TECHNICAL GUIDE

Mangrove Restoration

Summary of the key elements to be considered in any restoration project

ICRI
International Coral Reef Initiative

Pôle-Relais
Zones Humides Tropicales

CONTENTS

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Mangroves are currently threatened by a host of anthropogenic pressures, including pollution, land take, infilling, aquaculture and urbanisation etc. A significant proportion of the world's mangroves have already been lost, including within the French Overseas Territories.

Mangrove restoration is therefore being increasingly undertaken, often in the form of replanting mangrove stands with seedlings. In spite of the efforts involved in these initiatives, the results are often disappointing due to a lack of forward planning. Problems include poor choice of location area, mono-specific coverage or lack of consultation with local stakeholders, all of which can limit the medium- or long-term success of these actions, and thus fail to restore a functional mangrove forest. A successful restoration action must result in the establishment of a relatively large, diverse, functional, and self-sustaining mangrove forest that can provide environmental and human benefits.

There are **two different fundamental approaches** to ecological restoration:

Photo P. Coquelet

Natural Colonisation

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

Photo A. Caillaud

Mangrove Planting

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

Prior to any restoration undertaking, managers must consider a number of essential questions:

- What is the origin of the disturbance or degradation? Is it irreversible?
- What are the objectives of the restoration programme?
- How much involvement will local stakeholders have?
- Under the given conditions, is letting nature take its course an appropriate strategy?

The answers to these questions will determine the best approach for conducting a mangrove restoration project. It would be preferable to allow natural colonisation if possible (depending on the specific context), or technical intervention involving:

- the restoration of hydrological characteristics that will allow natural colonisation to occur;
- the establishment of a mangrove plantation according to the steps described in this technical guide.

- **Favour natural colonisation** when we observe the development of new individuals via a natural supply of propagules (which should be observable after the fruiting period).
- **Study abiotic parameters in advance** when re-establishing hydrodynamic conditions for natural colonisation or when organising a planting site.
- The restoration site must be completely within **the intertidal zone.** The highest tides, from a topographical perspective, determine the upper limit of the planting area.

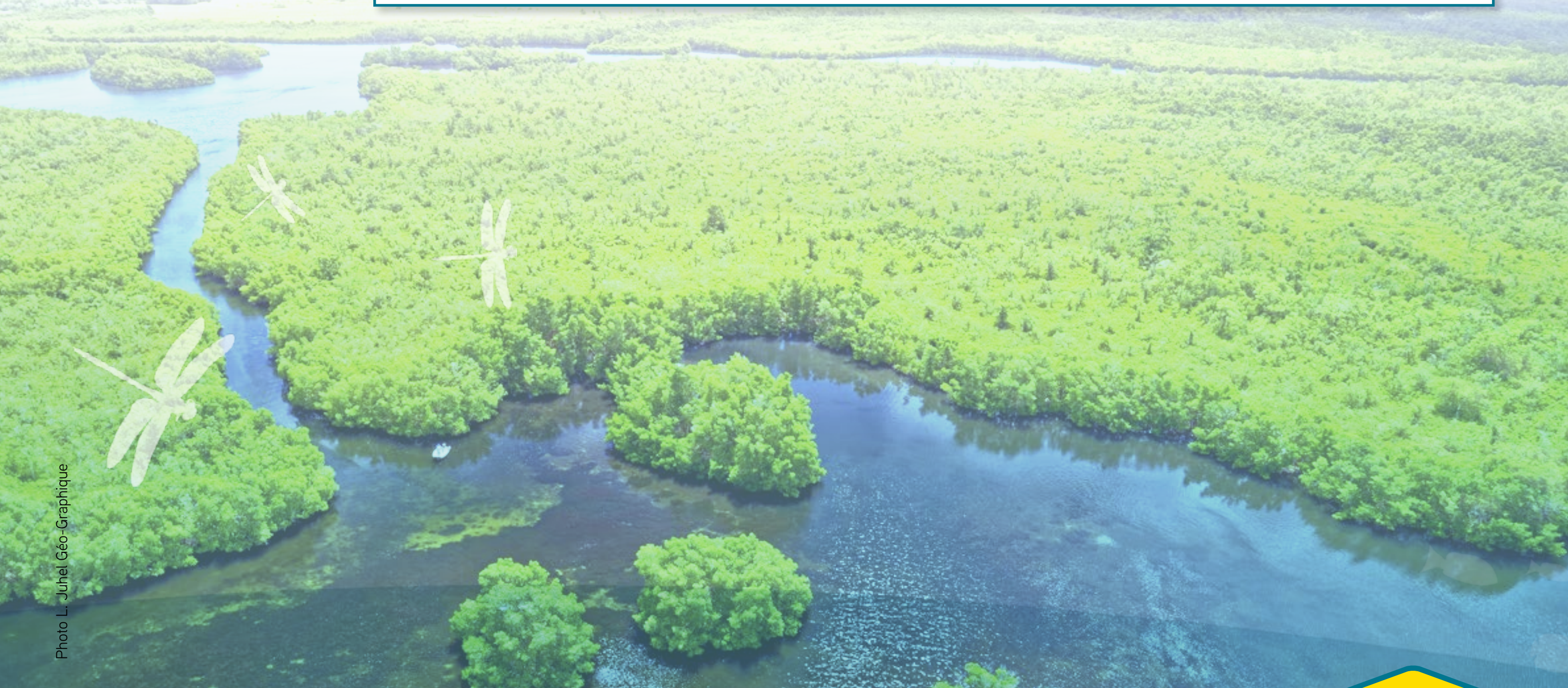


Photo L. Juhel Géo-Graphique

CHAPTER I

Natural Colonisation

STEP 1 Analysis of abiotic parameters

Key parameters must be analysed in order to understand the physical geography of the site. These largely determine the zonation of mangroves within the foreshore area. Once compiled, these parameters are crucial in:

- re-establishing favourable hydrological conditions for natural colonisation to occur, whether using breaches, geotextiles, or more extensive intervention etc. (see Page 11),
- arranging the replanting site, by knowing which species to plant, and where and how they should be planted (see Page 15).

TYPE OF PARAMETER	Physico-chemical	Hydrodynamic	Topographic	Hydrodynamic
INDICATOR	Substrate salinity	Wave energy	Slope	Submersion

I.1. Substrate salinity

• **Objective :** this parameter makes it possible to identify suitable areas for each species according to their degree of halophytism[1].

• **Protocol :** determine the salinity of the substrate along a transect[2] perpendicular to the sea. Establish a salinity gradient of the area to be restored, in diagrammatic form.

- **How to do this:** For each survey, it is preferable to take 3 values to obtain a more accurate mean value. The distance between the surveys should allow the site to be covered in a relatively homogeneous manner.
- **When:** Never after a rain event. If comparisons between sites are required, during the same chosen time period from the onset of exposure to air (as the tide retreats).
- **Where:** Interstitial water in the sediment (water that occupies the space between the sediment grains).

• **Measurement:** g/L.

• **Tool(s):** Salinometer

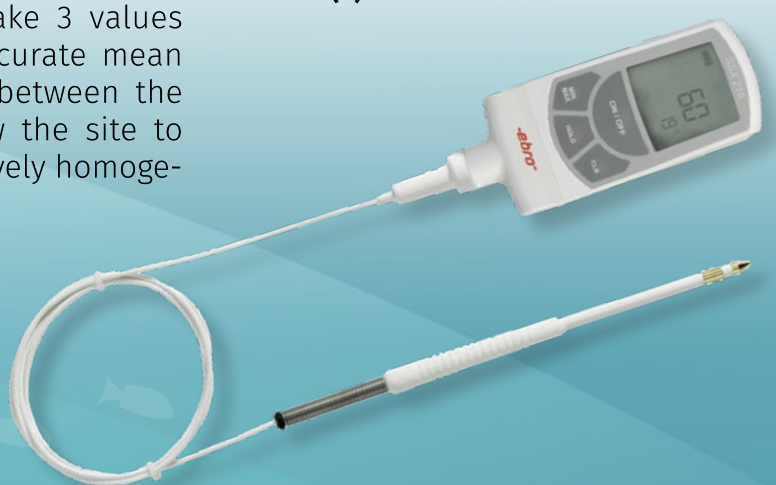


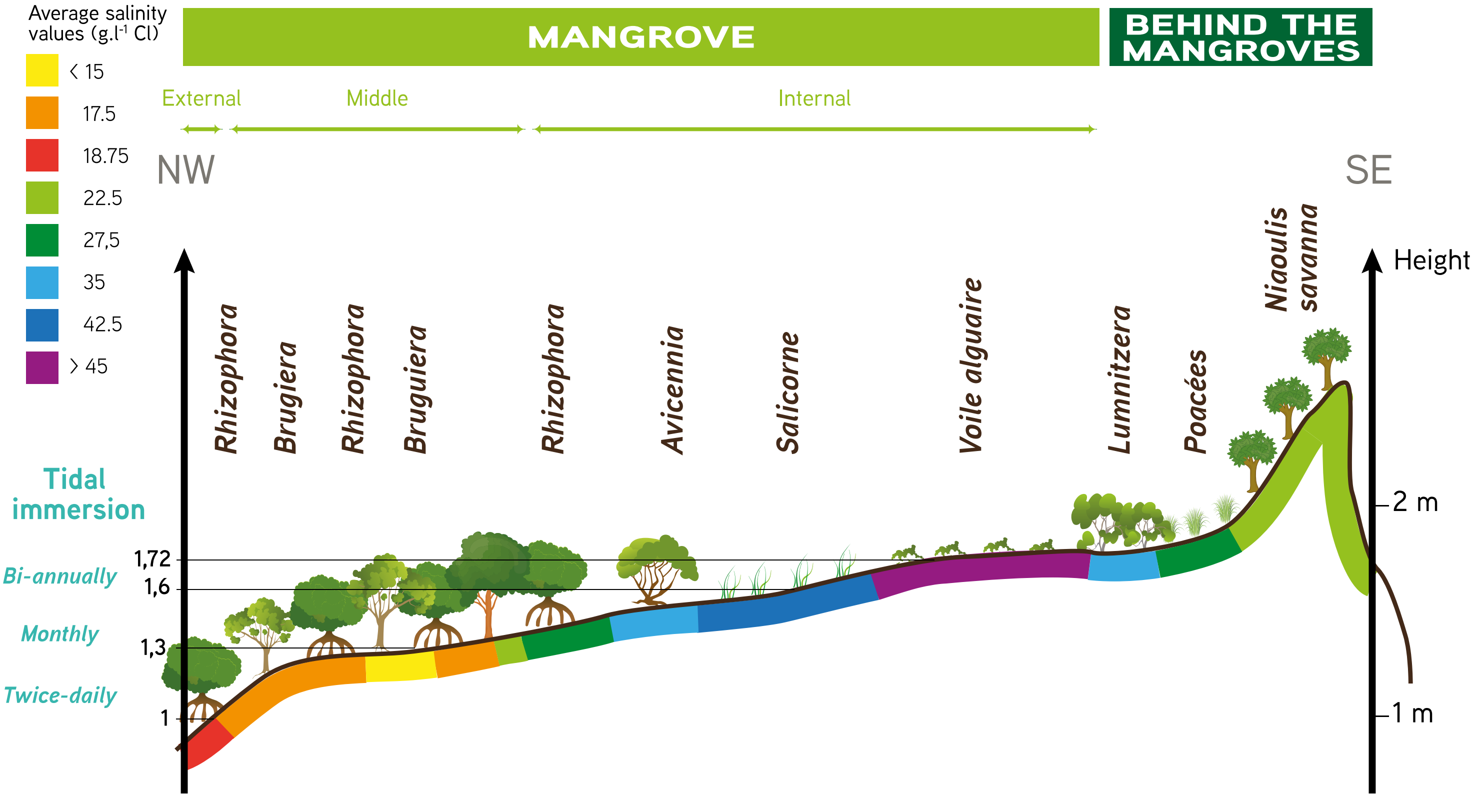
Figure 1 *- Salinometer.*
(source : www.conrad.fr)

1. Capacity for resistance/tolerance to salinity
2. A straight line along which scientific monitoring is conducted (usually using a rope or tape measure)

Figure 2

Profile of a mangrove forest in New Caledonia with average salinity values.

(Source: based on EMR, 2014)



By measuring salinity, a gradient can be established, as shown above (see Fig. 2). The species associated with the different salinity levels can be determined in parallel. Be aware, however, that the profile shown above only relates to one type of mangrove forest in New Caledonia.

Ideally, a profile of the area to be restored should be created, as shown in figure 2. After having indicated the salinity gradient on a diagram, the associated mangrove species can be identified using a **reference mangrove forest contiguous** to the site (if it exists) or in the vicinity of the site. This approach will be discussed further in Chapter 2, in relation to the choice of species.

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Focus on sulphate-acid soils

Mangrove soil can develop into an **acid sulphate zone** if excessive clearing has taken place. This clearing then causes a large amount of oxygen to be added to the soil. The organic matter will decompose rapidly. The oxygen will transform the iron sulphides present in the soil into sulphates, aided by micro-organisms. Indeed, mangroves naturally capture large amounts of metals, and the natural combination of iron and sulphur allows the formation of iron sulphide, the basis for the formation of sulphates. The accumulation of sulphates will lead to an acidification of the habitat, which becomes inhospitable to mangroves. These acidic soils, which are often devoid of vegetation, become veritable traps for metals, which are then redistributed in the natural environment with sometimes harmful consequences along trophic chains.

I.2. Wave energy


Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats

Wave energy is a key abiotic parameter but it remains difficult to understand. This factor can contribute to the uprooting of young plants if their root system has not reached a sufficient stage of development to resist, or induce localized or site-wide erosion. A scientific study published in 2011 indicates thresholds for uprooting and resistance of ***Avicennia alba*** seedlings as a function of numerous mathematical parameters.
Balke, Thorsten et al. 2011. « Windows of opportunity: thresholds to mangrove seedling establishment on tidal flat ». Marine Ecologic Progress Series. Vol. 440, N°1. PP. 1-9.

Excessive energy can be detected empirically if **bedrock is visible in places.** This means that sediment has been removed but not deposited. In this case, it may be necessary to reduce this energy through the use of geotextiles or structures made from bamboo or other materials (see step 2 on page 11). In sheltered, low-energy areas such as bays, this parameter may be less constraining.

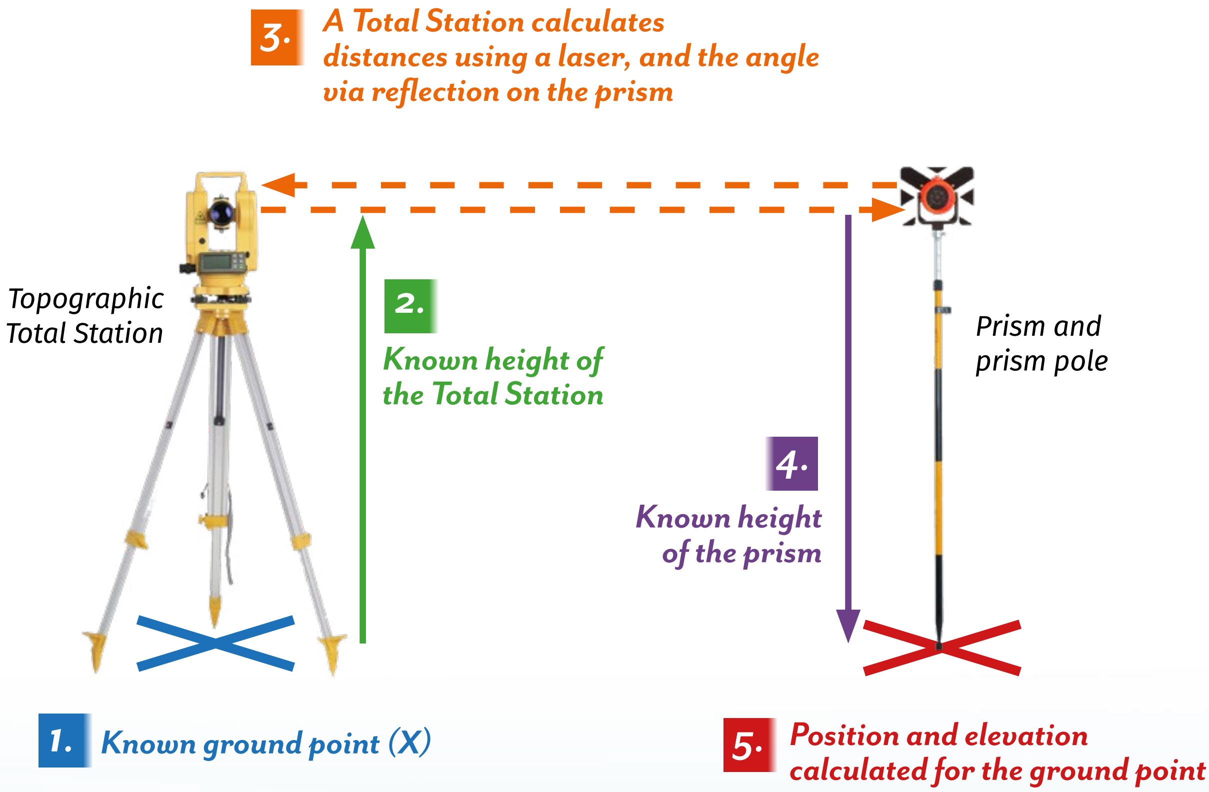
I.3. Slope (topographic profile)

- **Objective:** To determine the topographic profile of the restoration site. This parameter is mainly related to the submersion parameter. The topography will directly influence water depth and salinity levels.
- **Protocol:** Use an altimeter or, preferably, a Topographic Total Station. If using an altimeter, establish a topographic profile using data collected along a transect perpendicular to the shoreline.
- **Measurement:** Elevation (in metres).
- **Tool(s):**
  - Topographic Total Station
  - Altimeter

Figure 3
Garmin eTrex Vista HCx GPS with temperature-compensated barometric altimeter - the most accurate type of altimeter on the market
(source : www.garmin.com)

The use of a Topographic Total Station is ideal but this equipment involves substantial investment (units may cost €4,000) and technical training. However, it provides more precise measurements, and it can be used to produce digital terrain models (DTM) (see fig. 4). External service providers can carry out these surveys at a lower cost.

The project could also obtain an altimeter at prices varying from €50 to €700 or more depending on the degree of sophistication. Barometric altimeters are among the most dependable. Muddy foreshores require precise measurement due to their relatively gentle gradients.



This is an example of a map made using a Total Station. The **areas in red** have the highest topographical elevation. This type of map can assist the manager when hydrological conditions have been modified and are preventing the establishment of mangrove forests: **adaptable structures** (i.e., structures with small spatial dimensions that are removable and reversible) can be used to curb wave energy, or counteract the impact of former aquaculture ponds, etc. (Lewis & Brown, 2014).

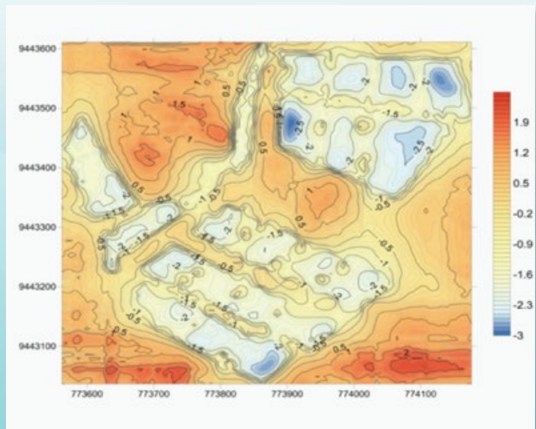


Figure 4
A map of abandoned aquaculture ponds produced using a topographic Total Station. Makassar, Indonesia.
(source : Lewis & Brown, 2014)

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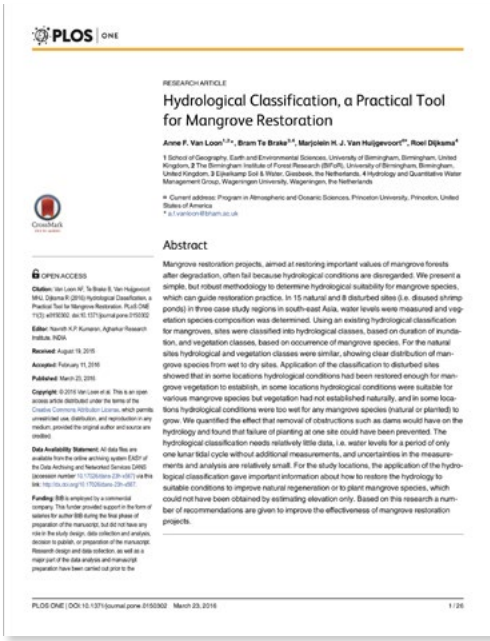
I.4. The inundation parameter

Objective: This factor relates to the selection of suitable areas in which to replant each species, according to their degree of tolerance to inundation. These areas are referred to in the scientific literature as 'inundation classes'. The aim is to divide the foreshore into classes - or zones - which are more or less homogeneous in terms of water height, duration and frequency of inundation. Species are assigned to these inundation classes on the basis of their physiological characteristics. Rather than describing a specific method, which is complex to implement, we provide links to relevant studies. If staff lack the time or expertise to develop inundation classes for the area to be restored, an 'empirical' approach (i.e. derived from observations of mangrove species present in the vicinity of the site, and under similar conditions in terms of substrate type and stability, frequency of submersion, etc.) is possible.

Study proposing a methodology for defining inundation classes
(this methodology relies on the use of expensive hardware and complex analyses):


PLOS | ONE

RESEARCH ARTICLE

Hydrological Classification, a Practical Tool for Mangrove Restoration

Anne F. Van Loon, Bram Te Brake, Marjolein H. J. Van Huijgevoort, Roel Dijksma

Abstract

Mangrove restoration projects, aimed at restoring important values of mangrove forests after degradation, often fail because hydrological conditions are disregarded. We present a simple, but robust methodology to determine hydrological suitability for mangrove species, which can guide restoration practice. In 15 natural and 8 disturbed sites (i.e. disused shrimp ponds) in three case study regions in south-east Asia, water levels were measured and vegetation species composition was determined. Using an existing hydrological classification for mangroves, sites were classified into hydrological classes, based on duration of inundation, and vegetation classes, based on occurrence of mangrove species. For the natural sites hydrological and vegetation classes were similar, showing clear distribution of mangrove species from wet to dry sites. Application of the classification to disturbed sites showed that in some locations hydrological conditions had been restored enough for mangrove vegetation to establish, in some locations hydrological conditions were suitable for various mangrove species but vegetation had not established naturally, and in some locations hydrological conditions were too wet for any mangrove species (natural or planted) to grow. We quantified the effect that removal of obstructions such as dams would have on the hydrology and found that failure of planting at one site could have been prevented. The hydrological classification needs relatively little data, i.e. water levels for a period of only one lunar tidal cycle without additional measurements, and uncertainties in the measurements and analysis are relatively small. For the study locations, the application of the hydrological classification gave important information about how to restore the hydrology to suitable conditions to improve natural regeneration or to plant mangrove species, which could not have been obtained by estimating elevation only. Based on this research a number of recommendations are given to improve the effectiveness of mangrove restoration projects.

VAN LOON, A. et al., 2016. «Hydrological Classification, a Practical Tool for Mangrove Restoration». PLoS ONE. 11(3): e0150302. https://doi.org/10.1371/journal.pone.0150302

The definition of flood classes is of particular value in regions where the tidal range is relatively significant (in the order of metres) ie. Mayotte, New Caledonia, Wallis and Futuna.

Important points to remember

- The analysis of key **abiotic parameters** is an important preliminary exercise, as it provides information on the potential for mangrove establishment for different species.
- Ideally, the preliminary analysis should, at the least, consider substrate salinity, inundation parameters, topography and wave energy. **An empirical approach** can also be employed: a reference mangrove forest, contiguous to the site if possible or else in close proximity, can be used as a guide to the species composition and zonation of the area under restoration. For example, on Wallis Island, *Bruguiera gymnorhiza* is located behind belts of *Rhizophora samoensis*. The former species should therefore always be planted behind (landward of) *R. samoensis* stands.
- When hydrodynamic conditions have been modified (development or clearing at the frontal edges of forests etc.), it is important to attempt to re-establish suitable conditions: where hydrodynamic factors cause excessive stress, the use of geotextiles or bamboo structures can act as **breakwaters**. In the case of abandoned aquaculture ponds, the walls, dykes or mounds still in place can modify the hydrology and thus prevent the natural dispersion of propagules: **the re-establishment of a hydrological connection is then necessary** (breaches allowing water to flow in and out with the tide).
- When two areas (natural and degraded) are comparable, or when the area's state prior to degradation and the cause of the degradation are known, **a description of the physico-chemical conditions is not necessary.**

STEP 2 Restoring favourable hydrological conditions

Where hydrodynamic conditions have been altered (development, clearing of the frontal edge of forests etc.), efforts should be made to re-establish suitable conditions for the dispersal and natural establishment of propagules (LEWIS & BROWN, 2014). Firstly, wave energy, swell and tidal currents can induce erosion or uprooting of young shoots. Substrate instability is therefore detrimental to the establishment of mangroves, while this failure of seedling establishment can then lead to further erosion. The deployment of energy-absorbing structures is then necessary. Secondly, the presence of dykes, mounds or walls around aquaculture ponds can modify current patterns and prevent the dispersal of propagules or seeds. It is then advisable to re-establish a hydrological connection, in particular through the creation of breaches to allow water to flow with tides and through natural channels.

I.6. Structures to limit energy and substrate erosion

Installing geotextiles or bamboo structures that act as breakwaters can be ideal for sheltering future propagules and helping them to remain in place.

- These breakwaters (or barriers) can be made of stone, bamboo, geotextiles or other locally available non-polluting materials.
- The breakwaters are positioned **downstream** (seaward) of the settlement area and **perpendicular** to the direction of the current (see Fig. 5).
- Over time, breakwaters also contribute to the accumulation of sediment and thus to the elevation of the surface of the substrate, which can allow for a progradation (seaward advance) of the pioneering mangrove front, and thus effectively combat coastal erosion and sea level rise. It is therefore possible to position the breakwaters in a site-specific manner at low tide, some metres in front of the constantly submerged part of the foreshore (excluding exceptional spring tide events). If sediment accumulation is favoured, the mangrove forest will naturally advance into the sea. See figure 5, photographs A and B.

Figure 5
5 Photos A, B, and C: walls used as breakwaters: rapid mangrove growth is evident within one year. Photo D: bamboo structures to disperse wave energy.

The following figure (see Fig. 6) shows a specific case study in Southeast Asia. In 2010, two breakwaters 1 to 2 m high and 70 to 110 m long were built to restore a mangrove forest that had been severely eroded, and site parameters did not allow for natural colonisation. This goal of this intervention was to make the area suitable for the development of mangroves, which previously existed there.

After the breakwaters were left in place, the substrate within the protected area rapidly rose by 10-50 cm. By 2 years post-installation, accretion had also occurred on the seaward side of the breakwaters, with the appearance of a 9 m wide sandy-muddy bank (PRIMAVERA et al. 2012). Thus, it is quite likely that mangrove forests have been advancing toward the sea over the decades.

Figure 6
Example of the installation of breakwaters to promote the recolonisation of a mangrove forest.

Although some seedlings were planted in the protected area, as shown by the alignment of some plants, the authors of the study emphasized that spontaneous establishment of propagules from the surrounding mangroves also occurred.

I.7. Restoring hydrological connections (breaches, excavators, culverts and drains)

The development of aquaculture ponds (New Caledonia) or other types of construction such as roads often modifies the hydrodynamics of the area and, consequently, the natural dispersal of propagules or seeds. This situation limits the supply of new propagules that can recolonise areas or improve vegetation cover (LEWIS & BROWN, 2014). The construction of low walls, dikes or canals modifies or even blocks water flow, thus trapping propagules. Excavation of aquaculture ponds to increase their depth and thus their productivity changes the topographic profile and the substrate height: this can lead to mortality in low areas, as shown in the example below. Constructions can also harm mangroves located upstream of a site by limiting or preventing tidal flooding.

The following photograph (see Fig. 7) was taken in Silay in the province of Negros Occidental, Philippines. The author explains that the difference between the survival of mangroves in the background - as well as that of young trees that have been planted on the seafront - and the visible area of mortality between the two yellow lines is based on a difference in elevation of approximately 5 cm only (PRIMAVERA et al. 2012).

Several options are available in order to re-establish hydrological connections conducive to natural colonisation or even to ensure the survival of one or more mangroves.

Figure 7
The mortality zone between the two yellow lines, which is topographically lower due to the excavation of aquaculture ponds, prevents any natural recolonisation of this section of the foreshore. This mortality is explained by a different elevation in relation to the mangrove survival zone. Restoration of topographic levels is therefore necessary to promote the natural return of trees.

Where the presence of former aquaculture ponds (New Caledonia), dykes, walls or mounds prevents hydrological connectivity

- Breaches can simply be made with shovels and picks to allow the flow of water (see Fig. 8).
- The use of excavators may sometimes be necessary in specific cases where the required work is too great for manual labour. The figure below shows a breach made using this type of vehicle (see Fig. 9).

Figure 8
The dyke is high enough to prevent drainage of the water body in the background. A hydrological reconnection is required.
(source : modified d'après Lewis & Brown, 2014)

Figure 9
Example of the creation of a breach in a human-modified mangrove area using an excavator. This operation resulted in subsequent natural colonisation of the area behind the topographic feature: 6 different species flourish there!
(source : Lewis & Brown, 2014)

The use of culverts or drains to provide hydrological connectivity

Photo L. Juhel

Figure 10
With hindsight, we can see the importance of maintaining connectivity between the wetland (where the mangrove forest has been established) and the sea (tidal movement and water flowing off the land).

Seventy-three percent of the Rhizophora mangrove forest in Oundjo, New Caledonia, was destroyed between 1954 and 2008 due to the construction of a road (EMR 2014 - 2010 data). This type of infrastructure can in some cases block the hydrological connectivity and jeopardize the ecological balance of a mangrove ecosystem.

Figure 10 illustrates the value of culverts in road developments, for example at the Port-Louis wetland site in Guadeloupe. Culverts must be relatively wide so they only reach capacity during heavy rains, and they must be regularly maintained.

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Mangrove Planting

Caution. Planting is only recommended if restoration methods via natural colonisation are not possible, or if it is necessary to rapidly regain plant cover.

Social acceptance is a necessary pre-requisite for a successful restoration project (Lewis & Brown, 2014). This is especially true when the cause of mangrove degradation is anthropogenic (excessive removal of woody biomass, land clearing, aquaculture, etc.). Depending on the context, **awareness-raising** and **involvement** of local populations must occur simultaneously if restoration is to be sustainable over time.

The project manager must remain involved for several years after organising the replanting operation. Post-restoration monitoring is essential to ensure that the project is carried out properly. Several indicators should be monitored, following a very precise time frame.

II.1. The choice of species

The choice of species is made on a case-by-case basis according to local site characteristics. Species found in the immediate vicinity of the site should be chosen, and monospecific plantations should be avoided.

Pioneer species are suitable for prolonged submergence conditions (e.g. *Sonneratia alba* in Mayotte, or *Rhizophora mangle* in the West Indies) while some species are adapted to the most saline areas (e.g. *Avicennia germinans* in the West Indies, but not in French Guiana where it is more likely to occupy a frontal position). The analysis of abiotic parameters, as well as a sound knowledge of mangrove distributions in the vicinity of the restoration site, allows the identification of suitable zones for each individual species.

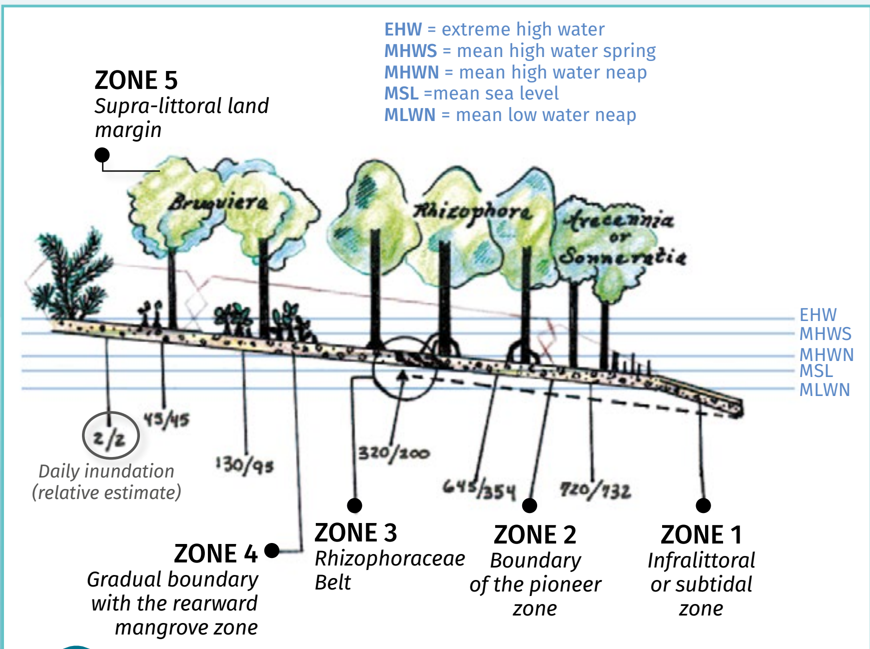


Figure 11
Profile of a Southeast Asian mangrove forest. The zonation of the species is indicated according to the daily submergence (semi-diurnal tide, i.e. two cycles per day).
(source : Lewis & Brown, 2014)

It is advisable to make a species distribution diagram from a mangrove forest contiguous or near to the restoration site, with roughly similar conditions. As in Figure 12 below, it is best to fill in the associated abiotic parameters in parallel with the species zonation. These include substrate salinity, elevation, and duration and frequency of flooding.

This type of graph may be found in the literature (but not for all regions), and can also guide the choice of species for planting if the capacity exists for recording the types of measurements used in this case.

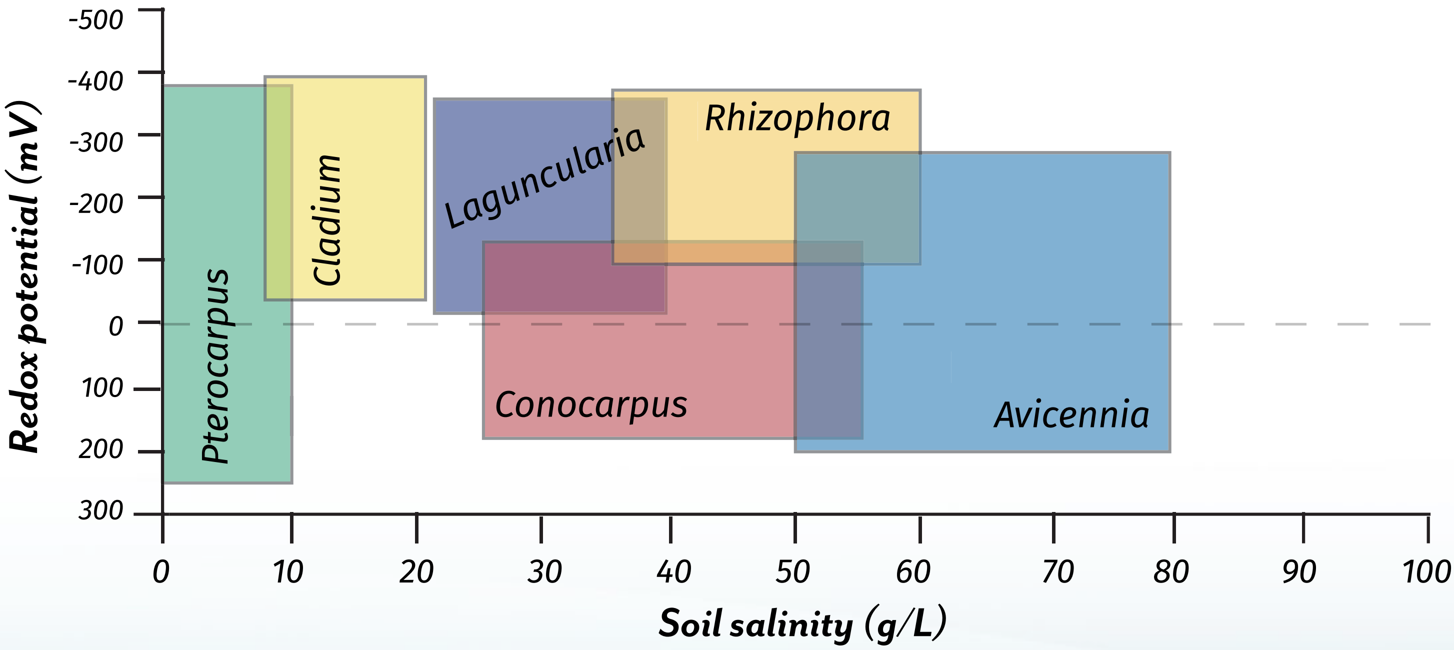


Figure 12
Distribution of dominant genera according to salinity and oxidation/reduction potential in Guadeloupe.
The redox potential is a measure of soil mineralization and the frequency of inundation: the less frequent the inundation, the higher the redox potential.
(source : Stubbs, 2002)

II.2. Two methods of restoration by planting

Collection and storage of propagules for direct implantation into the substrate

The technique discussed in this sub-section involves collecting seeds directly from the mangrove species for direct planting in the area to be restored.

The collection is also used to supply a nursery, for which the methodology will be discussed later. Depending on the species, the propagule may germinate on the parent plant (viviparity, as in the case of *Rhizophora spp.*) or germinate within a fruit (e.g. *Avicennia spp.*). Harvested propagules must be mature (see maturity criteria in Fig. 13). They may be planted directly into the substrate of restoration area or stored temporarily according to the recommendations on the next page.

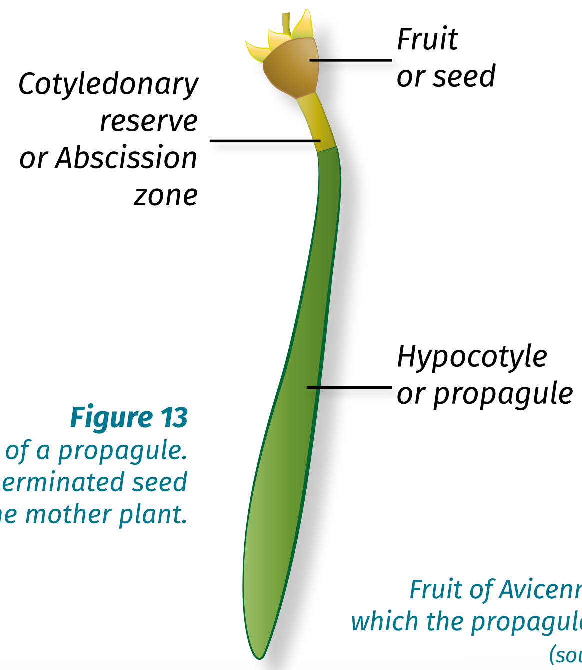


Figure 13
Illustration of a propagule. It is an already-germinated seed developing on the mother plant.

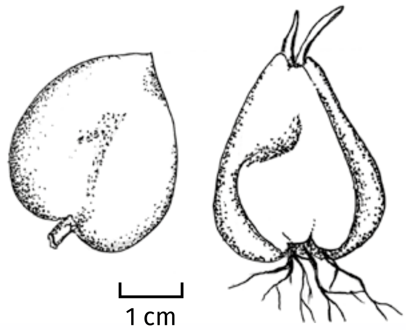


Figure 14
Fruit of Avicennia marina, in which the propagule germinates.
(source : EMR, 2014)

SPECIES	TYPE OF SEED	FLOWERING	PROPAGULE/FRUIT MATURATION PERIOD	INDICATION OF MATURITY	SIZE OF MATURITY
Avicennia marina	Propagule	Mid-September	Dec., Jan., Feb.	Yellow propagule	Weight > about 30 gr
Bruguiera gymnorhiza	Propagule	April to August	March to December	Reddish-brown	Length: at least 20 cm approx
Xylocarpus granatum	Fruit	December to February	Sep., Oct., Nov.	Yellow/brown fruit Floats on water	Weight of a seed inside the fruit: approx. 30 gr
Sonneria spp.	Fruit	Almost all year round	Different stages of maturity are possible on the same tree	Floats on water	Fruit at least 4 cm approx.
Rhizophora stylosa	Propagule	April to May	Dec., Jan., Feb.	Yellow Collar Green Propagule	Length: at least 20 cm approx
Rhizophora apiculata	Propagule	April to May	Dec., Jan., Feb.	Reddish collar	Length: at least 20 cm diam. approx. 14 mm
Lumnitzera spp.	Fruit	May to July and October to November	March to November	Floats on water	_

Figure 15
Phenology and seed maturity criteria of certain mangrove species: this approach should be adapted to the geographical context - this example is from New Caledonia. (source : D'après Lewis, 2005 et EMR, 2014)

Propagules can be **stored** in hessian bags, and immersed in the sea: the bags must be subjected to the movement of the tide. Propagules can also be stored in weighted plastic crates, immersed in the sea and covered with a cloth (protection against the sun and predators). It is recommended that storage should not exceed 2 weeks, as the viability of seeds decreases over time (EMR, 2014).

Figure 16
Methods of storage of propagules (in bags or bins): in both cases, the propagules must be subject to tidal action.
(source : EMR, 2014)

• Vehicle access to the collection site greatly helps in the transportation of equipment and personnel.

• The collection site should be as near as possible to the storage site to avoid unnecessary transport of the fragile seeds.

• The collection site should be close to the sea in order to be able to store the propagules under ideal conditions.

• For *Avicennia marina*, it is recommended to soak the propagules in fresh water for 24 hours to drop the pericarp before planting.

« For the planting, we have 2 protocols: (1) we pick from standing trees, and immediately replant them in the mud within a defined area where we can remove them if necessary after a few weeks; (2) collection takes place every day on the seafront, where we leave the fruit in perforated planting bags immersed in the mangroves (to remain under the influence of the tides) for 3 to 4 weeks so that they can start to put down roots. In this case, we replant them on other more distant sites or we put them in mud bags to create a true nursery » - SOS Mangroves NC

Setting up a nursery

The development of a nursery involves starting the growth of the plants in a relatively controlled environment. This method has the advantage of increasing the chances of survival during planting, since the propagules have already achieved some growth and developed a more substantial root system.

The establishment of the nursery, or the choice of location, should follow these very specific criteria:

1. the site must be within the tidal range,

2. the site must be easily accessible,

3. The site must be flat and of sufficient size to contain the plants and allow them to be handled without hindrance.

An average of 100 plants per m² or one plant every 10 cm is probably a good compromise (EMR, 2014).

Once the nursery site has been chosen, structures known as racks should be built to hold the seedlings in place. Racks can also be placed outside of the nursery itself. The racks can temporarily hold the seedlings for later transfer to the nursery. They should then be placed 'upstream' of the nursery. The positioning of the racks depends on the species they contain. Therefore, species will be placed according to their ecological requirements (for example, a rack of *Rhizophora spp.* which is more tolerant to submersion, should be placed in the areas that are submerged for the longest periods of time).

"We use both the 'direct' method (implantation of propagules in the substrate) and the 'indirect' method (growing in the nursery). At the beginning of the fruiting season (January/February), once the propagules are harvested at low tide, we plant them and arrange them in pots around high tide, when the direct method is not possible. Finally, around May and June, the seedlings are transplanted when they have 2 pairs of leaves."
- Association for Sustainable Development in Mauritius

Figure 17
Example of racks. A capacity of approximately 100 plants per m² can make a good compromise. 1.6m x 6 m racks.
(source : EMR, 2014)

Figure 18
Example of racks arranged behind the nursery (foreground) and in the nursery (background). The location of the racks requires a sheltered environment, such as the upper part of a bay.
(source : EMR, 2014)

Figure 19
An artisanal nursery at high tide in New Caledonia.
(source : EMR, 2014)

Figure 20
Nursery with breakwaters fixed onto heavy moorings, at low tide
(source : EMR, 2014)

• It is advisable to shade the nursery for the first 2 or 3 months using geotextiles that allow rainwater to infiltrate but limit direct sunlight, which is detrimental to the seedlings. The shading can then be removed when the plants have acquired some resistance (EMR, 2014).

• The installation of breakwaters is recommended in order to protect the front of the nursery, which is vulnerable to wave action that can destabilize the seedlings and wash out the substrate in which they rest when they have just been planted. The photo above right shows a homemade breakwater in front of the nursery.

The harvested propagules should be planted in **biodegradable nursery bags** for placement in the nursery. The substrate should be composed of 50% silt and 50% mixed sand, and the bags should be 2/3 full for easy handling. The bags can be placed in temporary racks or directly in the nursery. It is preferable to place them in position at low tide, which allows the substrate to consolidate and thus not be washed out. Propagules should not be planted too deeply or too shallowly, and nursery bagging should follow collection as soon as possible - within a maximum of 15 days (EMR, 2014).

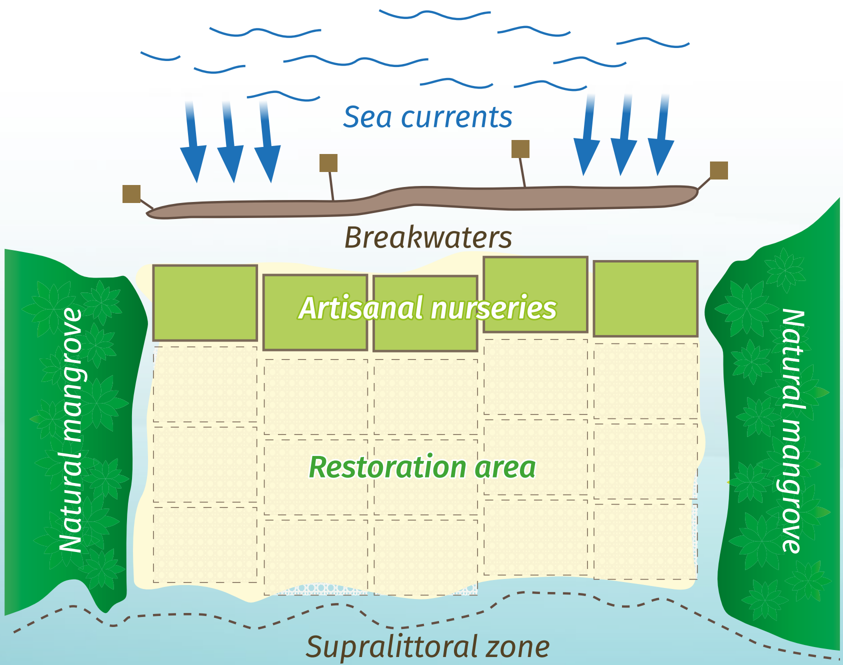


Figure 21
Diagram of the layout of a restoration area on bare substrate.
(Based on: EMR (2014) modifié d'après Duke, 2011)

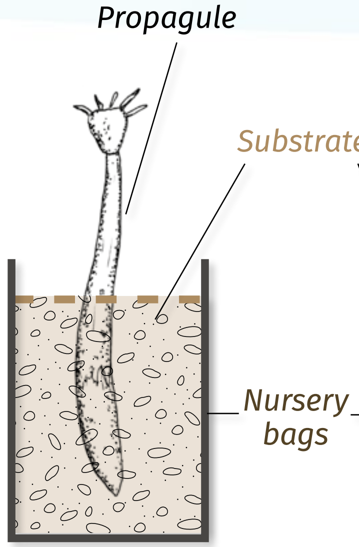


Figure 22
Horticultural bagging of a Rhizophora sp. propagule.
(source : EMR, 2014)

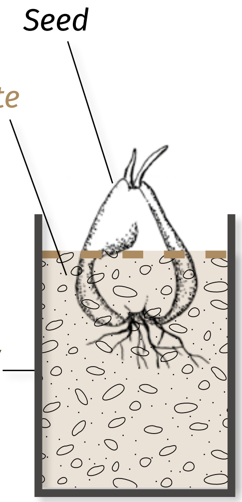


Figure 23
Horticultural bagging of an Avicennia sp. propagule.
(source : EMR, 2014)

Figure 24
Seedlings enclosed in horticultural bags, to be placed in the nursery.
(source : © Chloé Desmots)

- The choice of bagging location is very important: ideally, it should be located close to both the collection site and the nursery, in order to minimize the transport of propagules.
- The location should be accessible and practical, as bagging requires equipment such as shovels to fill the bags, wheel-barrows to mix the substrate, nursery bags with a diameter of 10 cm and a height between 15 and 30 cm, and trays to keep the bags upright prior to placement in the nursery or temporary racks (EMR, 2014).
- The substrate may come from the nearby mangrove area (although pay attention to any regulations in force). The consistent principle of a mix of 50% sand and 50% mud must be adhered to.
- Remove all waste in the vicinity of the nursery (bottles, plastics, plant waste, etc.).
- Ensure that diseased or parasitized plants are removed from the nursery (monitor seedlings regularly).
- Promote good air circulation in the nursery.

An alternative nursery model is also feasible. In this case, the seedlings are not subject to tidal movement, but grow in land-based structures close to the shore.

Figure 25
Ex-situ nursery, on dry land, in Falaleu, Wallis Island.
(© Chloé Desmots)

- In this example, local materials have been chosen so that the project can be easily and cheaply replicated.
- Construction is associated with 'traditional falé' type shelters, and involve the use of local resources such as the invasive Falcataria moluccana (commonly known as 'falcate') and bamboo.
- Coconut leaves are used for shade (for at least the first 2 to 3 months) and to allow rainwater to infiltrate.
- Purchase of mesh pig pens or the use of crates in order keep crabs away from the bags.
- Horticultural bags are provided by the Environment Department.

- A nursery may also be located near a river, which allows the plants to be watered with fresh and then brackish water to promote their growth (a significant benefit to *Avicennia marina*) before planting.
- When planted, however, seedlings from this type of nursery may experience greater stress because they have been isolated from tidal conditions and variations in salinity.

Figure 26
Plants 4 months after planting in Mata-Utu.
(© Chloé Desmots)

Figure 27
Seedlings bagged and placed in trays, destined for the Halalo nursery.
(© Chloé Desmots)

Illustration of nursery bagging:
propagules/seeds and planting by mangrove genus

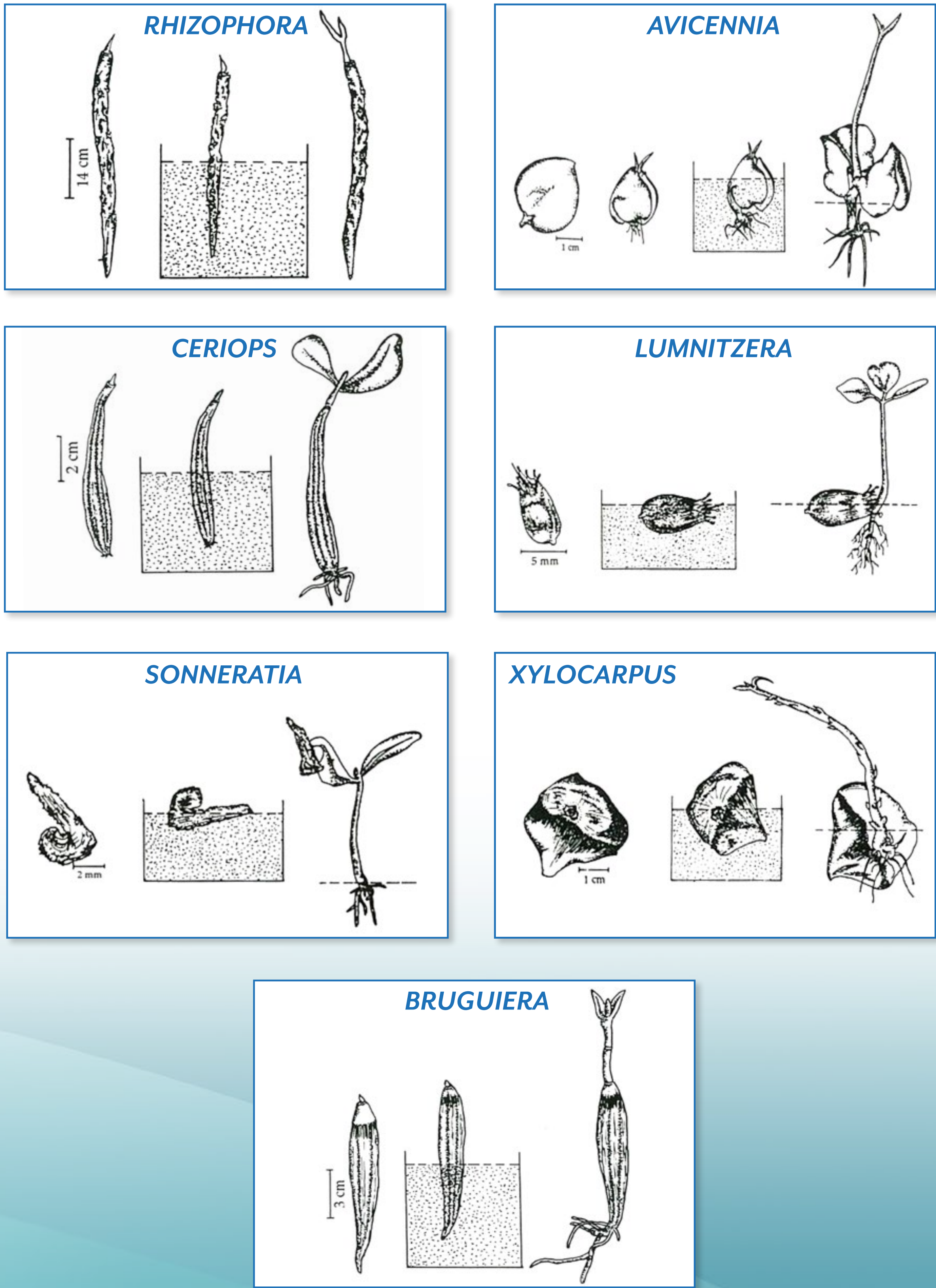


Figure 28
Illustration of nursery bagging: propagules/seeds and planting
depending on the type of mangrove. *(Source : EMR (2014), modified from N. A. Siddiqi et al., 1993)*

II.3 The planting process

Planting requires shovels, wheel-barrows and possibly containers to transport the seedlings to the field. After removal from the container, a seedling should be placed in a hole in the substrate. The hole should be 1.5 times the size of the plant's root ball (Lewis, 2009) (Source: EMR, 2014).

Cutting off the bottom of the nursery bag with a machete prior to planting.

Inserting the seedling within its cut-out bag into the hole: the bag is simply pulled upwards, and the hole then filled in.

Figure 29

Materials required for planting at the site. (source : © Anne Caillaud)

Spacing between the seedlings

Certain case studies recommend the use of transects, laid down using ropes, to guide the planting. We recommend not using this method, as it may create 'artificial' channels that can alter the hydrology.

Seedlings should be planted 'randomly' and at a specific spacing - excessively high densities should be avoided, as spontaneous plant dynamics will then take over (Lewis, 2009).

"At the beginning of our involvement, on the advice of the Ministry of Fisheries, propagules were planted at 1 m intervals. During the last fiscal year of 2014, this interval was increased to 1.5 m, again on the advice of the Ministry of Fisheries. Volunteers from local villages are involved in mangrove planting operations after a training phase supervised by the Ministry of Fisheries and our association. A special tool has been designed to facilitate direct planting" - Association for Sustainable Development (Association pour le Développement Durable) in Mauritius.

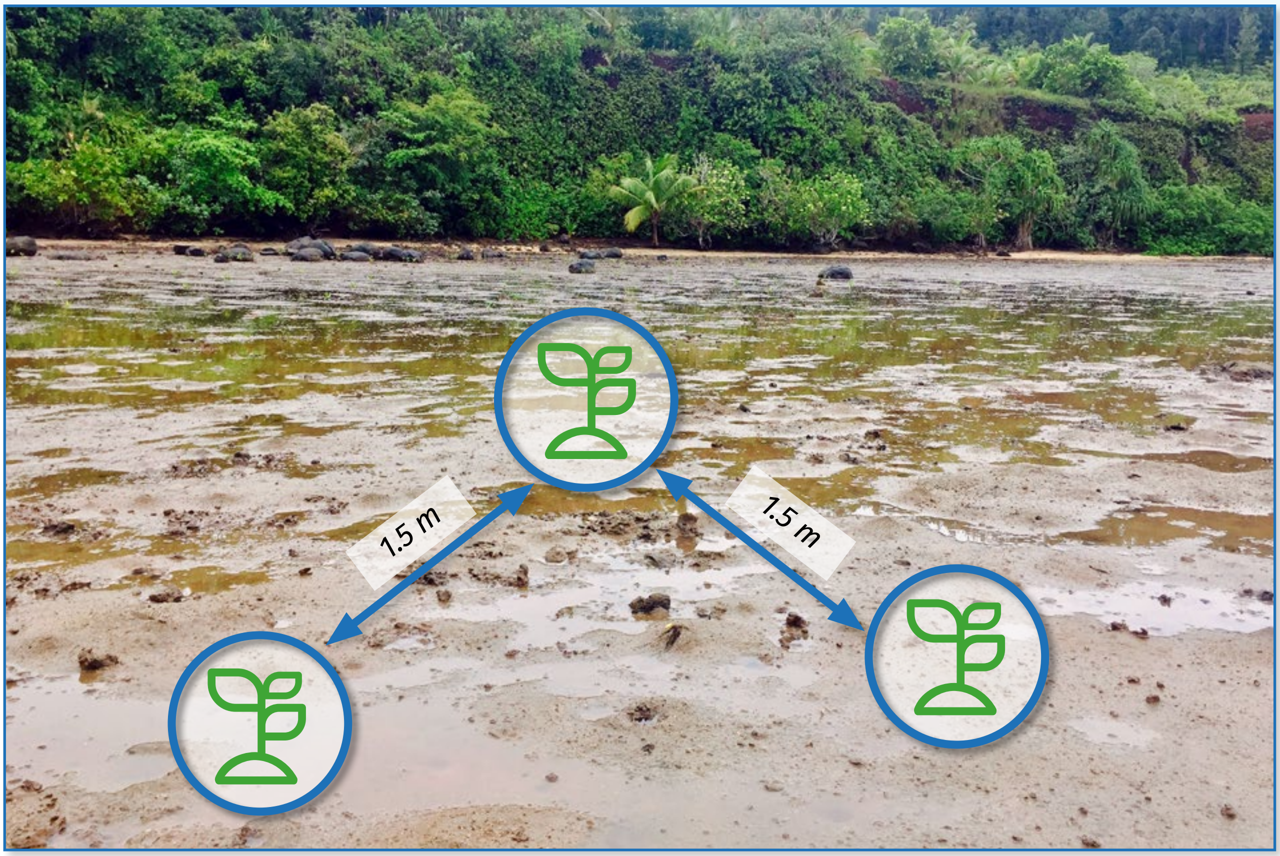


Figure 30
Random planting of separated seedlings, following technique n°1 above. (© Anne Caillaud)

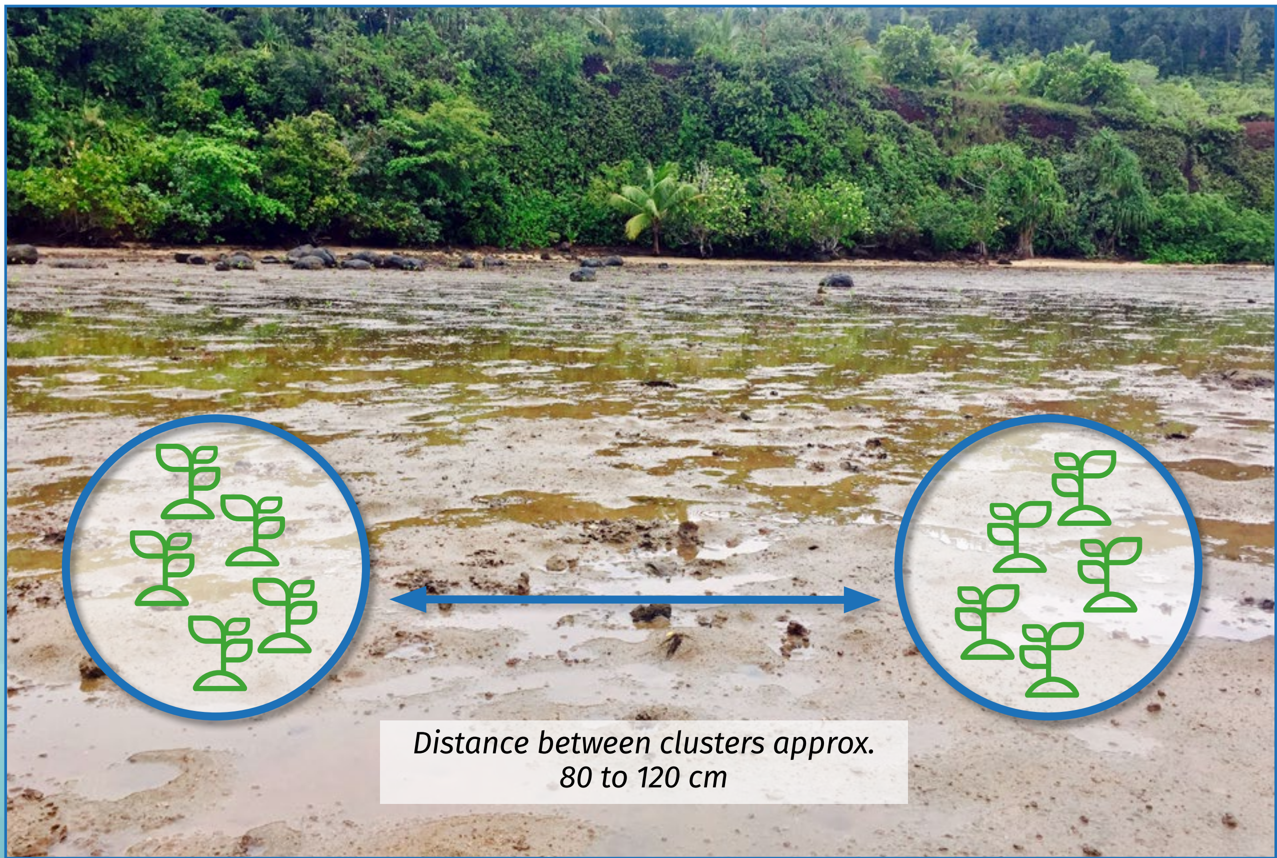


Figure 31
Planting by seedling clusters - around 5 individuals - following technique n°2 above. (© Anne Caillaud)

Planting in clusters is interesting, in that it draws on intraspecific interactions between plants under difficult conditions for survival. For example, as a group, the immature mangroves will gradually help to improve the substrate in their surrounding area (substrate oxygenation etc.). This technique is reported to have shown excellent results over a long period of time (4 years on) at several restoration sites (Gedan & Silliman, 2009).

Figure 32

Use of a tool designed to assist in the planting process.

(source : ©Association for Sustainable Development, Mauritius)

"A dedicated tool, made from metal rods, was designed by a member of the association. It has a pointed end with 2 iron bars, one of which is fixed about 30 cm from the end to exert more force and thus facilitate the implantation of the propagules". – Association for Sustainable Development, Mauritius.

Important points to remember

- The recommended optimal density varies among experts and studies, ranging from 1 plant/m², or a 2-metre spacing between plants. The ideal spacing is **a distance of 1 to 2 metres between plants.**
- For the cluster technique, allow a distance of between **80 cm and 1.20 m**.
- Random planting is preferable, while respecting the required spacing between plants if the 'cluster' technique is not used.

Organising the post-operation monitoring

Monitoring indicators

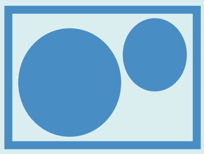
Several indicators should be recorded at regular, precise time intervals. At the very least, the following should be monitored:

- Mortality (ratio between the number of seedlings planted and the number of dead seedlings, i.e. the survival rate).
- The recovery rate (%): this is an evaluation of the spatial distribution of the vegetation (at least once a year).
- Seedling growth (in cm, measured monthly or fortnightly, or the average of all seedlings when using quadrats).

SITE	No. of seedlings planted	Dead or missing seedlings	Survival rate (%)
1 A	13 868	2 452	82,4
1B	8 312	601	92,8
2A	14 007	480	96,6
2B	975	34	96,5
3	150	35	76,7
TOTAL	37 312	3 602	90,4

Figure 33
Example of a table showing the results of indicator monitoring. Here, only mortality is shown.
(source : Association for Sustainable Development, Mauritius)

- Monitoring may involve all individuals that were planted, or may involve a representative sample if the restoration site is too large in relation to the monitoring capacity of management. Monitoring along transects, which is discussed below, should then be undertaken. In the case of 'cluster' planting, **monitoring of all clusters should be conducted (ie. not using transects) with the same indicators recorded.**

SURVIVAL RATES	$\frac{\text{Number of surviving plants}}{\text{Initial number of plantss}} \text{X } 100$
RECOVERY RATES (%)	 ± 60%
GROWTH (average when using quadrats)	$\frac{\text{Sum of the heights}}{\text{Number of plants}}$

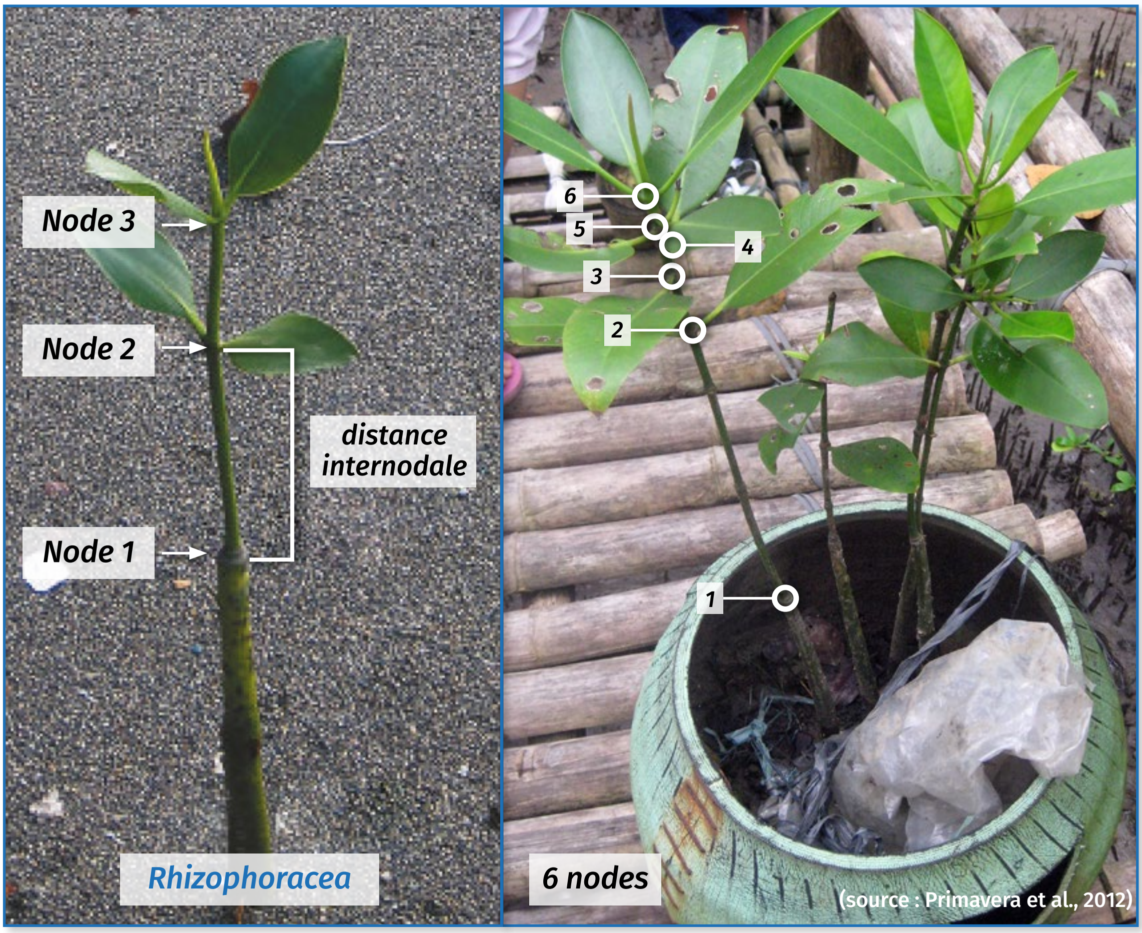


Figure 34
Illustration of plant nodes and internodal distance.

The measurement of growth is made from the top of the propagule (Node 1 in the above photo) to the apex (the tip of the plant). This is the minimum measurement to be recorded. Ideally, it would be accompanied by internodal measures, along with leaf counts at each node (Primavera et al. 2012).

Monitoring protocol

It would be ideal to monitor all planted seedlings. However, if the restoration site is too large, monitoring should be done by transect, and using quadrats. This method involves **laying transect lines, along which quadrats are placed at predefined intervals**. Sampling should be representative of the entire site. In order to obtain reliable and representative measures, at **least 10%** of all individuals should be sampled (EMR, 2014). In addition, for each subsequent survey, the transects and quadrats should be placed in exactly the same location.

- For example, if we assume a seedling density of 1 plant/m², and 1000 plants have been planted, then a minimum of 100 plants will need to be monitored, i.e. an area of 100 m², requiring four 25 m² quadrats to be distributed along the transects (EMR, 2014). This will need to be scaled according to the size of the area.
- If possible, the beginning and end of a transect line, as well as the position of the quadrats, should be recorded with the **GPS**. Alternatively, **securely-attached tags** should be used.

• For each quadrat, the number of live and dead plants, the height of the plants, and the recovery rate should be recorded on the first field data sheet (page 30). A second summary sheet enables the user to record other indicators that contribute to an overall comparison (page 31).

• Data storage and management is very important: an Excel spreadsheet can be a valuable tool when every seedling is recorded (this can involve large numbers of records, e.g. the monitoring of 13,868 seedlings in the restoration project in Mauritius). When all seedlings are monitored, the same indicators should be used as for the quadrat monitoring. The recovery rate will then be measured at the plant level.

Several configurations are possible when setting up transects. The principle of a minimum sample of 10% must always be followed.

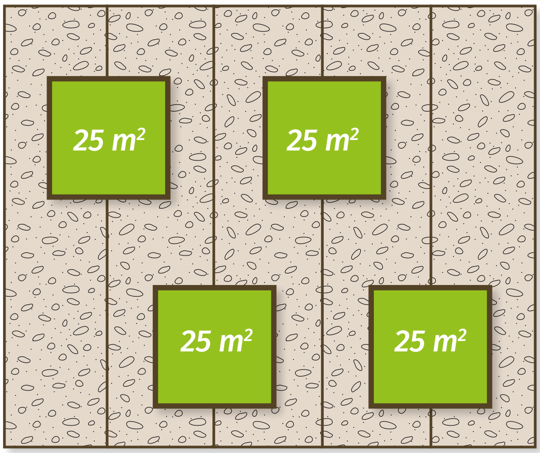


Figure 35
Schematic example n°1 with a total site area of 1000 m² (1 plant/m²).

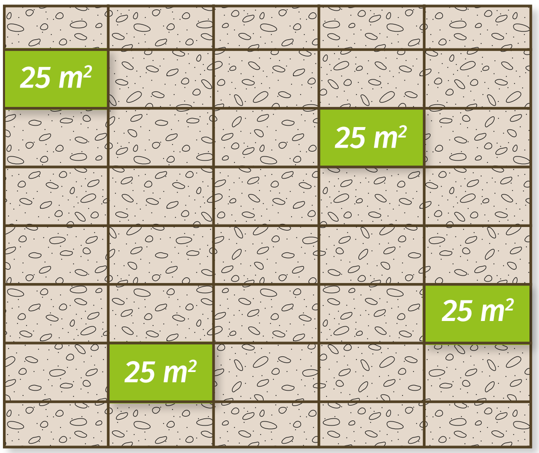


Figure 36
Schematic example 2 with a total site area of 1000 m² (1 plant/m²).

• During the initial measurements, one should be sure to note the reference heights (H1 for example) which will be used to measure growth. GPS mapping of seedlings may be considered, as physical markers such as tags are exposed to natural hazards and can fall off. To avoid variations in coordinate readings from one visit to another, an accurate, good quality GPS is recommended.

• If the plants are positioned in clusters, each cluster should be numbered and located, again either by marker (tape, or a rigid, firmly anchored marker) or by an accurate GPS. The recommended parameters should be measured for each plant in each cluster.

Monitoring equipment

- A camera to illustrate the observations.
- A measuring instrument with millimetre divisions (measurement of plant growth).
- In the case of quadrats, a field data sheet in which the measurements of the various indicators are recorded, as well as a summary sheet.
- A permanent marker.
- In the case of transects, a tape measure to delimit the quadrats, and a spool of line for transects are required. Alternatively, a GPS may be used to georeference transects or even the monitored plants.

Managing predation and disease

- The management of predation before and during post-restoration monitoring is essential to ensure the success of the restoration action:

The risk of predation by crabs, livestock (e.g. zebus, goats) and molluscs must be factored into the choice of restoration site. If the site is in the vicinity of villages, it is important to consult with local livestock owners in order to agree on measures to be put in place (cf. the case of Tsoundzou 1 in Mayotte, where half of the plants were grazed by zebus near the village edge).

Field monitoring datasheet - transects

Observer:		Tidal coefficient:			Water level at high tide:
Date:		Time of high tide:			Water level at low tide:
Transect start time:		Time of low tide:			Transect No.:
Transect completion time:					
Quadrat	**Number of plants**	**Number of dead plants**	**Height of plants (cm)**	**Recovery rate within the quadrat (%)**	**Observations (predation, necrosis etc.)**
Q1			P1		
			P2		
			P3		
			P4		
			(etc.)		
Q2			P1		
			P2		
			P3		
			P4		
			(etc.)		
Q3			P1		
			P2		
			P3		
			P4		
			(etc.)		
Q4			P1		
			P2		
			P3		
			P4		
			(etc.)		

This field data sheet is designed for transect-based monitoring, and can be adapted according to the configuration, the number of quadrats and the number of plants within them. Each plant should be marked to allow the periodic monitoring of individuals. On the initial field sheets, a reference plant height can be recorded, which will be used as a basis for calculating growth, which is then entered in the summary sheet.

Download:
- *XLSX FORMAT:*
https://www.pole-tropical.org/field-monitoring-datasheet/

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Summary Sheet

Date:
Transect No.:

Quadrat	Number of plants	Survival rate (%)	Average plant height (cm)	Recovery rate within the quadrat (%)	General observations (predation, necrosis etc.)	Average plant growth (cm) T1 / T-1
Q1						
Q2						
Q3						
Q4						
(etc.)						

This summary sheet should be completed using the data contained in the field monitoring sheets. This summary enables us to gather further information on other types of indicators, which are more difficult to calculate under field conditions. One example is the average growth, which allows an analysis of plant dynamics at the quadrat scale as well as inter-quadrat comparisons. The survival rate can also be derived from the comparison between dead and live plants. Finally, the average height of the plants also allows a relative estimate on a broader scale than that of the individual.

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- *XLSX FORMAT: https://www.pole-tropical.org/summary-datasheet-office/*

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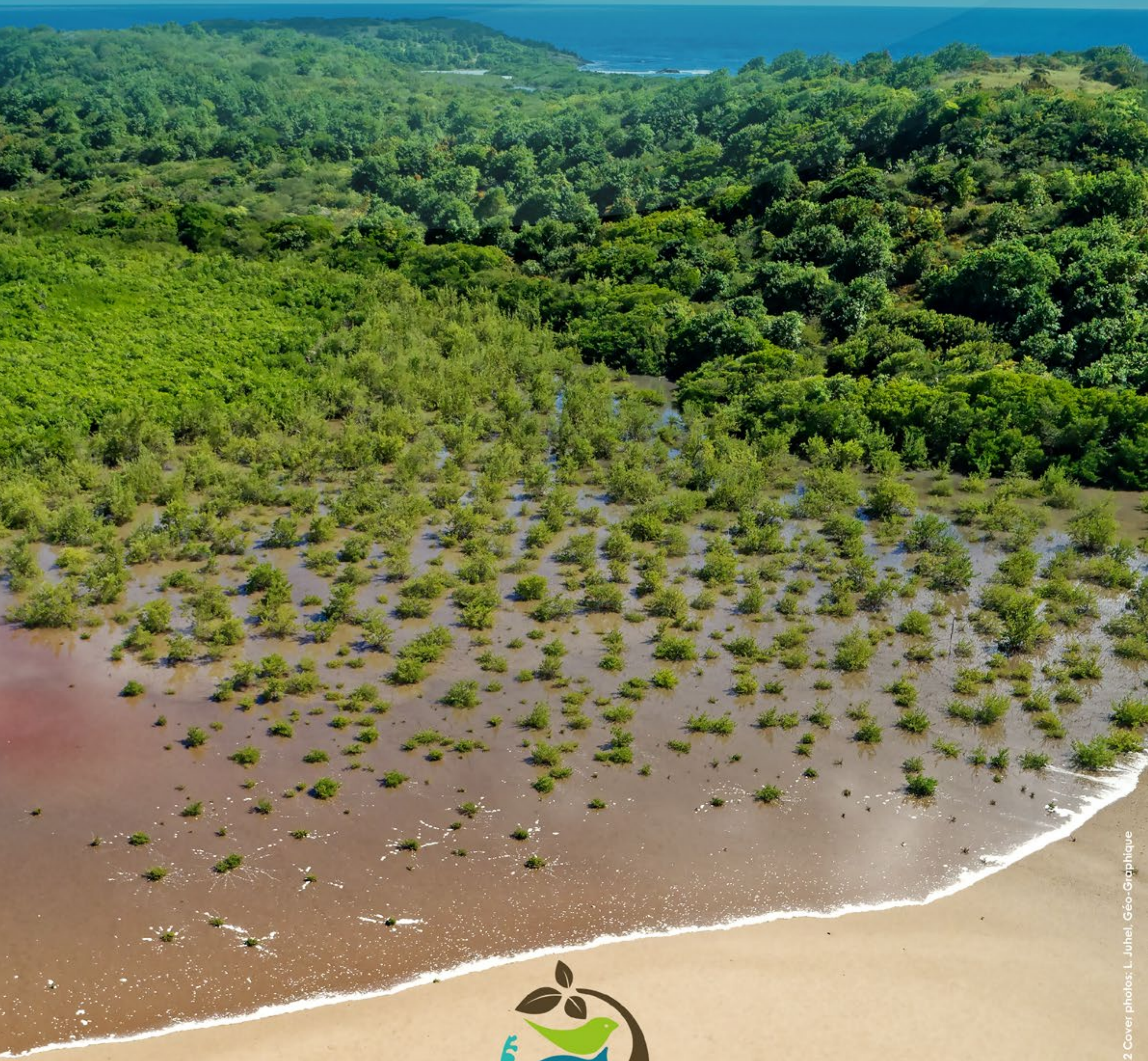

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