition to other bioremediation products such as certain Yucca species, seaweed (*Ascophylum nodosum*), nitrogen compounds, available phosphoric acid, soluble potassium oxide and maltodextrins, as well as bacteria from the *Bacillus* and *Paenibacillus* genera.

Rebuilding at Terraba Sierpe© C. Agraz Hernández

It is also advisable to trim 2/3 of the total leaf biomass before transplanting. This practice improves the root/foliage ratio, reducing any water imbalance during the period of adaptation to transplanting. Triming of *Rhizophora*, *Avicennia* and *Laguncularia* should be carried out with care, limiting triming to the twigs, and should not be carried out on the main shoots or branches (with the largest diameter). It is important to note that the cost of reforestation using this method is very high and that the success rate is lower than with the use of propagules.

Reforestation: it is advisable to establish a planting density with distances of between 1.5 m and 2.0 m. If you follow this planting pattern, you will obtain a density of between 4,400 and 2,500 plants per hectare. Higher densities are only recommended for sites where invasives are to be eliminated. One should take account of a mortality rate of 50 % due to factors such as transplanting, competition between seedlings and parasites, among others.

© C. Agraz Hernández

The density of seedlings or propagules proposed here is based on results obtained in Mexico without invasive species, where survival is high at the start of growth. Then, competition for natural space leads to mortality. It has been observed that at lower densities (plants spaced further apart), mortality is higher. On the other hand, using young plants or larger plants, greater spacing is recommended; the larger the plant, the greater the volume of root system it will need, so it is necessary to space the plants further apart.

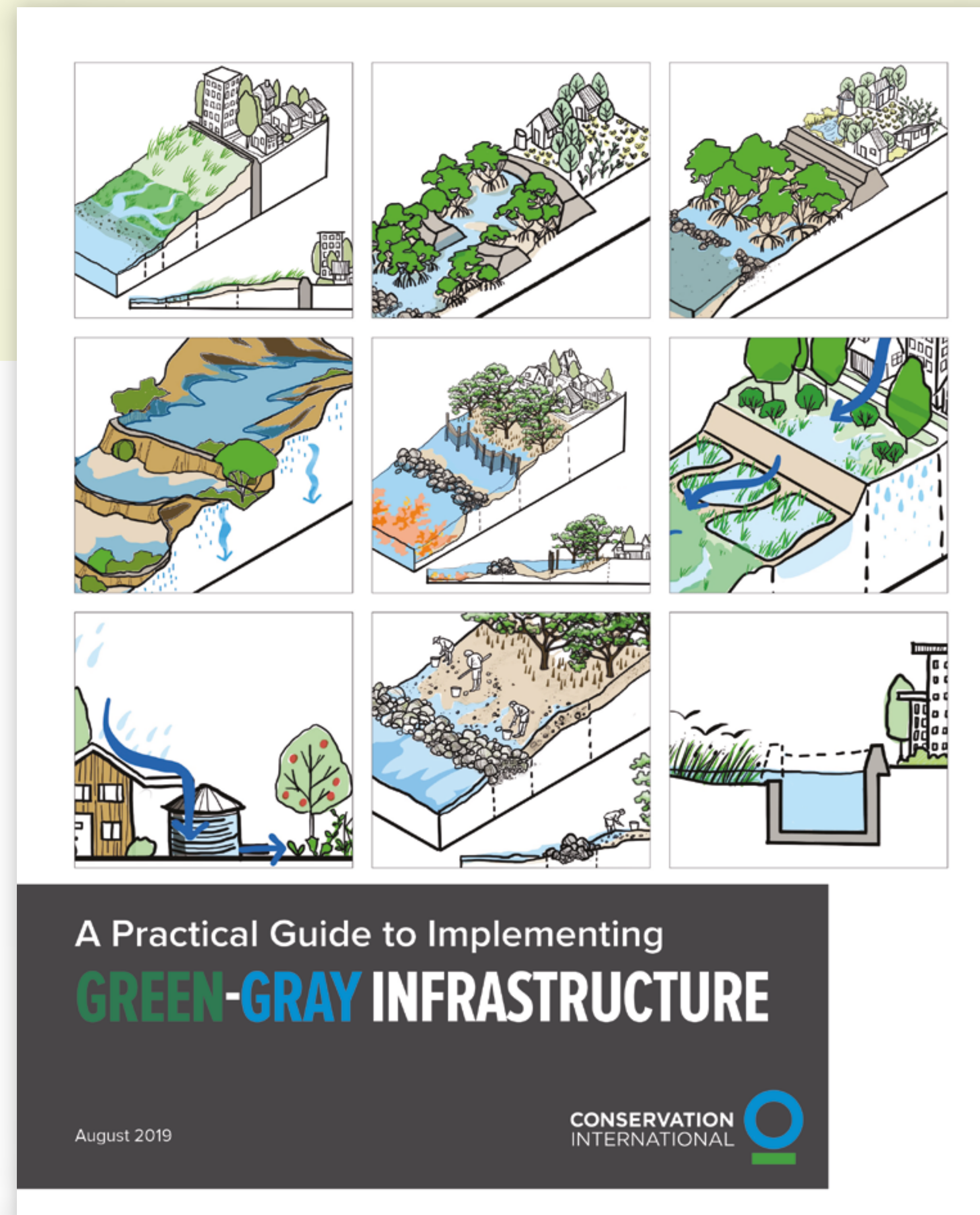
COMBINING GREEN AND GREY INFRASTRUCTURE

An original approach can also combine so-called "grey" infrastructure (traditional, engineering-based solutions) and "green" infrastructure (solutions based on nature, where the good condition of certain ecosystems contributes to the desired effect).

Green and grey infrastructure combine the conservation and/or restoration of ecosystems with the selective use of conventional engineering approaches such as dykes or breakwaters to mitigate waves and control flooding.

This present advantages in resilience and adaptation to climate change by combining the benefits of both solutions.

As part of a FFEM project in the Philippines supported by Conservation International, a practical guide to implementing green-grey infrastructure has been produced (2019) https://initiative-mangroves-ffem.com/philippines/



Traditional Niominka fishing net, Saloum delta, Senegal© Cormier-Salem, IRD

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CHAPTER 5

VALORIZING THE MANGROVE

Author: Marie-Christine CORMIER-SALEM

.1
INTRODUCTION

To meet the three pillars of the Convention on Biological Diversity (conservation, sustainable use and equity) and the objectives of sustainable development (adapting to climate change, maintaining life on land and at sea, fighting poverty and hunger, equity, etc.), international mangrove conservation policies (see general introduction) encourage the implementation of actions to enhance value on the field, for the benefit of local communities. The development of income-generating activities for communities is thus offered in most mangrove restoration projects, in particular to compensate for the restrictions on access to and use of resources resulting from these projects and to encourage users to make the rules theirs. However, increasing the income of mangrove dwellers is far from being the only way of enhancing the value of mangroves.

This section aims to explain the diversity of forms of mangrove's value enhancement and to describe the tools (economic, legal, institutional) that contribute to the conservation of these socio-ecological systems and their diverse components.

VALORIZING?

Valorizing means maintaining or restoring ecosystems to a healthy state, but also ensuring the well-being of local residents and users. Valorization or value enhancement initiatives are first and foremost economic opportunities, making it possible to reconcile conservation with a fair share of benefits. They are also opportunities to rethink local development and to design territorial development on new bases, by creating spaces for negotiation between all the stakeholders, from the local to the international level.

Figure 22. System of values associated with mangroves. (IPBES, 2022, https://zenodo.org/records/6810036)

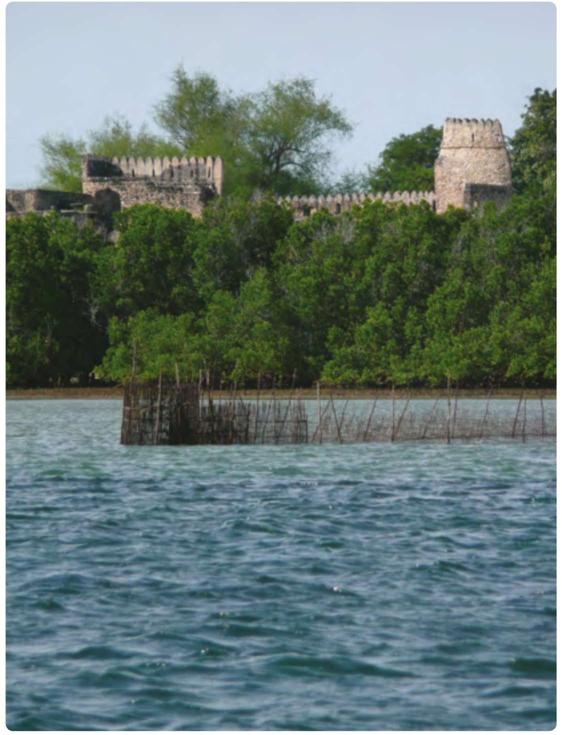
1.1 I WHAT VALUES?

Values can be instrumental, linked to the direct and indirect uses of natural resources and mangrove landscapes (see Appendix 1). In this case, they are measured in monetary terms, through the marketing of products from various extractive practices (fishing, wood cutting, salt collection, etc.). But these values can also be relational (heritage value, existence value, ritual value, etc.). Mangroves are not simply a commodity. They also provide services that can be developed, such as remarkable landscapes that are promoted as tourist sites, bird sanctuaries or marine protected areas. The mangrove in its various components can thus be recognised as a heritage, a space inherited from ancestors that the community wants to pass on, in its current state or enriched, to future generations. The symbolic, identity and sacred significance of mangroves should not be underestimated. Recognizing the ties that bind a community to "its" mangrove is a way of guaranteeing the resilience of the socio-ecological system.

To ensure the success of development initiatives, all development operators must follow two imperatives:

- Use local categories, practices, knowledge and rules of local residents and users as a starting point, and analyse how they relate (or do not relate) to other (academic) knowledge and standards, most often laid down at international level, and regulations (positive or official law). The valorization instruments studied (formalised 'recognition' instruments of the 'geographical indication(GI19), label, quality sign, park marks, eco-certification, etc.) must be considered in the light of the singularity of local contexts;
- Co-construct the approaches with the interested parties, support them and measure their added value with relevant monitoring indicators, defined at the start of the process: how do these approaches help to increase the economic income of communities and recognise mangrove users with their rights, knowledge and links to the mangrove.

This guide is not prescriptive; it provides a framework to "guide" or direct any stakeholder in the field (operator, manager, NGO, association, etc.) to ask the right questions, grasp the opportunities and anticipate the risks.



The Kilwa Islands, off the coast of Tanzania, a remarkable heritage© Cormier-Salem, IRD

There are two parts to this chapter:

1. initiatives to valorize mangrove products, referred to as "localised productions".
2. Promoting mangrove heritage through eco-tourism, museums and eco-museums.

In both cases, the questions to ask are: Who? What? How?
Examples are provided, based in particular on fieldwork carried out in West Africa.

The creation of mangrove as a local heritage is a process of collective claim, linking past (memory or tradition), present (territory, identity) and future (intergenerational transmission).

.2 VALORIZING MANGROVE PRODUCTS

Mangrove products should never be preselected by the operator, but always identified with the groups concerned. The aim is to understand what makes sense to them, what belongs to their heritage, what has a history, a tradition and a link with their territory.

The first step is therefore to answer the "who" question: identify and recognise the actors; the second step is "what": what are the products and associated practices; and the third step is "how": measure, evaluate, give monetary value, develop signs of recognition and promote the product.

2.1 | STEP 1: IDENTIFY THE STAKEHOLDERS INVOLVED AND THE TARGETS

Enhancement initiatives must answer a demand from stakeholders in the value chain, i.e. producers, distributors, processors, traders and finally consumers or final users. Very often, they are initiated by stakeholders foreign from the environment, to compensate for the introduction of an MPA or a restriction on use, for example. In both cases (bottom-up or endogenous approach) and top-down (or exogenous approach), the target stakeholders must be identified; they are the ones primarily concerned by the process; in our case, they are the local mangrove users.

The operator must therefore identify these stakeholders using an inclusive approach, i.e. endeavouring to take into account all these stakeholders (regardless of gender, age, race, status, etc.) or groups of stakeholders, which often means using various techniques for gathering information, which are classic in social sciences (individual interviews with a representative sample of the site concerned, semi-open surveys, discussion groups, etc.). Depending on the context, it may be important to organise several groups according to gender, age group, caste, etc. to enable them to express themselves more openly.

The aim is to understand their knowledge and practices, as well as their needs and aspirations in terms of promoting mangrove products.

THE VALUE CHAIN, in the case of mangroves, refers to all the stakeholders and activities that take a mangrove product from the production stage (extraction of the resource: fishing, gathering, hunting, agriculture) in the various areas (from salt-rich areas to back mangrove tannas to the seafront), to the product processing, then to distribution and marketing, through to final consumption, a process in which value is added to the product at each stage.

2.2 | STEP 2: IDENTIFYING PRODUCTS AND THEIR POTENTIAL MARKETS

Saltworks operated by the women of Niodior, Gandoul Island, Senegal © Cormier-Salem, IRD

There are many mangrove products that could be better known and recognised. Several examples are listed in Appendix 1, along with the associated uses. This diversity of products deserves to be known and recognised (traced, labelled) within the framework of a more or less formalised document, or specification, highlighting the target species, the production's perimeter or location, the production and transformation processes.

The operator therefore has to make choices, but on what basis? The expectations of the communities and the feasibility of selling the products on the various markets are central.

While the starting point must be the local context, we must not lose sight of the outlets or target market for each product, which will largely determine the types of instruments used to qualify and promote the product. For example:

- Placing products on a local weekly market does not justify costly and time-consuming certification procedures, since local relationships based on trust and direct transactions between producers and consumers are the best guarantee of traceability;
- On the other hand, the certification process is worth the cost for a niche market, an export market and a high added-value product.

Markets will therefore be studied at local, national, sub-regional and international levels, depending on the product.

CONCEPTS TO BE CLARIFIED:

- The term **"localised production"** is preferred to "local product". It refers to a production system characterised by a local presence and a product whose specificity is partly due to its origin. The link to place is most often expressed explicitly in the product designation. *For example, oysters known as Casamance oysters are clearly from the Saloum delta on the Dakar markets.*
- **Quality:** product quality is intrinsic, i.e. it relates to the product itself from a nutritional, organoleptic and health point of view, and extrinsic, i.e. it relates to its environment and the conditions under which it is produced (eco-friendly use, respect for animal welfare, ban on child labour, etc.). The product's quality is linked to its place of origin and/or to the knowledge and skills of its producers.

Mangrove honey, produced by the same species of bee (Apis mellifera), has a different quality depending on the plant species foraged but also on the collection methods and therefore the know-how of the beekeeper.

Mangrove honey, Niodior, Saloum delta © Cormier-Salem, IRD

The further a market is from the production site, the greater the opportunities for adding value to the product, but also the greater the risks, with the entry of stakeholders such as intermediaries who can divert part of the profits to the detriment of local stakeholders.

2.3 | STEP 3: CHOOSING THE RIGHT APPROACH, TOOL OR SYSTEM FOR VALORIZING YOUR BUSINESS

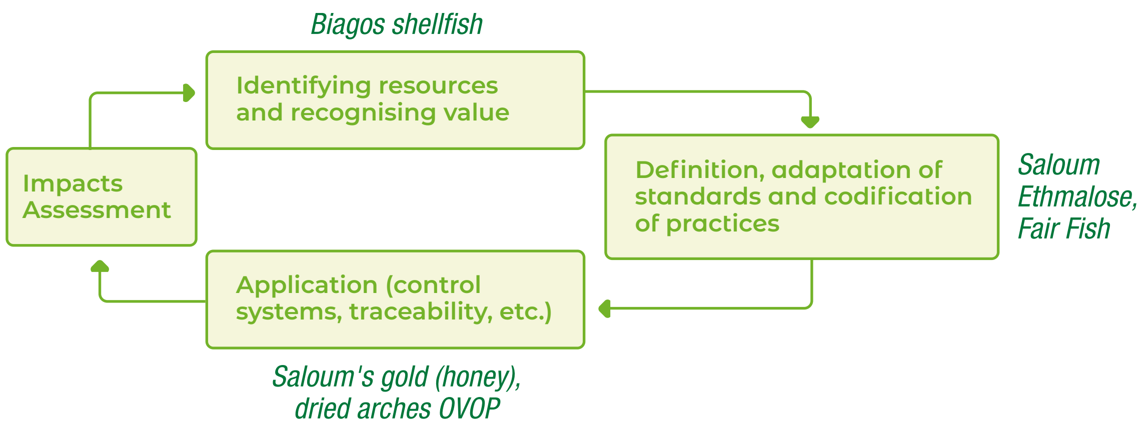


Figure 23. Stages in the process of qualifying localized production: examples from West Africa, showing that the process is far from complete.

There are various more or less sophisticated stages in these approaches, depending on the product and the context, the simplest stage being trust between producer and consumer, which recognises the quality of the product, with the most elaborate being labelled local products, for example under the European PGI Protected Geographical Indication label[23] :

- The first stage of value enhancement is therefore the one that brings added economic value, but also a valorization in terms of identity, knowledge, etc. (hence the importance of defining what values and value enhancement are); it is a question of simple identification and recognition, without a label, without a "completed" labelling process.
- More advanced qualification procedures for local production are interesting for products that are a little exceptional (cf. above: niche market, export market, product with high added value). A wide variety of labels exist to promote these products. These are voluntary and more or less restrictive.

A wide variety of labels: There are diverse signs of recognition or instruments for labelling products, including (or among the best known): Protected Geographical Indications (PDOs and PGIs in the EU), park brands, fair trade (Fair Trade, Origin, Slow Fish), organic and red labels, eco-certification (e.g. Marine Stewardship Council). According to works carried out in West Africa, these approaches are costly and restrictive, especially for highly perishable fish products that do not meet the diktat of international health standards, if not to the detriment of the product's typicality: what would be a "yet", *Cymbium spp.* fermented and dried, that met international health standards[24]? If we have to give up qualifying these products for export to the European market, other outlets are conceivable (see Box 3). This point is essential. The operator must therefore carry out a proper market study and consider various market segments: local, national, sub-regional and international.

These value-adding approaches are innovative, and as with any innovation (technical, economic, institutional), it is important to identify the opportunities (added value, recognised value, material and immaterial benefits) including the preservation of biological and cultural diversity and the risks (commercialisation, the diktat of sanitary quality... to the detriment of specificities and typicities).

FIGURE 24. WHAT THE OPERATOR MUST DEFINE WITH LOCAL STAKEHOLDERS :

Location,

Setting standards ("specification")

and **traceability** (the origin or provenance of the product)

CHOOSING THE MOST APPROPRIATE APPROACH AND TOOLS

Depending on objectives, context and resources:
- Standardisation: ISO;
- Labelling, official sign of quality, certified or not: trade, fair trade, BA, red label, etc.
- Intellectual property rights:
- individual brands,
- collective brands (parks, etc.),
- designations of origin (AOC/PDO, PGI)

THE PARTNERS

Quite often, the tools and approaches are exogenous, coming from external stakeholders, but they can also be endogenous.

The operator must be attentive to this aspect, giving priority to local logic, without excluding potential, external support.

Finding the right compromises between the various logics and fruitful "hybridisation".

Fadiouth cemetery, shellfish island, Senegal © Cormier-Salem, IRD

LOCALISED MANGROVE'S PRODUCTS IN SENEGAL AND GUINEA BISSAU

The mangrove products valorizing by local communities are shellfish (Arca spp, Murex, Pugilina, Cutilena) and honey in Boloma-Bijagos Archipelago Biosphere Reserve, and shellfish (Arca spp, Murex, Cymbium, Crassostrea gazar), honey and salt in the Saloum Delta Biosphere Reserve. Most of these local products have a reputation, with a clearly identified place of origin that reflects a whole system of production-processing-marketing and the know-how of certain well-recognised stakeholders. Their typicality gives them a sought-after quality and therefore a higher price on the market. They are intended for the domestic market, and are based on relationships of trust and proximity between stakeholders in the sector. They do not require the extensive certification procedures required for PDOs and European labels (see below).

The OVOP label is one of a number of labelling schemes adapted to the local context.

"One Village, One Product", supported by the Japanese International Cooperation Agency (JICA), aims to enhance the image of rural areas suffering from depopulation and to promote income-generating community initiatives through the recognition of local specialities. The label is original, it focuses less on the quality of the products than on the ability of those involved in the sector to organise themselves, become independent and control the value-chain. Launched in 2011 in Senegal, this label has been awarded to various EIGs (Economic Interest Groups) that promote mangrove products: Murex (or tuffë) by the EIG of Ngodane, honey by the EIG Mboga Yiff, fishery products from EIG Gnassemane.

For example, the EIG of the Saloum islands brings together women from the village communities of Falia, Dionewar and Niodior, who master the shellfish value chain. In 2012, this EIG was awarded the OVOP label, which has enabled it to improve drying techniques (drying racks and hygiene rules), acquire collection equipment (knives to remove the skin from the oysters, boots and gloves), drying equipment (solar-powered drying racks), vacuum-packing and labelling, and to overcome three bottlenecks: access to credit, information and training, and finally, to the market, to ensure they are no longer dependent on the bana-bana, intermediary traders.

Adding value to local products is a means of economic and social empowerment for women and an alternative to rural depopulation (particularly the mass departure of young people) and over-exploitation. On this last point, according to surveys carried out in the Saloum Delta (Sarr et al., 2009), the increase in the sale price of shellfish means that women are better paid for their work. One might fear that women may be tempted not to reduce their pressure on resources, but rather to increase it in order to earn more money. However, apart from respecting the rules of use and access to the mangroves, they are constrained 1) by the tidal cycle (they only fish when the tide goes out) and 2) by other domestic and productive activities.

This example shows the importance of regulation and value-enhancement mechanisms established in consultation with users in order to sustain the value chain.

EIG of Niodior, Gandoul Island, Senegal© Cormier-Salem, IRD

WILD MANGROVE SILK IN MADAGASCAR

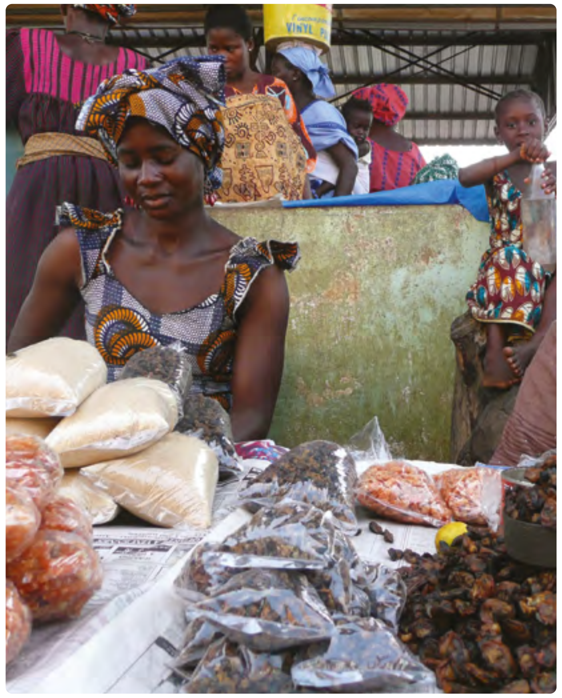
Wild silk (Borocera cajani/madagascariensis) is currently produced in Madagascar's mangrove forests, in the Boeny region.

Women's groups have been set up to collect the cocoons, spin and weave this wild silk. Cocoons and silk threads are the two main products destined for export. They stand out on the international market because of their very specific characteristics.

Silk cooperatives have been set up by the "Femmes entrepreneures environnement Mahajanga" (FEEM), who have been involved in the wild mangrove silk industry for over 20 years, right through to the final woven product. Natural dyes from plants are used to dye the weavings and make the silk products. The organisation creates jobs for around 200 women, particularly in the commune of Boanamary.

2.4 | CONCLUSIONS

Certification systems for products derived from biodiversity, such as mangroves, are complex, restrictive and even exclusionary. Because behind the protection of a name, a method of production and a geographical origin, in the logic of free movement of products, labelling systems are accompanied by complex quality control procedures (intrinsic and extrinsic) including hygiene. Operators must therefore ask themselves how these value-enhancement tools can be adapted to meet the expectations of local populations and improve their well-being, while satisfying the objectives of conserving biological and cultural diversity, and without deviating from the product, depriving it of its typical character or excluding stakeholders.



Boucotte market in Ziguinchor, Casamance, Senegal© Cormier-Salem, IRD

Table 6. Points of attention for the operator

ANTICIPATING POINTS OF TENSION	HIGHLIGHTING OPPORTUNITIES
Link between the product and its origin (places of extraction, collection, transformation)	Market segmentation and expansion
Standardising procedures	Valorizing ecological services
Marginalisation of certain stakeholders	Setting up original local schemes
Potential impact on biodiversity	Fighting heritage theft

.3
PROMOTING MANGROVE HERITAGE

Given the uniqueness of local contexts, the aim of this section is to guide the operator in providing relevant (sustainable and equitable) support for initiatives aimed at enhancing the value of mangroves as a heritage, whether material (various components and levels: genes and species, populations and communities - animal, plant and mineral, etc.) or non-material - (knowledge and know-how, oral traditions, tales and myths, dances, rituals, etc.).

As with any approach to valorizing natural resources, the operator must ask himself the following questions:

- What are the heritage objects that should be on show, that make sense to local stakeholders, that are likely to be staged?
- Who are they being shown to? Who are the targets?
- What instruments are likely to be mobilised and to meet what expectations?
- How can we assess the success and limitations of these approaches?

A range of activities can be considered,

- On the one hand, relatively traditional activities such as discovery tours, birdwatching trails, and land or underwater trails,
- On the other hand, exhibitions, festivals, fairs, resource centres, heritage centres, etc. These events can be temporary, ephemeral or permanent, seasonal.

THE NATURAL HERITAGE OF MANGROVES

A set of living organisms (natural and cultural) or elements of biodiversity that a group considers sufficiently essential to its identity and collective memory and that it wishes to preserve in order to pass them on to future generations. There appears to be three main characteristics (Cormier-Salem and Roussel, 2000): these elements are supposed to be inherited from ancestors, sufficiently appreciated and valued to be passed on to future generations and to serve as identity references for a community. It can include plant and animal species (mangroves, tigers, crocodiles, turtles, birds), ecosystems and landscapes (e.g. the shell mounds of the Saloum delta, classified as cultural landscapes) and local naturalist knowledge.

Ecotourism circuit in the Gandoul islands, Saloum delta © Cormier-Salem, IRD

3.1 | DISCOVERY TOURS AND OTHER MANGROVES TOURS

Boat trips to observe the flora and fauna are undoubtedly the most widespread way of promoting mangrove tourism. The operator should care to identify the impact on the local population; such excursions, which are often offered as part of tour operators, who hardly share the economic benefits with the communities, except through the remuneration of a few individuals from the riverside villages, employed as pirogue drivers and guides (see Box: Developing tourism of the Gandoul Islands).


Shellfish beds at Niodior, Gandoul Island© Cormier-Salem, IRD

DEVELOPING TOURISM ON THE GANDOUL ISLANDS, SENEGAL

The Saloum delta in Senegal has touristic opportunities thanks to its rich natural heritage (mangroves, birds, dolphins, turtles, etc.), which was designated a National Park in 1976, a UNESCO Biosphere Reserve in 1981 and a Ramsar site in 1984. Its appeal to tourists is also due to its cultural heritage, namely the thousands of shellfish cluster, which are both archaeological remains that served as tombs for notables, sacred sites and modern constructions linked to the ongoing exploitation of shellfish. In 2011, the Saloum delta was included on UNESCO's World Heritage list for its cultural landscapes. These attractions give rise to several forms of tourism development, including pirogue excursions in the tidal channels, and fauna discovery trails, as well as picnics and swimming along the riverbanks. However, this green manna is more often than not monopolised by private operators from outside the area. Mangrove dwellers denounce the low economic benefits from these activities and the inconvenience caused by these mass visits, such as the costly upkeep of the sites and the difficulty of managing waste in island environments, not to mention the trampling of the sites, disturbance of the fauna, noise pollution from motors, etc.

Somone ecological trail
© Awa Ndoye

ECOLOGICAL TRAIL OF THE SOMONE MPA, SENEGAL

The Somone Natural Reserve of Community Interest, created in 1999 and set up as an MPA in 2020, covers an area of seven hundred (700) hectares. It is a historical, religious and cultural heritage, with sites such as the well of El Hadj Omar Foutiyou Tall, the protective genie (Keur Sangu) and the dwarf baobab.

The MPA is also home to a 1.2km ecological trail, a strip of land surrounded by mangroves and the Somone lagoon. Set up in 2011 by a French volunteers' couple, this trail offers a wealth of discoveries: more than 57 species of birds (pelicans, herons, egrets, pink flamingos, ospreys), crustaceans (fiddler crabs, prawns), molluscs (Senilia senilis, Crassostrea tulipa), 27 species of fish, jackal (Canis mesomela), green monkey (Cercopisthecus aethiops), white-tailed mongoose (Ichneumia albicauda) Nile monitor (Varanus niloticus) and green turtle (Chelonia mydas). There are several tours on offer: a pirogue trip on the lagoon to see the bolongs, mangroves and birds, walk along the ecological trail past the oyster-farming women's restaurant, horse-drawn carriage excursion to see jackals at the tannes, visit to the craft village.

The MPA management committee has introduced differentiated rates according to the origin of visitors and their status: schoolchildren do not pay, nor do researchers; the price paid by a Senegalese is different from that paid by foreign tourists.

Part of the revenue is paid to the four villages surrounding the MPA and managed by the women's associations, which have been involved in the conservation of the site and the development of the oysters from the beginning. Another part of the revenue is used to maintain and develop the ecological site.

Local residents would like to see this pathway better known and promoted, given that it lies at the heart of one of Senegal's main seaside tourist regions.

3.2 | MUSEUM ENHANCEMENT

Given the lack of museum initiatives promoting mangroves, this section aims to inform operators about such initiatives and provide guidance. The operator, accompanied if possible by museologists and museographers, must explore various forms of valorizing tangible and intangible heritage to encourage their complementarity; it will be in their interest to organise them into a network, for example:

- a village-wide community museum, where objects are collected, authenticated, documented, inventoried and presented in exhibitions,
- a living museum that celebrates a ritual with the objects that enter and leave the museum, hence the notion of "living" cultural objects,
- a cultural training centre to preserve heritage and develop traditional and cultural activities.

THE SEAFOOD CENTRE, A PROJECT IN MBOUR, SENEGAL

At the request of artisanal fishing professionals and following several months of consultation with local stakeholders from the Petit Côte and the Saloum islands in Senegal, it was decided to design a regional museum, in one of the villas in the centre of Mbour, focusing on seafood and mangrove products, including:

- **exhibition rooms** showcasing species, knowledge, processing techniques, fishing gear and the geographical environment, with one room dedicated to mangroves and the fishing of marine invertebrates (as well as salt and mangrove honey), and another to the coastline, sea fishing and other fish products;
- a **shop** selling local products from the sea and mangroves;
- a **tasting area** for culinary specialities based on these same products.

This house, located in Mbour on the Petite Côte, was to be **networked with other sites, managed directly by local stakeholders**, in the Gandoul islands (interpretation centre at Niodior, resource centre at Toubakouta), a living museum at the Mbour fishing quay, and another at Mballing, where fish products are processed.

Objects from an museum, Senegal
© Cormier-Salem, IRD

3.3 | VADEMECUM FOR SETTING UP AN ECO-MUSEUM OR COMMUNITY MUSEUM

The main questions to guide the operator are as follows:

What objects should be displayed? What heritage to showcase?

- About the collections or collection of so-called heritage objects, both natural and cultural, tangible and intangible, how can they be enriched and enhanced? Who chooses? According to what criteria?
- Who has knowledge? From systematics experts and taxidermists to bird guides and amateur ornithologists. Particular attention should be paid to local knowledge and traditional practices.
- How are objects collected, stored, handled and preserved?

What is the target audience or who are the targets?

- Several itineraries can be designed depending on the target visitors: young people from the villages, who no longer know their heritage, schoolchildren accompanied by their teachers, national or international tourists, adults or children (requiring an educational, more playful approach and objects at the level of the young public);
- If foreign visitors are targeted, we need to look at the reception conditions and capacity, and even consider quotas to avoid damaging the site.

By what means?

- If the target audience is primarily local or national, free admission to museums seems unavoidable, but then what kind of support and subsidies are available for these museums?
- If the public is foreign, income can be generated by promoting local products, culinary specialities or handcrafts: without offering the same products as those found on every market, you need to offer "top-of-the-range" contemporary products that showcase the creativity of craftspeople, highlight local materials and local knowledge adapted to the modern world.

What kind of governance? Which stakeholders? For whom? Who benefits from it? What are the benefits for local communities?

- One of the sensitive issues that the operator must address is the contribution of civil society, whether as actors or spectators in the staging. This point is linked to the legal status of the museum's project, with various levels of involvement of local stakeholders in the governance of the structure: They can be "simple" informers or suppliers of objects for a resource centre, guides to define and accompany the routes of an ecological trail, consultants to create dioramas and panels for an exhibition, or even ex officio members of the management committee of an eco-museum. The involvement of civil society varies greatly from one project to another, and this point must be clearly explained when the Scientific and Cultural Project (SCP) is drawn up.
- The operator will be keen to be inclusive and to implement processes enabling effective consultation and coordination between the stakeholders on an ad hoc scale, in order to diversify the staging offers, avoid competition, ensure that the actions complement each other and enhance the specific features of the villages, and respond to the diversity of expectations and demands at various scales and according to the stakeholders.

BRINGING LOCAL MUSEUMS TO LIFE: THE SANGAWATT MUSEUM IN DIEMBERING, SENEGAL

The Sangawatt living museum is the brainchild of a young man (Ousmane D) who has returned to his native community after several years spent in Dakar and abroad. It is a journey of discovery into the Joula animist culture, with all its components, including the mangrove forest. The sacred forest is staged by Ousmane D., who welcomes visitors in a traditional costume and with ritual songs. This museum aims to be a showcase for the ritual heritage of the Joula land and a place where many young adults can meet, exchange ideas and find employment.

- Another sensitive issue is the risk of folkloric representation or romanticised and fixed portrayals of local communities' lifestyles and resource management practices. Certainly, there are traditions that should be highlighted, but traditions are constantly being reinvented and must adapt to global changes, which encourages innovation (see box 'Objects to collect or create: examples of fishing gear').

OBJECTS TO COLLECT OR CREATE: EXAMPLES OF FISHING GEAR

In the Saloum delta in Senegal, nets that were once made of cotton are now made of nylon, and nets and traps made of plant fibres are now made of plastic. All these objects, old and new, have their place in a museum.

3.4 | GENERAL RECOMMENDATIONS TO MAKE THE MOST OF THE CULTURAL HERITAGE OF MANGROVES

Heritage enhancement offers from the mangrove, really designed with the stakeholders on the ground, showing its diversity and uniqueness, are still very limited in number and poor in terms of the objects presented, often repetitive and not very well thought out in relation to the local context.

These forms of valorization offer opportunities in a variety of ways: as a means of providing symbolic and economic recognition to local knowledge, of empowering local users, of attracting a new audience, and of supporting the education and transmission of heritage.

The operator will be careful to anticipate the internal contradictions of these innovative approaches, insofar as choices have to be made, which very often result in the loss of objects that have not been selected; there is a risk that the narrative will fix in tradition, and that the objects exhibited will see their meanings deviated. The commodification of living things can lead to asymmetries between stakeholders. It is recommended to:

Diversify

- Diversify the tools by testing them in the field (operationalisation), and by exploring more artistic approaches to promoting them (e.g. choreography in the mangroves), as well as more playful or convivial formats (culinary workshop, tasting, recipe book, etc.);
- To diversify the range of activities on offer, whether for museums, tourism or socio-cultural purposes, in line with visitors' requests and the expectations of local populations;
- Making visible the creative singularity of the populations and their modes of attachment to the mangrove:

1. In addition to permanent exhibitions, we also need to design virtual and ephemeral museums, as well as more educational websites, especially for secondary school students;
2. Contextualisation is essential because it highlights strong local specificities, which are a source of richness;
3. The "character" of each site (as with each protected area or national park) needs to be enhanced to make it more attractive to visitors. Sites should complement one another, and circuits or networks of sites should be developed.

Training, information and exchange

It is advisable to be accompanied by museographers and museologists in order to :

- Inform operators and mediators about the various possibilities and the most appropriate schemes to the local context; also to help them draw up specifications for a sign of recognition for local production, or an eco-tourism or ecomuseum charter;
- Training guides, ecoguides and curators :
  1. on museological techniques,
  2. on the scientific information to be passed on to visitors.
- Carry on the co-construction or co-sharing knowledge;
- Scale up through exchanges of experience.

CHAPTER 6

6 MONITORING AND EVALUATING THE RESTORATION'S EFFICIENCY

Authors: Claudia AGRAZ HERNANDEZ, Julien ANDRIEU and Marie-Christine CORMIER-SALEM

.1

MONITORING THE ECOLOGICAL RESTORATION'S PROCESS AND EVALUATING THE RESTORATION'S EFFICIENCY

Restoration monitoring is a lenghty activity, from the reference state (T0) of the diagnosis, then throughout the restoration process and finally after the restoration, in order to assess its success and long-term evolution, up to many years later. However, the time available for projects does not always allow for post-project monitoring to continue, and this monitoring must then be taken over by a local or national body. If several of these monitoring activities require scientific knowledge, various levels of monitoring can be scientific:

A restoration action is considered successful when a plant species' survival rate of at least 85% is achieved. At this level, mangroves can regain a functionality similar to that of natural stands and continue to develop (Komu, 2021).

Assessment by trained managers, rapid assessment by communities. The Merci-Mangrove method (Chapter 3) can in this case be used during and after the restoration.

1.1 | SPATIAL ANALYSIS USING REMOTE SENSING

Issues of scale and resolution discussed above for the use of remote sensing in feasibility diagnoses are similar for monitoring. However, there are a number of additional complexities.

- Monitoring is generally carried out at the time of the post-ex assessment (i.e. shortly after restoration), which makes remote sensing monitoring tricky if the plants are low and spaced out. Waiting until the vegetation is tall and dense for monitoring does not correspond to the timing expected by the stakeholders of the project.
- Like the diagnosis, such monitoring needs to be enriched by an analysis on a smaller scale (the immediate surroundings).

If Google Earth offers high-resolution images from shortly before the project that are comparable (season, tide) to a recent image, a simple diachronic visual interpretation is possible:

- digitise the areas restored without mangroves before the project,
- digitise the areas covered by mangroves after the project,
- extract surfaces, publish the map.

If the area is large enough and the mangrove is dense enough, the use of multispectral satellite images (Sentinel-2) will be interesting, as this will make it easier to produce reproducible maps of the dynamics of the mangrove on the restored site and its environment. This way, we will be able to compare the effects of restoration with other environmental dynamics that have influenced the mangrove at the same time.

FIRST EXAMPLE: THE SENEGAL RIVER

Remote sensing mapping of the dynamics of the Senegal River delta initially shows that mangroves have increased in the project area (WACA project at the mouth of the Senegal River near Saint Louis). However, this observation needs to be qualified by the simple fact that, as a whole (like all the mangroves in Senegal), the mangroves in the river delta are naturally in a spontaneous regeneration phase in response to the resumption of rainfall since the mid-1990s; successful restoration should therefore have generated increases greater than the natural changes (if they had accompanied this dynamic), but here they are less than those quantified on the scale of the delta.

1.2 | ANALYSIS OF PASSIVE ACTIVITIES IMPLEMENTED

The assessment will aim to measure progress in terms of the integration of mangroves included within protected perimeters, improvements in mangrove management and shifts in community perceptions of mangrove use towards more sustainable practices.

1.3 | CONTINUOUS ANALYSIS OF BIOPHYSICAL PARAMETERS

During the restoration phase (temporal and spatial monitoring): all parameters relating to the structure of the mangrove, the distribution of mangrove species, the hydroperiod, the topography and the physico-chemical parameters of the water and sediments studied in the diagnosis, which determine the distribution of mangrove species, will have to be monitored monthly, or at least four times a year, and compared with those of the reference site, throughout the restoration phase.

Regular comparison with the T0 (diagnosis) of the restored site and with the reference site will ensure that the parameters of the restored area remain within the desired ranges in relation to the reference areas.

This will make it possible to check the quality and efficiency of the hydrological rehabilitation and, if necessary, revise the strategy.

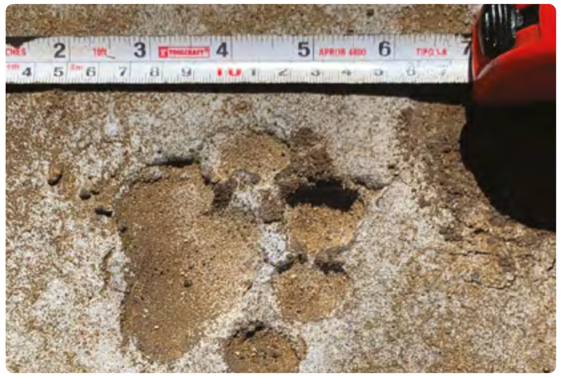
If circumstances allow, seasonal monitoring is desirable. Experience has shown that many hydrological rehabilitation and reforestation programmes, carried out empirically without taking into account seasonal variations in these parameters, result in only limited reforestation success, with survival rates of less than 40%. There may be a number of reasons for this, such as the fact that the seedlings were not subjected to adequate flooding conditions during a certain period of their development.

ITEMS TO FOLLOW	PARAMETERS TO BE TAKEN INTO ACCOUNT	SAMPLING MODE
Forest structure	Density, frequency, height, basal area, dominance, IVI	Two 100 m2 quadrats (10x10) in each physiognomic type (facies)
Hydroperiod	Frequency, height and duration of flooding	Markers installed every 10 metres along the vegetation profile to measure the height of flooding, from sea to land, covering the different physiognomic types (facies).
Soil topography	Field heights	Restoration site< 20 ha: level bottle method along the vegetation profile Restoration site > 20 ha: RTK (Real-Time Kinematic) method: various points in the area to be studied
Salinity, pH and potential parameters redox, nutrients pore water	Salinity, pH, oxidation-reduction potential, Nitrites, nitrates, ammonium, sulphates and phosphates	Restoration site divided into 100 m x 100 m plots; at least 8 piezometers per ha buried to a depth where the root system is most developed (around 50 cm from the sediment surface)
Mangrove peat* (Sediment)	Granulometric study of the three fractions (sand, silts and clay), and total organic carbon**	Soil samples taken at various depths in the first 20 to 30 cm
Invasive species	Characterisation and ecological impact, biodiversity, physico-chemical parameters, alterations to the nutrient cycle, decomposition and water dynamics	Identification, determination of presence, distribution and density. Comparative monitoring plots need to be drawn up. Define propagation mechanisms.
Monitoring environmental parameters and biological variables relating to the recovery process at 2, 5, 10 and 15 years	Density of reforested individuals and invasive species	Divided into plots of 10 m× 10 m; at least 4 per hectare, counting the total number of living individuals over time
	Vertical growth rate	In plots measuring 10 m× 10 m, tag 30% of the individuals and measure the total height of seedlings and juveniles (< 2 m) with a metric tape, from base to apex, and that of trees (> 2 m) using a clinometer. Frequency of measurement: every 6 to 12 months
	Survival	In the sample plots, count the number of living individuals and, starting from , establish the percentage survival over time
	Canopy coverage	GIS analysis using satellite images or drones to compare changes in the canopy
Natural regeneration	Richness and diversity of species	Shannon-Wiener index (H'): assesses specific diversity as a function of relative abundance
	Importance Value Index (IVI)	Simpson index (D): measures the dominance of certain species in the ecosystem
	Seedling and juvenile density	By counting the total number of living individuals over time
Recovering ecological connectivity	Habitat coverage and continuity	Using satellite images, GIS and drones to measure landscape connectivity
	Density and distribution of ecological corridors	Number and location of habitat islands facilitating species mobility
	Frequency observation	Using photographic traps and direct observation
	Bioindicators	Measurement of herbivores, detritivores and propagule dispersers, as well as crabs, molluscs, herbivorous and carnivorous fish

Table 7. Elements to be monitored over the long term to assess the recovery process

** organic sediment rich in decomposed plant matter*
*** Assess sediment fertility and carbon storage capacity.*

The information in the table opposite will be applied in the same way to the reference site. A comparison between the results obtained on the restoration and the reference site will be carried out. This reference will enable us to refine the strategies, methods and techniques for restoration, in order to restore the structure and functionality of the ecosystem in the best possible way.



Restoring the mangroves of Cuajiniquil and Terraba Sierpe: the return of wildlife © Chavarría Díaz and E. Delord.

After the restoration phase: To assess the success of the ecological restoration, T0 (start of restoration) is compared with years T3, T5, T10 (depending on the species installed by natural regeneration or reforestation), using the same methodology as for the environmental diagnosis (table 7).

There are also parameters relating to the recovery process:

- natural recruitment rate,
- plantation survival rate,
- growth rate,
- forest structure and stand diversity (specific richness and diversity),
- recovery of carbon storage and sequestration capacity.

Assessing the quality of the habitat, in terms of the fauna returning to the site (birds, fish, crustaceans, mammals) is also a very good indicator; among the indicators of fauna recovery, the specific richness and diversity and the size of individuals should be analysed in particular.

Monitoring using the RAM-Mangroves method

In addition to the above monitoring tools, the RAM Mangroves method, presented in chapter 3 (and appendix 2), is a useful complementary tool for managers. This method is only relevant for monitoring in cases where it has been deployed upstream of the project to characterise the initial state. It can thus be used to estimate the potential socio-ecological gains induced by restoration actions. However, it is crucial to emphasise that this method cannot replace the entire monitoring system. Indeed, monitoring efforts must be carefully tailored to the specific restoration objectives of each project, taking into account the ecological and socio-economic particularities of the area concerned. This personalised approach ensures that monitoring accurately reflects the effectiveness of restoration interventions.

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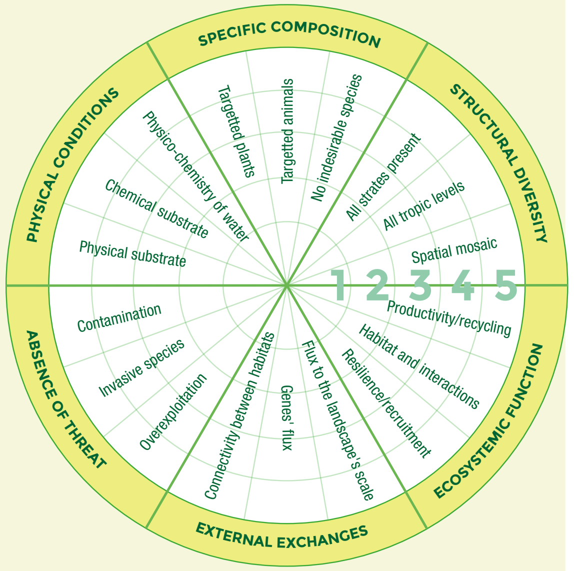
EVALUATION MODEL
OF THE ECOLOGICAL RESTORATION COMPANY

For assessing ecological and socio-economic restoration, it is recommended to use the project assessment model - Wheel of Recovery - from the Society for Ecological Restoration (SER - McDonald et al, 2016).

This system is used to assess the progress of an ecosystem on an ecological recovery trajectory compared with the reference model. This model is based on a series of ecological parameters (below) and socio-economic parameters (corresponding paragraph).



1. Specific composition
Targeted plants
Targeted animals
Absence undesirable species

2. Structural diversity
Recovery of vegetation strata
And trophic levels
Spatial diversity of habitats

3. Ecosystemic function
Productivity/recycling
Habitat and plant-animal interactions
Resilience, recruitment

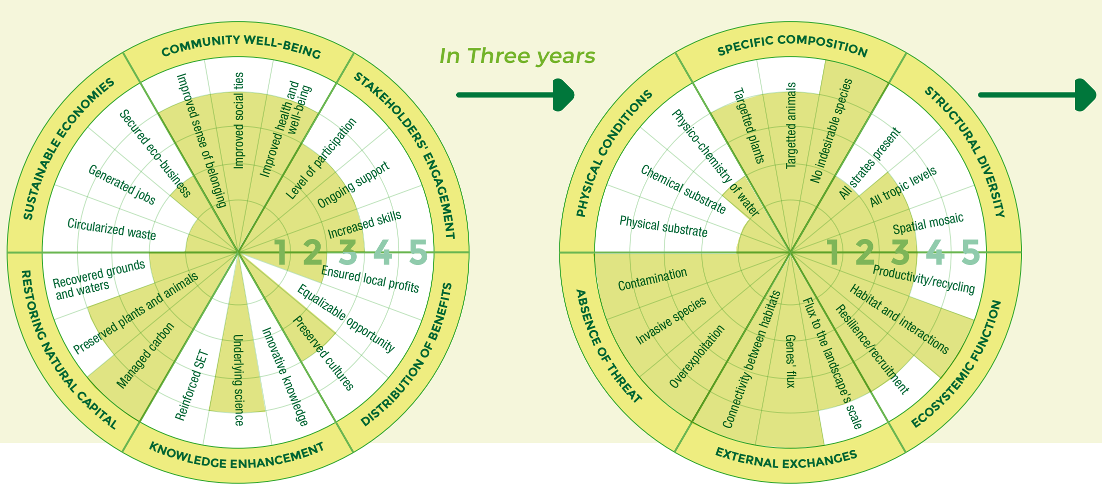
4. External exchanges
Flux to the landscape's scale
Gene flows
Connectivity between habitats

5. Absence of threats
Overexploitation
Invasive species
Contamination

6. Physical conditions
Physical substrate
Chemical substrate
Physico-chemistry of water

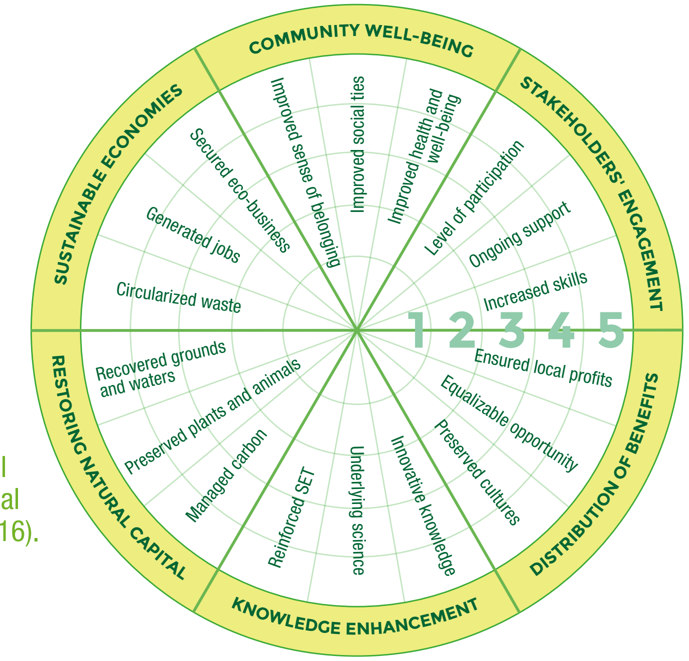
Each parameter is rated from 1 to 5, from worst (1) to best (5) performance/quality.

By regularly assessing the parameters, you can see the progress of the restoration visually on the wheel (below).



6.2 ASSESSING SOCIO-ECONOMIC IMPACTS

In the same way as for the ecological assessment, we recommend, to assessing the impact to restoration on local communities, the use of the social impact wheel developed by the Ecological Restoration Society (McDonald et al, 2016).



The indicators are organised into 6 main themes:

1. Community well-being
Improved sense of belonging
Improved social ties
Improved health and well-being

2. Stakeholders engagement
Level of participation
Ongoing support
Increased skills

3. Distribution of benefits
Ensured local profit
Equalizable opportunity
Preserved cultures

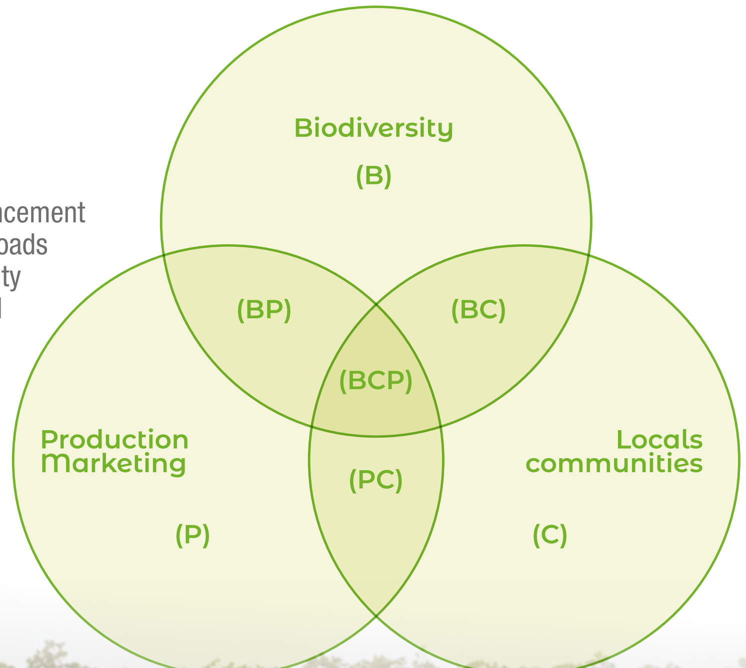
4. Knowledge enhancement
Enhanced science and technology
Hybridization of knowledge (scientific and local)
Shared knowledge

5. Restoring natural capital
Soil and water: quality restored
Plants and animals conserved
Managed carbon

6. Sustainable economies
Circularized waste
Generated Jobs
Secured eco-business

.3 ASSESSMENT OF VALUE-ENHANCING ACTIVITIES

The indicators of the value-enhancement of the products are at the crossroads of three dimensions: Biodiversity (B), Local Communities (C) and Production- Marketing (P), which translates into seven sectors: B, C, P, BC, BP, CP and BCP (cf. diagram) and the construction of related indicators (table 8 and appendix 4).



© IRD

Young shellfish fishermen, Saloum delta, Senegal c Cormier-Salem, IRD"

IMPACT	EFFECTS ANALYSIS GRID	IMPACT INDICATOR
Has the scheme enabled products to be promoted?	• Changes in: price, demand, supply • Diversification of sectors, new professions • Product's notoriety	• Growth rates: demand, supply, prices, income, exports • Market segmentation • More and more production, processing and distribution sites • Number of labels and brands • Existence of counterfeiting
Has the system helped to enhance and preserve biological diversity?	• Changes in the state of exploited resources and their associated ecosystems • Ecosystem health and landscape quality	• Sampling level • Changes in the height and/or weight of individuals sampled • Changes in the number of species exploited and associated. • Indicator of ecosystem health and landscape quality
Has the scheme helped to enhance and preserve (socio) cultural diversity?	• Re-reading and changing representations, uses and rules of access • Knowledge transfer • Technical change • Identity reformulation • Spatial reorganisation • Exchange networks • Heritage awareness • Culinary heritage	• Fines • Existence of counterfeiting • Average age of producers • Percentage of producers in the total workforce • Number of events focusing on these products • Labels and produced images • Specification of demand and supply • Songs, myths, tales and stories • Number of institutions involved in the scheme

Table 8. Mangrove valuation table

7

CHAPTER 7

EXAMPLES OF RESTORATION PROJECTS

Authors: Claudia AGRAZ HERÁNDEZ, Ebenezer HOUNDJINOU and Maria Martha CHAVARRÍA DÍAZ

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7.1

RESTORATION IN COSTA RICA

The Costa Rica-Benin project developed by the FFEM from 2016 to 2024 aimed to increase climate change mitigation and adaptation in the coastal wetlands of Costa Rica and Benin, by restoring mangroves, ensuring their sustainable management and promoting South-South cooperation exchanges.

The ecological restoration covered an area of around 31 hectares on three sites in Costa Rica and 30 hectares in Benin, Africa. Restoration at the various sites was based on technology transfer applied in ecological restoration programmes in Mexico. This was achieved by managing the hydrological dynamics of the site using hydrodynamic models and physico-chemical analyses of the quality of the pore water, followed by the recovery of plant cover using mangrove propagules.

In Costa Rica, two mangrove sites have been restored: Cuajiniquil and Terraba Sierpe.

1.1 | RESTORATION OF THE CUAJINIQUIL SITE

Photo: former saltworks, Cuajiniquil site (BRLi, Sept 2016)

The mangroves of Bahía de Tomas, Costa Rica, suffered a loss of 7 ha 60 years ago as a result of cutting for wood, charcoal and tannin production, as well as salt production. A pilot restoration project was carried out to test techniques in dry, high-impact climates, based on technological development carried out in Mexico. The aim of the project was to re-establish the minimum and maximum tolerance ranges for the physical (hydroperiod and microtopographic distribution) and chemical (salinity and redox potential) conditions of *Avicennia germinans*, *Rhizophora mangle* and *Laguncularia racemosa* on the site.

The degradation was mainly due to the hypersalinity of the soil and water, changes in hydrological behaviour and sediment dynamics, and the fragmentation of the wetland due to the construction of salt marshes and rustic roads built to facilitate coastal fishing.These modifications had generated anoxic and hypoxic conditions in the pore water and soil.

Covering an area of 7 hectares, various restoration activities have been carried out to restore and improve the structure and function of the ecosystem. Firstly, an exhaustive assessment of the physico-chemical parameters of the pore water and soil was carried out, providing crucial information on the current state of the environment. Next, hydrological rehabilitation actions were undertaken to restore the behaviour of the hydrological cycle and improve water quality. Reforestation activities were then carried out using undergrowth seedlings, and natural regeneration was encouraged through introducing propagules of *L. racemosa* and *A. germinans*.

Five years later, it was possible to recover and simulate the natural behaviour of the hydroperiod, which led to significant differences in the chemical conditions of the pore water (comparison before and after restoration). Mainly by decreasing salinity by 22.8 g/Kg ($F1, 324 = 3.38, P < 0.035, p \leq 0.05$) and increasing oxygenated conditions ($F1, 321= 6.50, P< 0.002, p\leq 0.05$).

The survival rate of reforested and regenerated seedlings of *A. germinans* was 72.7% and that of naturally regenerated *L. racemosa* was 97%, thus contributing significantly to restoring the habitat of fish, crustaceans, birds and mammals, among others.

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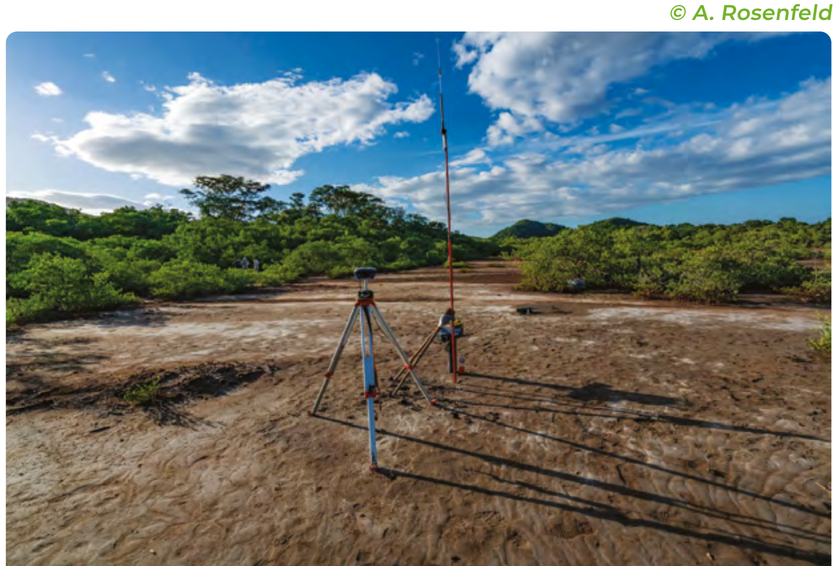

Comparison of google earth photos from 2013 and 2023

Figure 25. Ecological restoration applied to recover mangrove area: Guanacaste Conservation Area, Costa Rica

1.2 I RESTORATION OF TERRABA SIERPE

Context

The Térraba-Sierpe national wetland is located at the mouth of the Térraba and Sierpe rivers on Costa Rica's south Pacific coast. This wetland, the largest mangrove area in Costa Rica, covers 30,654 hectares and is a unique biodiversity reserve. It is subject to considerable pressure from agricultural development, in particular oil palm cultivation, which is growing rapidly in the region, rice cultivation, pollution of catchment areas and the invasion of the Acrostricum aureum (Negra Forra) fern as a result of the degradation of the mangroves, with a loss of 20.4% of mangroves in 64 years.

Terraba Sierpe © Pucci

Given this situation, 6 ha of wetland invaded by A. aureum were selected. The aim was to eliminate the A. aureum by applying ecological restoration techniques, with manual removal of the fern.

Various ecological restoration activities have been carried out to develop techniques for rehabilitating and improving the structure and function of the ecosystem. Firstly, a detailed assessment of the physico-chemical parameters of the pore water and soil was carried out, providing key information on the current state of the environment.

The Negra Forra was then removed and covered with plastic, causing the ground level to fall. Hydrological restoration measures were implemented to re-establish the behaviour of the hydrological cycle and improve water quality by excavating a peripheral channel and dredging two natural channels, dividing the area into three 2 ha units. Reforestation was then carried out using propagules of Rhizophora racemosa, Rhizophora mangle and Pelliciera rhizophorae, and natural regeneration was encouraged introducing propagules of Laguncularia racemosa, R. racemosa and R. mangle. Reforestation was carried out using a total of 11,110 propagules over the 2 ha. The results show that by eliminating A. aureum, topography decreased by -36.4 cm, by correcting for hydroperiod, salinity decreased by 3.2 ± 4.6 g/Kg, temperature (28.8± 0.3 °C) and sediment acidity (6.7 ± 0.02) remained stable, and sulphates increased ($F1.46= 4.8$, $p \leq 0.033$).

A 93% disappearance of A. aureum was observed from 2019 to 2023, as well as the height of reforested propagules of+ 5.5± 0.8m. Thanks to the restoration, the mangrove cover has been re-established and the behaviour of the hydrological cycle has been restored, with a reforestation survival rate of 97.3% over a period of 6 years, thus making a significant contribution to restoring the habitat of fish, crustaceans, birds and mammals, among others.

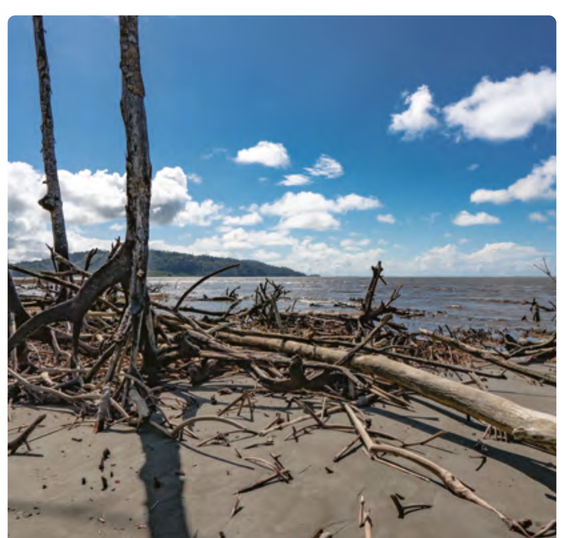

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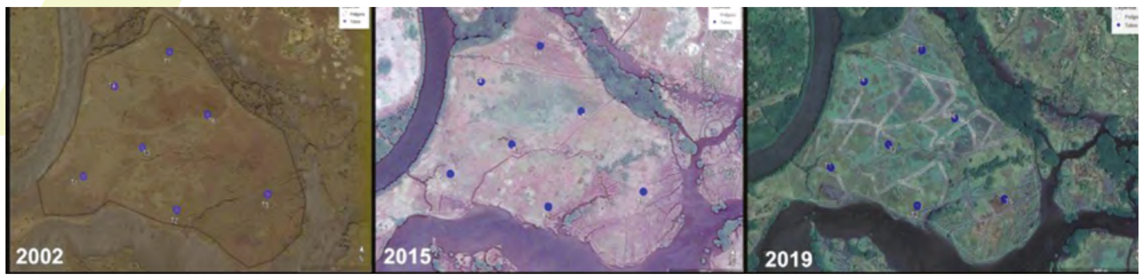
Figure 26. Ecological restoration applied to reconvert areas invaded by invasive plants: Terraba Sierpe national wetland, Costa Ric. Photos © C. Agraz Hernández

.2
RESTORATION IN BENIN



Context

In Benin, mangroves border coastal lagoons, and its coasts are exposed to wave action as the country has no active deltas.There are six different species of mangrove (UNEP, 2007), mainly *Rhizophora racemosa* and *Avicennia germinans.* Stands of *Laguncularia racemosa* and *Conocarpus erectus* are rare. Efforts are underway to identify their distribution areas.

The main threats to mangroves in the area are linked to the destruction of habitats and, in particular, extensive deforestation, as mangrove wood is used for salt extraction. Drastic changes in environmental conditions over the last 30 years, due to these activities, have created conditions conducive to the invasion of Paspalum vaginatum (an invasive species that is resistant to flooding, high temperatures and salinity), by increasing the topography of the soil, retaining sediments through the root system, causing less flooding, anoxia, higher temperature and salinity in the interstitial water, and therefore the displacement of mangrove species.

Several ecological restoration activities were carried out on a 30-hectare site to recover and improve the structure and function of the ecosystem. Firstly, an analysis of the physical and chemical parameters of the interstitial water and soil provided information on the state of environment. Next, the *Paspalum vaginatum* was removed, thereby correcting the soil level. Hydrological rehabilitation actions were implemented to restore hydrological behaviour and improve water quality. In addition, reforestation activities were carried out using *Rhizophora racemosa* propagation and encouraging the natural regeneration of this species. These actions have led to the recovery of the mangrove and hydrological dynamics, with a significant impact on the recovery of the habitat of species of commercial and ecological importance.

Figure 27. Ecological restoration applied to reconvert areas invaded by invasive plants: Ouidah, Benin

Hydrological rehabilitation work began in 2019, with the dredging of 19 pre-existing canals that were silted up and the construction of 26 artificial canals, covering an area of 30 ha, with the support of 258 people from the Ouidah community. This hydrological restoration has increased the frequency of flooding and the availability of dissolved oxygen, while at the same time reducing the salinity and temperature of the pore water. The establishment of these physical and chemical barriers prevented the regeneration of *P. vaginatum.*

Then, in parallel with the natural regeneration and to accompany it, reforestation was carried out: 367,140 hypocotyls of *Rhizophora racemosa* were reforested over 30 hectares, with densities of 7,156 hypocotyls/ha.

Survival rates of 79.4% were achieved over a period of 2.5 years, with natural regeneration on the canal banks of *R. racemosa* and *Sesuvium portulacastrum* over the 30 ha, both at 10%. Over the entire restoration area, the mortality of *P. vaginatum* has reached 95%. The site is showing signs of habitat recovery for crabs, fish and birds.

8 APPENDICES

APPENDICE 1 MAIN CONTRIBUTIONS FROM MANGROVES

Main contributions of mangroves Source: Cormier-Salem, 2013

TYPE OF SERVICE	MANGROVES SERVICES	MAIN FUNCTIONS (EXAMPLES)
Control	Erosion control	Stabilisation of coastlines, trapping and stabilisation of sediments by mangrove roots
	Protection against storms	Mangrove forests act as a barrier against storms, cyclones and tidal waves; the canopy attenuates the power of the wind and the complex structure of mangroves, with their tangled roots, trunks and low branches, break the power of the swell and absorb the waves.
	Flow regulation	Circulation and exchanges of water through tidal movements, hydrographic networks and coastal currents.
	Filter between land and sea	Mangroves act as buffers between land and sea: by stopping sediments from flowing down from catchment areas and smothering marine ecosystems, and by filtering pollution, they protect coral reefs and phanerogam beds downstream.
	Waste treatment	Assimilation of waste by vegetation, Water purification
Self-production	Air purification	• Carbon export or sequestration by mangroves • Energy conversion and storage through biomass
	Water purification	Soil trapping of metal pollutants
	Soil constitution	Polderisation and colonisation of the loose, oxygenpoor substrate by the root system
	Nutrient cycle	Energy and materials processing and storage
	Enrichment of coastal waters	Direct transfer of productivity from mangrove forests to coastal waters via tidal channels and floods; decomposition and mineralisation of detrital organic matter; mixing of continental and oceanic waters
	Biodiversity	• Refuge habitat for birds; • Breeding and nursery area for ichthyofauna (retention, feeding and growth area for aquatic fauna); • Spawning ground for many species (fish, crustaceans, etc.); • Refuge from predators thanks to the shade provided by the trees, the tangle of mangrove roots and the turbidity of the water; • Habitat for grazing gastropods of the genera Littorina, Pachymelania and Terebralia, and filter-feeding bivalves such as oysters, arches and cardiums.
Procurement	Food	Mangrove forests, tidal channels and associated ecosystems, support for agro-sylvopastoral and halieutic resources and food products (rice; salt; honey; fish, oysters, prawns, etc.)
	Drinks and alcohol	Wood, flower, leaf and fruit for fermented drinks, alcohol, vinegar, herbal tea
	Fuel	Firewood and charcoal (for smoking fish and heating brine to make salt)
	Health	Leaves and fruit for medicinal and cosmetic uses
	Material	Construction and timber: beams, poles, logs for houses (stilts), boats; farming tools (handles, ploughshares, dykes); fishing gear (bass, creels and nets); kitchen utensils (mortar, pestle); tannin and tincture (bark); lime from shells; glue...
	Trade	Commercial, estuarine and coastal fishing (fish - mullet, skipper, carp - and prawns); crab, cockle and oyster harvesting; aquaculture
	Livestock feed	Fodder and pasture for cattle, goats and other livestock; salt cure
Cultural	Spiritual	Sacred sites, totemic species;
	Leisure	Living space; tourism and ecotourism (canoeing, animal watching, sport fishing, etc.)
	Aesthetics	Oral traditions (myths, songs and poems); staging the mangrove swamp

APPENDICE 2 ATTRIBUTES, INDICATORS AND SCORES FOR THE RAM-MANGROVES METHOD

Source: Macera, 2024

ATTRIBUTES	INDICATORS	NOTES
Landscape context	**Connectivity** Is the adjacent area free of human structures that hinder the progress of the mangrove?	0. The area is hampered by human infrastructure located less than 50 metres from the mangrove forest, which prevents the potential spatial extension of the mangrove.
		1. The area has one or more human infrastructures preventing the progress of mangroves, but these infrastructures are fairly far away or only on one side (>50 m).
		2. The area has human infrastructures that do not hinder connectivity between zones and do not prevent the mangrove from progressing (for example, infrastructures on stilts allowing water to circulate).
		3. There is no human infrastructure in the area adjacent to the mangroves. Mangroves are free to grow throughout the tidal zone.
Assessment of mangroves	**Species richness** Number of mangrove species present in the study area as a proportion of the total number of species present in the region	0. There are no mangroves in the area.
		1. The area has less than 50% of the total number species.
		2. The area contains at least 50% of the total number species.
		3.The zone has the maximum number of species.
	Mangroves cover rate	0. Between 0% and 25%.
		1. Between 25% and 50%.
		2. Between 50% and 75%.
		3. Between 75% and 100%.

ATTRIBUTES	INDICATORS	NOTES
Assessment of mangroves	**Population dynamics** Number of young mangrove shoots (height > 30 cm)	0. No young shoots or very young mangroves composed solely of young shoots.
		1 A few seedlings are observed along the transect, but in very small numbers (around 5 or fewer).
		2. Young shoots are observed along the transect. More than 3 young shoots are observed and their number is easily counted, at around 20 or less.
		3. A very large number of young shoots were observed, more than 20 in all.
	Canopy height All species combined	0. Between 0 metres and 1 metre.
		1. Between 1 metre and 3 metres.
		2. Between 3 metres and 5 metres.
		3. Greater than 5 metres.
	Mangrove mortality rate	0. The area contains 100% dead mangroves.
		1. More than 50% of the mangroves in the area are dead.
		2. The area has less than 50% dead mangroves.
		3. The area has< 5% dead mangroves.
	Vitality of mangroves The signs of the most common diseases are holes or spots on the leaves *N. B.: Mangroves using the system salt excretion by leaf mortality have more yellow/brown leaves, without this being a sign of degradation.*	0. Mangroves have almost no foliage or only yellow or brown leaves and/or all the leaves show signs of disease/parasites.
		1. Mangroves have little foliage, a lot of yellow or brown leaves and/or most of the leaves show signs of disease/parasites.
		2. Mangroves have dense, green foliage, but some parts have less dense foliage with a few yellow or brown leaves and/or show signs of disease/parasites.
		3. Mangroves have very dense, very green foliage, with very few yellow or brown leaves and no signs of disease or parasites.
Soil evaluation	**Substrate texture**	0. The soil is 100% sand.
		1. The soil contains less than 50% silt and more than 50% sand.
		2. The soil contains more than 50% silt and more than 50% sand.
		3. The soil is at least 90% silt.
	Interstitial water salinity	0. The soil is constantly dry, with no trace interstitial water.
		1.Extreme hypo/hyper saline conditions: salinity <20 g/L or >60 g/L for the Rhizophora sp. zone; salinity <40 g/L or >90 g/L for the Avicennia sp. zone.
		2. Hypo/hyper saline conditions: salinity between 20 and 35 or 45 and 60 g/L for the Rhizophora sp. zone; salinity between 40 and 55 or 65 and 90 for the Avicennia sp. zone.
		3. Ideal conditions: salinity between 35 and 45 g/L for the Rhizophora sp. zone and 55 and 65 g/L for the Avicennia sp. zone.

ATTRIBUTES	INDICATORS	NOTES
Soil evaluation	**Sedimentation**	0. Severe erosion: The slope formed by the substrate at the front of the mangrove has a very curved shape resembling a small ditch. The sediments present are very compact. The site is very exposed to wave energy and swell.
		1. The mangrove zone is subject to slight erosion: curved slope, compact sediments, moderate exposure to wave and swell energy.
		2. Sediment dynamics in the mangrove zone are stable: flat or slightly concave slope, loose sediments, protection against wave energy and swell.
		3. Positive sedimentation: The slope formed by the substrate at the front of the mangrove is concave. The sediments present are loose and very fine. The site is protected from wave energy and swell.
Associated biodiversity	**Abundance of crabs** Crab abundance is a bioindicator for soil suitability for the development of mangroves	0. The area shows no signs of crabs, burrows or recent drilling.
		1. The area shows some traces of crabs, burrows or recent drilling.
		2. The area shows traces of crabs, burrows or recent drilling, but these are largely countable.
		3. The area has a very large number of crab traces, burrows, and recent drillings-so many that counting them would be difficult.
	Associated flora and fauna Remarkable species are those that are keystone species in the ecosystem.	0. The area contains few or no species associated with mangroves.
		1. The area is not very rich in species, most of which are common, and does not contain any remarkable or protected species.
		2. The area is very rich in species, most of which are common, and does not contain any remarkable and/or protected species.
		3. The area is very rich in species and/or contains remarkable and/or protected species
Relationship between society and mangroves	**Variety of uses by local communities** Sustainable uses of mangroves are included, while harmful uses are excluded.	0. No use is made of mangroves.
		1. Mangroves are used for one purpose only.
		2. Mangroves are used for more than one purpose.
		3. Mangroves are used for a number of purposes, at least one of which is essential to communities.

ATTRIBUTES	INDICATORS	NOTES
Relationship between society and mangroves	**Level of protection of the area** IUCN protection categories *N.B.: Scores 3 for this descriptor and the previous one are in tension. An Integral Reserve zone obtains 3 in "protection" and 0 in "uses". This low average between these two descriptors is in line with this socio-ecological system approach, where participative governance is considered to be a better state than strict reserves.*	0. Area with no protection status.
		1. The site is located within a recreational species conservation area. There are no restrictions on uses in the area, and urban development is permitted.
		2. The site is located in an area designated for the protection of spaces and species with no recreational vocation. Uses are controlled but not restricted. Urban development is prohibited.
		3. The site is located in a scientifically managed nature reserve and is not used for recreational purposes. Uses are controlled and may be restricted.
	Pollution from macro-waste Includes particles of more than 1 cm in diameter, plastic, fabric or metal	0. Presence of very large quantities of macro-waste completely covering the ground.
		1. Macro-waste was observed, covering part of the ground.
		2. Some macro-waste is observed in small quantities.
		3. No macro-waste observed.

APPENDICE 3 VALORIZATION OF MANGROVES' PRODUCTS: SOME USES

Source: Cormier-Salem, 2022

RESOURCES	USES	SPECIES	SOME EXAMPLES OF USES AND/OR ENHANCEMENT
FOREST PRODUCTS			
Wood	Fuel: firewood, charcoal (domestic cooking, smoking fish and oysters, heating the brine for salt production, burning of oyster shells for liming rice fields), alcohol	All mangroves of various qualities, but especially *Rhizophora spp.*	Smoking oysters
	Lumber and timber for the house: posts, pillars, framework, for the kitchen (mortar and pestle)	*Rhizophora spp.*	In Benin: carpentry for homes; In Madagascar: house on stilts with frame and stilts made of *Rhizophora* (resistant to termites)
	Works of art	*Rhizophora spp.*	Fadhiouth craft village (Joal): art objects made from mangrove wood (*Rhizophora spp.*)
	Farming tools: hoe, plough, tapade; Anti-salt dams for rice growing		In Lower Casamance, farmers plant Avicennia in front of their fields (located behind mangrove swamps) to block the progression of salinity into the mainland.
	Fishing equipment: weir fences, traps, baskets, nets;		Small-scale fishing in Lower Casamance

RESOURCES	USES	SPECIES	SOME EXAMPLES OF USES AND/OR ENHANCEMENT
FOREST PRODUCTS			
Leaves	Artefacts and household utensils: fence, roof, mattress, shelter, paper and cigarette paper, glue	All mangrove species, but especially *Nypa fructicans*	
	Food: fermented drinks, alcohol, vinegar, herbal teas, condiments, leafy vegetables, salads, etc.	All mangroves	
	Animal feed: forage, pasture	*Avicennia, Sonneratia*	
	Medicinal uses: external (plaster, incense) and internal (decoction for malaria, gonorrhoea, digestion, measles, febrifuge, etc.).	*Avicennia germinans, Laguncularia racemosa* *Conocarpus erectus*	In Madagascar, treatment for illness (fever and stomach ache) In Benin, Conocarpus erectus is used as an anti-biotic and a body bath against scabies. A decoction of the senescent leaves of Avicennia germinans is recommended for women as a drink after childbirth to stop blood loss (haemorrhage).
Flowers and fruit	Ritual uses	*Avicennia spp. Nypa fruticans*	In the Saloum, a verse from the Koran written on Avicennia germinans leaves In Indonesia (and whole of Asia), Sanskrit manuscript inscriptions on Nypa fricticans leaves
	Honey, mead and beeswax (Apis mellifera)	*Ceriops, A. marina, RhiAzophora sp, Rhizophora mucro-nata, Ceriops tagal, Bruguiera gymnorhiza*	In Madagascar, nectar (flowers) for bees (mangrove honey and wax) Mangrove honey in Kenya
	Human food: alcohol; fruit seeds as flour, pulp as oil	*Avicennia germinans*	Valued especially in times of shortage or famine; the fruit is often eaten by livestock
	Float and stopper for fishing nets		
	Medicinal and cosmetic uses (beauty and protective masks); incense and fubrifuge	*Xylocarpus grana-tum*	In Madagascar (and along the East African coast), the fruit is used as a face mask to protect women from the sun.

RESOURCES	USES	SPECIES	SOME EXAMPLES OF USES AND/OR ENHANCEMENT
Bark	Artefact and domestic use: tannin and dye,	*Rhizophora spp., Bruguiera spp. and Ceriops tagal*	One of the first products to be traded over long distances in the 16th and 18th centuries, particularly between Madagascar and Mashreq countries to tan leather / Swahili network
	Ingredient in herbal teas and drinks, medicinal use (external treatment of haemorrhage; internal treatment of stomach ache, malaria, toothache, etc.).	*Rhizophora spp.*	Medicinal uses of 3 mangrove species in Ghana
Branches	Stakes, traps for fish or game	*Acrostichum aureum*	
	Ritual uses	Spp.	In Mayotte, garlands of old Korans hang from branches

LIVE FISH PRODUCTS			
Crustaceans	Crab fishing using baited traps or hooks	*Scylla serrata, Ucides spp., Sesarma mederi, Goniopsis peli*	Madagascar: Export and self-consumption Vietnam (more than 10 varieties)
	Fishing and shrimp farming	*Penaeus spp., Macrobrachium rosenbergii,*	
Molluscs	Fishing for shellfish and other molluscs at low tide in the mud or on shoals for: food; decoration and collection; incense	*Anadara senilis, Galatea paradoxa, Murex hoplites, Murex cornitus, Pugilina morio, Orbicularia orbiculata, Donax spp. Cymbium spp., Cultelus tenuis, Arca granosa, Terebralia palustris*	Madagascar: Foot fishing during low tide, generally carried out by women In the Saloum, from Murex lids to Maghreb-Machreb destinations
	Oyster fishing and farming	*Crassostrea gazar, Crassostrea rivularis*	In Benin, the shells are transformed into powder in the mill to be used as a feed supplement (calcium) for animals.
Fish	Fishing for fish (mullet, skipper, carp, ethmalose, etc.) using nets, weirs, traps and holes, etc.	*Epinephelus spp., Lates spp., Ethmalosa fimbriata, etc.*	
	Extensive fish farming ponds, trapping in retaining dikes	*Tilapia, Chano chano, Arius spp; Macrobrachium rosenbergii, Epinephelus spp., Lates spp,*	
Worms	Collecting bloodworms (polychaete)	polychaete	In Pichavaram, members of the Irula community gather worms to supply shrimp farms.

INERT PRODUCTS			
Mollusc shells	Shells to make lime (fertiliser),	Oyster shells *(Crassostrea gazar)* and shellfish	Shell mounds, sanctuaries for notables in the Saloum region
	Equipment for building or reinforcing runways, bridges and houses	Anadara shells, oysters, mudflats and clays etc.	Houses and tracks on the Gandoul islands, In Lower Casamance on Eloubaline Island, houses are built from mud and clay taken from mangroves. In Benin, oyster shells are used to solidify runways under the layer of yellow sand, especially in wetlands.
Salt	Salt is collected in the back mangrove areas (overburdened basins in the tannes); it is produced by boiling or evaporation.		In Madagascar, evaporative salt ponds Benin Senegal

APPENDICE 4 EXAMPLES OF ASSESSMENT INDICATORS FOR THE PROMOTION OF PRODUCTS

Source: Cormier-Salem, Biodivalloc, ANR05-2005

THEME	SUB-THEME	INDICATOR
Local Community	C1 Equity	Number of direct local jobs
		Number of indirect local jobs
		Level of direct income
		Level of indirect income
		Ratio of purchase from producers to market price
		Ratio of purchase price from producers to minimum price guaranteed by Fairtrade or other labels
		Fair trade labelling: yes/no
	C2 Social discrimination	Number of producers/total population
		Average age of producers
		Indigeneity
		Share of men/women in the sector
	C3 Knowledge and representations	Number of founding events with product presence
		Number of recipes that include the product
		Occurrences in tales, myths, songs and stories
		Local Community
Production Marketing	P1 Commercial success	Sales
		Number of production, processing and distribution sites.
		Share of commercial farming compared to subsistence farming
		Number of local, regional, national and international markets
	P2 Notoriety	Opinion poll
		Existence of counterfeits
		Number of kilometres travelled by the product
Biodiversity link **Local community**	BC1 Ecosystem services	Forest area
		Water quality
		Health of populations living off biodiversity-dependent resources
		Tourist numbers
	BC2 access to the resource	Existence of access rights
		Existence of rights of use
		Protection and control of the resource
Local community link **Production and marketing**	CP1 Conservation of know-how and practices	Standardisation
		Health standards
		Making certain practices part of the local cultural heritage
	CP2 Social dynamics	Number of product events
		Number of cooperatives
		Number of farmers' associations
		Number of NGOs present
	CP3 Economic dependence	Percentage of employees concerned
		Number of alternative income-generating activities
		Proportion of local GDP generated by production
		Share of commercial / subsistence farming

THEME	SUB-THEME	INDICATOR
Biodiversity link **Production marketing**	BP1 Intensity of production's impact on the ecosystem	Diversity of cultivated species/fished species
		Cultivated/operated area
		Surface area of forest / ecosystem considered
		Performance
		Aggregate Management Index
		Organic Agriculture label or other appropriate ecolabel (shade coffee for coffee...)
	BP2 pressure on the resource	(Sea) Available stock
		(Sea) Withdrawal level
		(Sea) Size of individuals caught
	BP3 ecosystem services	Protection, control of withdrawals or fragile areas
Biodiversity link **Local community** **Production marketing**	BCP1 Typicity of products	Recognition of typical taste: typicality index. Opinion survey.
		Number of similar or comparable products
		Maintaining/evolving technical itineraries: sustaining production practices
		Maintaining/evolving technical itineraries: sustaining processing practices
		Trend in the number of species exploited and harvested
		Trend in the number of associated species sampled
	BCP2 Spatial discrimination	Number and distribution of production/processing/distribution sites
		Mapping of gathering areas, cultivation zones and fishing zones
	BCP3 Food dependency	Culturally-significant cultivated species
		Importance of the product in the diet of local populations (quantity and quality)
		Specialisation index

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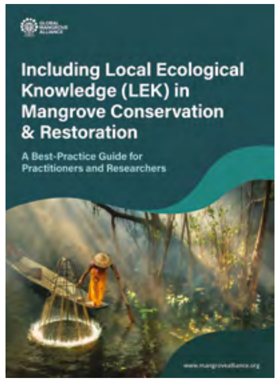
THE MAIN GUIDES TO MANGROVE RESTORATION

There are many guides to mangrove restoration (https://initiative-mangroves-ffem.com/veille-publications/), some of which are listed below.

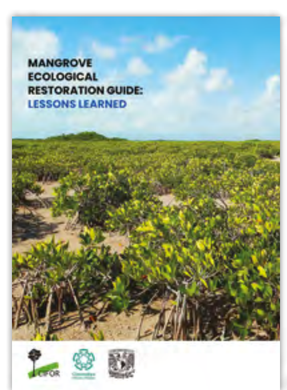


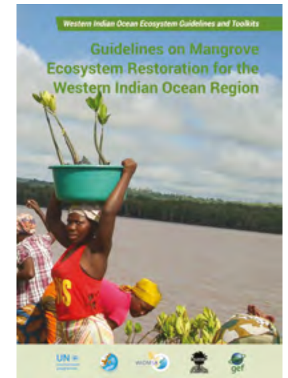
Reference: Kerry Grimm , Mark Spalding**, Marice Leal and al., 2023. Including Local Ecological Knowledge (LEK) in Mangrove Conservation & Restoration www.mangrovealliance.org A Best-Practice Guide for Practitioners and Researchers. Global mangrove alliance.
Date: 2023
Language: English
Geography: global

Reference: Beeston, M., Cameron, C., Hagger, V., Howard, J., Lovelock, C., Sippo, J., Tonneijk, F., van Bijsterveldt, C. and van Eijk, P. (Editors) 2023. Best practice guidelines for mangrove restoration. Global Mangrove Alliance Report. 278 p.
Date: 2023
Language: English
Geography: non specific

Reference: Claudia Teutli-Hernández and alii, 2021. Manual para la restauración ecológica de manglares del Sistema Arrecifal Mesoamericano y el Gran Caribe. UNEP-Convención de Cartagena, Mesoamerican Reef Fund.
Date: 2021
Language: Spanish
Geography: Central, South America and the Caribbean

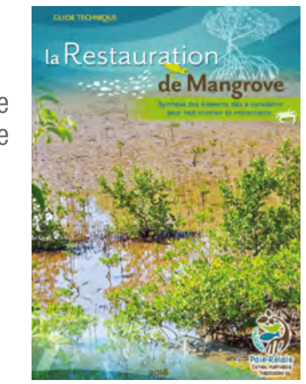
Reference: Teutli-Hernández C., J.A. Herrera-Silveira, D.J. Cisneros-de la Cruz., R. Román-Cuesta. 2020. Mangrove ecological restoration guide : Lessons learned. Mainstreaming Wetlands into the Climate Agenda: A multilevel approach (SWAMP). CIFOR/CINVESTAV-IPN/UNAM-Sisal/PMC, 42 p.
Date: 2020
Language: English
Geography: Central, South America and the Caribbean





Reference: UNEP-Nairobi Convention/USAID/WIOMSA (2020). Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region. UNEP, Nairobi, 71 pp.
Date: 2020
Language: English
Geography: Indian Ocean

Reference: Pole-relais zones humides tropicales, 2018. La restauration de mangrove: synthèse des éléments clés à considérer pour tout chantier de restauration. 32 p.
Date: 2018
Language: French
Geography: not specific to the French overseas departments and territories



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