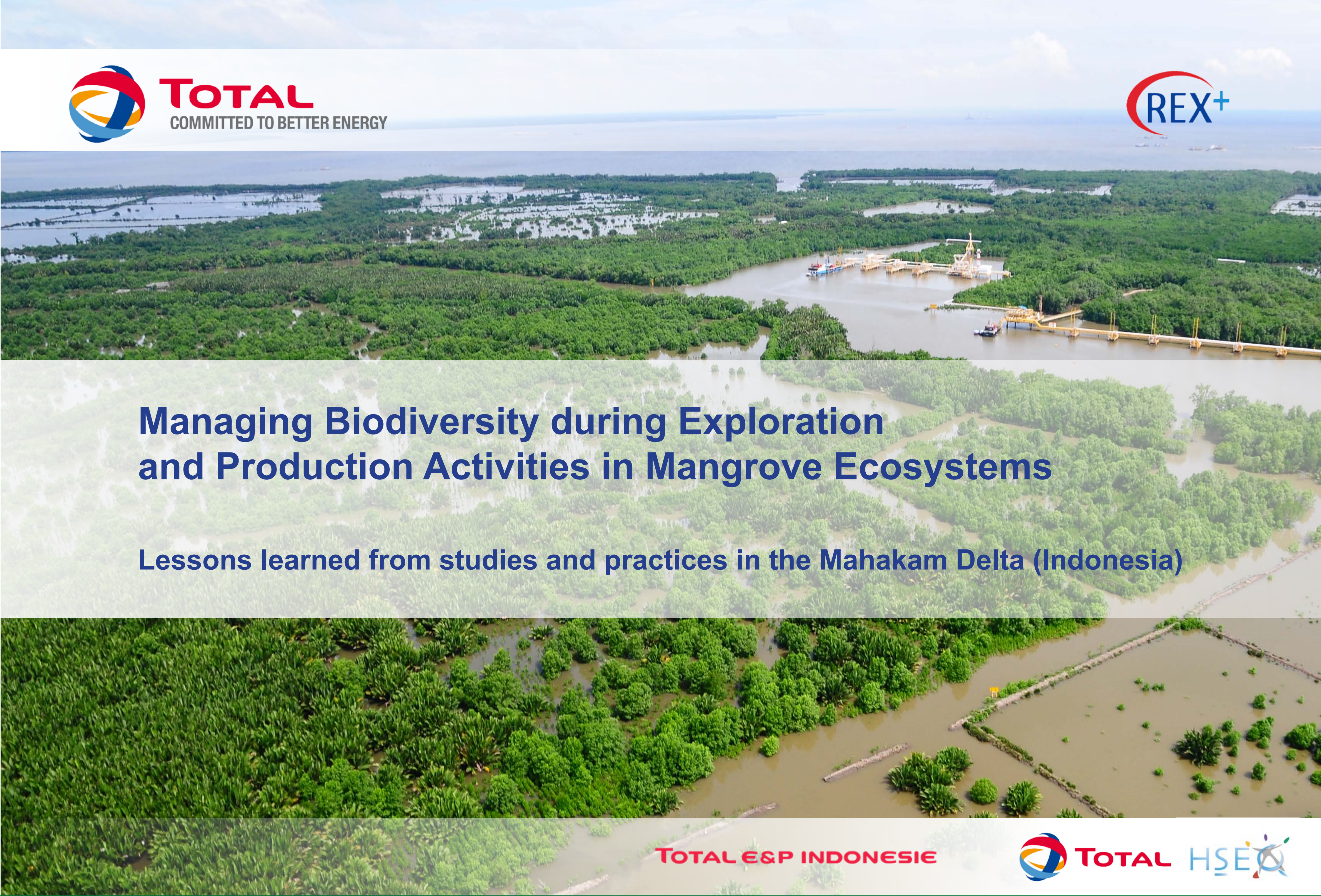

Managing Biodiversity during Exploration and Production Activities in Mangrove Ecosystems

Lessons learned from studies and practices in the Mahakam Delta (Indonesia)

TOTAL E&P INDONESIE

ISSUED BY DG/PSR/HSE/EP/ES/ENV - SEPTEMBER 2016

MANAGING BIODIVERSITY DURING EXPLORATION AND PRODUCTION ACTIVITIES IN MANGROVE ECOSYSTEMS

LESSONS LEARNED FROM STUDIES AND PRACTICES IN THE MAHAKAM DELTA (INDONESIA)

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INTRODUCTION

Mangroves can be defined as an association of trees and shrubs forming the dominant vegetation in tidal, saline wetlands, along equatorial, tropical and subtropical coasts.

Mangroves are important coastal ecosystems. They can protect shorelines, improve the water quality and store carbon. They form habitats and nurseries for a wide range of land and marine animal species, sustaining biodiversity and food webs and supporting commercial coastal fisheries. Their ecological, social, cultural and economic values have been demonstrated by several authors and international organizations. Therefore biodiversity and associated ecosystem services are of key importance in such areas.

Since mangroves are located within the coastal zone where most of the world population is concentrated, they are subject to the development of various human activities, and have become globally threatened. 35% of the worldwide mangrove area was lost between the 1980s and the early 2000s, which is greater than losses incurred by either tropical forests or coral reefs. Yet, some communities are strongly dependent on mangrove for their livelihood.

Total E&P Indonésie has been operating in the Mahakam river delta since 1968. The ecosystem rapidly changed over the past decades, with the development of coastal ponds for shrimps, milkfishes and crabs resulting in a massive deforestation. In addition, the oil and gas activity also contributed to a lesser extent to impacts on the forest ecosystem. In response to the delta's worsening condition, Total E&P Indonésie took the initiative to plant mangroves. A three-year-long R&D project on Mahakam Delta was performed from 2011 to 2014 to ascertain the ecological processes for mangrove restoration and assess the ecosystem resilience to disturbance caused by human activities.

This REX (Return of EXperience report) is intended to be used by Total affiliates when operations take place in or near mangrove ecosystems.

CONTEXT OF THE MAHAKAM DELTA

- ✓ A succession of vegetation types
- ✓ A threatened environment

CONTEXT OF THE MAHAKAM DELTA

A SUCCESSION OF VEGETATION TYPES

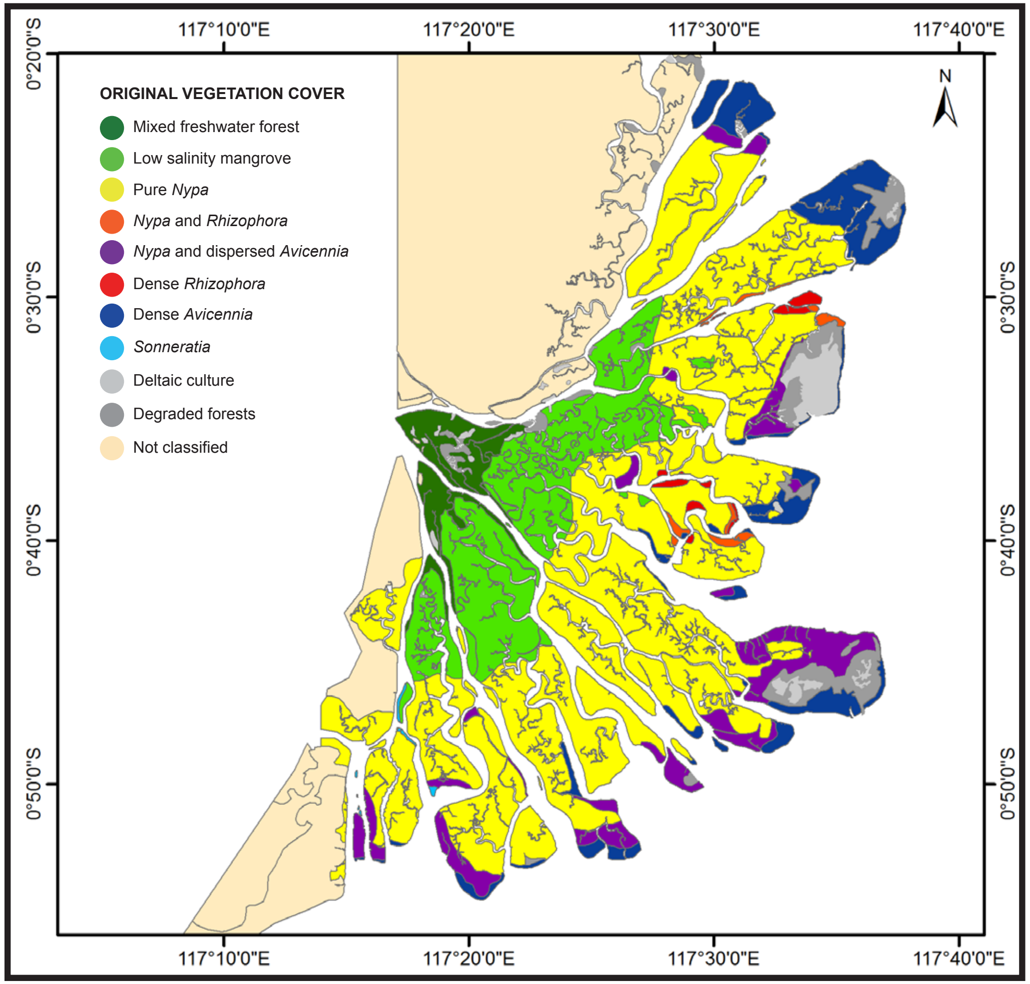
As an equatorial estuary receiving heavy rainfall evenly distributed throughout the year, the delta of the Mahakam River, located in Indonesia, East Kalimantan, Borneo island (0°21'- 1°10' S and 117°15'-117°40' E) is one of the most suitable sites for natural mangrove development.

The total surface of the Mahakam Delta is about 5,000 km², part of which is submerged, including the prodelta (2,700 km²), a delta front shallow at low tide and devoid of vegetation (1,000 km²), and a delta plain over which a luxuriant mangrove forest has developed. This is one of the largest deltas in Indonesia.

The various vegetation zones and plant communities, which are distinguishable by their structural properties and floristic composition, match hydrological features as is shown in a vegetation map of the delta first published in 1990 (Dutrieux et al., 1990) and later revised in 1996 (Gayte and Dutrieux, 1996).

- ✓ The peripheral zone, located at the mouth of the river, was covered by large stretches of *Avicennia spp.* communities, either as monogeneric stands, or mixed with other species.
- ✓ The central zone of the delta was occupied by an extended monospecific community of *Nypa fruticans* palm vegetation, with a 580 km² cover covering more than 50% of the delta plain area.
- ✓ Upstream, *Nypa* communities were mixed along riverbanks and/or gradually replaced by transitional communities less tolerant to elevated salinity. At the apex of the delta, salinity was very low and most of this area was not flooded at high tide. The same species as in the transitional communities, along with freshwater species, were hosted by this area (*Heritiera littoralis, Oncosperma tigillarum*).

Spatial distribution of the original vegetation communities in the Mahakam Delta. This figure represents the vegetation as it was in the early 1980's.



Tips

In a mangrove area, always examine the zonation of the vegetation during enviromental baseline and monitoring studies.

A THREATENED ENVIRONMENT

In the 1970s, Total E&P Indonésie started its operations in the delta. In the early 1980s, the Mahakam Delta mangrove forest was nearly unaltered by anthropogenic activities. Migrants were then attracted by the industrial development. Many of them had been working in the fisheries sector, and in the early 1980s, migrants opened a few aquaculture ponds in the mangroves. Refrigeration companies were encouraged by the success of intensive aquaculture in Asia and provinces of Indonesia and supported the opening of ponds in the Mahakam Delta by supplying, for example, excavators to shrimp farmers (Sidik, 2008). The shrimp farm industry grew exponentialy and about 85% of the delta (750 km²) were converted into aquaculture ponds.

The footprint of the Total facilities remained low and represented approximately 28 km² or 4% of the delta (Dutrieux et al., 2014).

Tips

In a new exploration area:

- ✓ Review historical data to explain past changes.
- ✓ Start environmental studies at the earliest stage of the project.

1988 : INITIAL SITUATION

In 1988, vegetation was still in its original shape. *Achrostichum* ferns landscapes alternated with *Avicennia* forest.

2001 : MASSIVE DEFORESTATION

By 2001, most of the vegetation had been transformed into ponds. Only some green belts, mainly *Avicennia*, remained subjected to erosional processes.

DATA ACQUISITION AND METHODOLOGIES

- ✓ Assessing the vegetation cover
- ✓ Assessing the fauna biodiversity in a mangrove ecosystem

DATA ACQUISITION AND METHODOLOGIES

ASSESSING THE VEGETATION COVER

The vegetation is the structuring element of a mangrove ecosystem and as such should be studied first.

The main objective of our recent R&D project was to describe the vegetation extent and associated biodiversity in the Mahakam delta for the 2011-2014 period, following drastic changes. Previous assessments had been done in 2001 for vegetation cover, and in 1987 for biodiversity.

The spatial distribution of mangroves was investigated using satellite images and validated by site surveys. These data were compared with GIS maps produced before 2010. Using both optical and radar datasets acquired in 2010, vegetation and mangroves distribution were mapped at a 1/10000 scale over the entire delta. Groundtruthing was facilitated by producing maps and was an important step to validate the final detailed maps.

The vegetation maps were supplemented by a botanical inventory on selected areas.

Vegetation mapping using recent satellite images

Two kinds of images acquired in 2010 were selected:

- ✓ A scene from the AVNIR (Advanced Visible and Near Infrared) instrument acquired by the ALOS satellite with a 10 m resolution.
- ✓ Synthetic Aperture Radar (SAR) images from the satellite TerraSAR with a 1.5 m resolution.

Green to very Near Infrared (NIR) spectral bands of the AVNIR image are adapted to extract vegetated and water surfaces. Cloud cover is generally problematic in tropical regions especially in the near-shore fringe. Consequently it is often difficult to acquire cloud-free satellite images in the Near Infrared (NIR) domain.

Radar cover is useful because microwaves are not affected by clouds, haze or dust. This last capability gives access to a larger amount of archive images. However, automatic classification of vegetation is not allowed by radar images.

In addition, an innovative tool for mangrove monitoring was used during this study: very high-resolution aerial photographs.

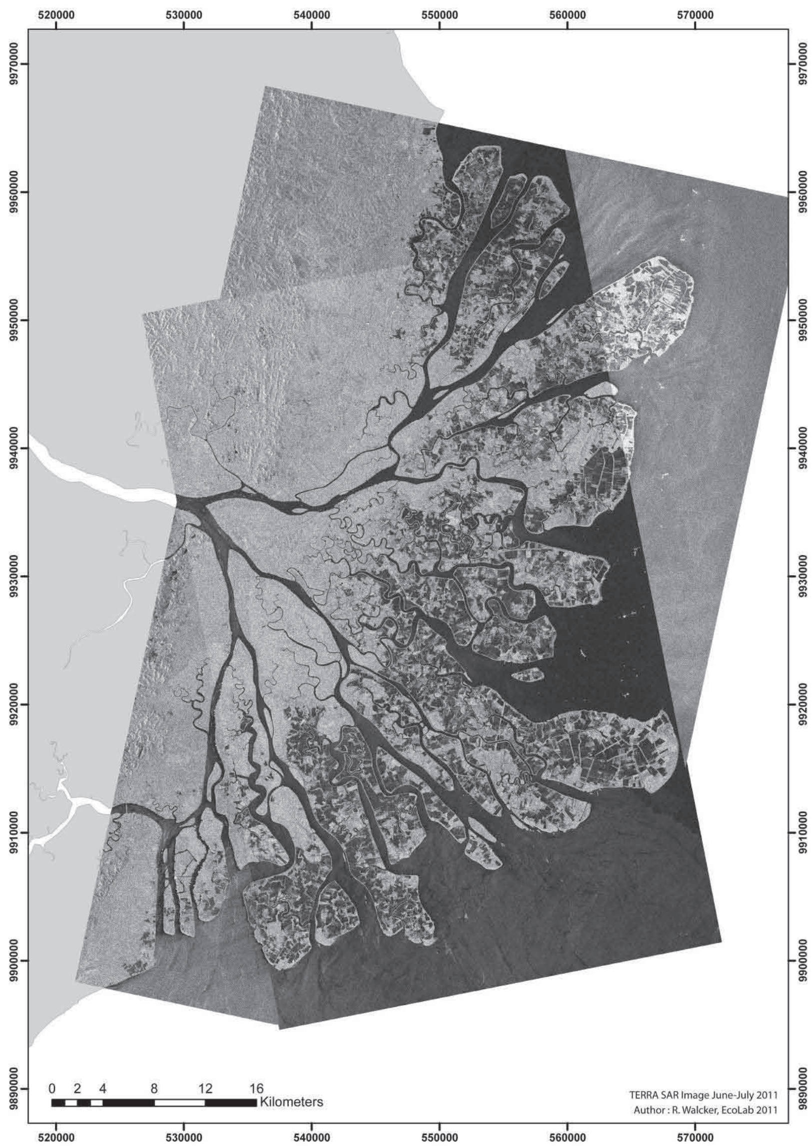
The use of very high resolution aerial photographs (10 cm/pixel) over a large study area requires extensive digitizing and visual interpretation. However, this method has allowed for significant advances in mapping and characterizing vegetation and human activity.

Tips

Both optical and radar images are complementary for vegetation cartography: automatic classification is allowed by optical images and can be completed by radar images especially in cloud-covered zones.

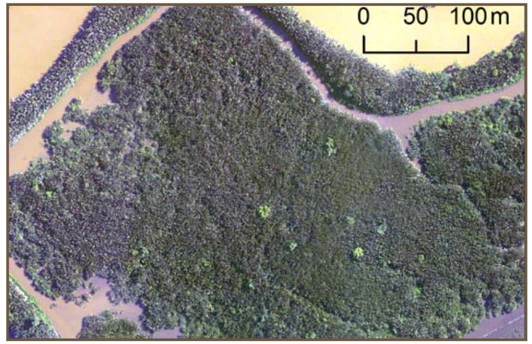
Tips

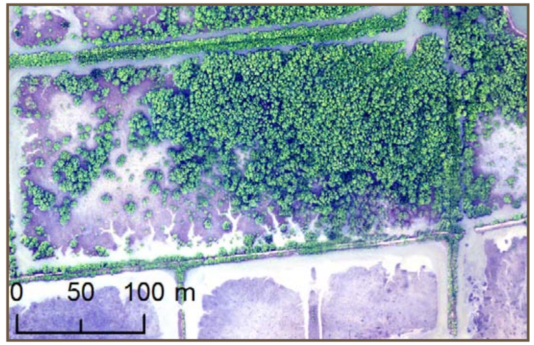
The use of aerial digital photography to assess and map landscape change is a crucial element of ecosystem management. Aerial photographs are ideal for mapping small ecosystems and fine-scale landscape features.



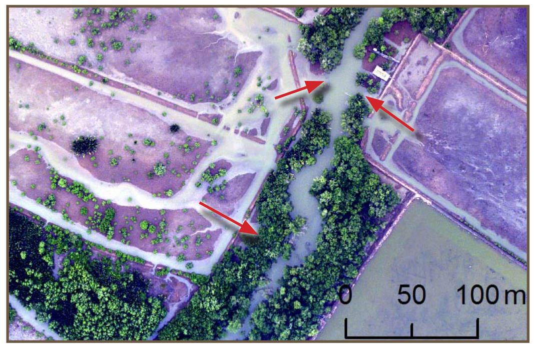
TerraSAR images acquired in June/July 2010 in the Mahakam Delta

Example of information provided by very high resolution images





Aerial photographs of *Nypa* palms formation (top), natural mangrove (bottom).



Aerial photograph of open ponds. Arrows point the breaches in the dikes.

Forest physiognomy

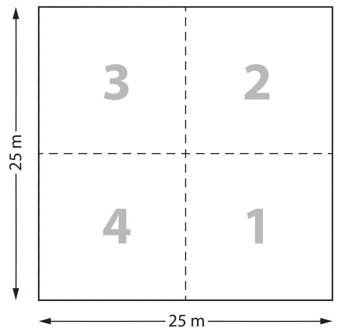
In order to provide information on the nature of the vegetation cover and details on the forest physiognomy, it is necessary to perform field investigations.

Each forest investigation includes, in a defined 625 m² area, trees species identification, counting, measurement of diameter at breast height (DBH) for all leaving trees (i.e., 130 cm above the ground for all trees and above aerial roots for Rhizophora species). These measurements should be complemented by salinity measurements of the upper mud layer and the water (mangrove trees are strictly dependent of salinity values).

Each tree is individually measured inside well defined plots.

Tips

The vegetation is the structuring component of the mangrove. Understanding of the mangrove cycle is done with detailed field studies.



Observations and assessment of the community structure are done using 25 x 25 meters (m) plots delineated using tape, cotton string, wooden pickets (left onsite for future surveys to allow comparaisons), and hand-held laser measurements.

DBH is measured with a diameter tape, a forestry tape measure allowing direct reading of a diameter.

Tree heights are estimated using a graduated stake for pioneer mangrove individuals or using a hand held lasermeter for adult trees.

Salinity is measured using a handheld refractometer.

Botanical inventory

The objective of the botanical inventory is to identify the plant species over an area. This complements the forest inventories which aim to describe the forest physiognomy in some defined plots.
Mangrove species are identified from boat within the middle and lower parts of the delta. Vegetation is assessed using rapid surveys conducted during stops at different places including riverbanks, shrimp ponds, replanted areas, and young to mature mangrove stands.


Sonneratia alba fruit

Tips

Botanical specialists are needed to perform such inventories.

The biodiversity of true mangroves is never very large and easily identifiable but associated species, especially in low salinity areas are more diverse.

Bruguiera cylindrica roots.



Avicennia officinalis fruit.


Bruguiera cylindrica fruit.

Rhizophora apiculata propagule.



Sonneratia alba tree.

Rhizophora apiculata tree.


ASSESSING THE FAUNA DIVERSITY IN A MANGROVE ECOSYSTEM

Mangroves form habitats and nurseries for a wide range of land and marine animal species, thereby sustaining biodiversity and food webs, and supporting commercial coastal fisheries (Nagelkerken et al., 2008). Their importance and their need of preservation is broadly recognized (Duke et al., 2007) and many international conventions aim or contribute to protect these ecosystems, including the Ramsar Convention on Wetlands, the Convention on Biological Diversity (CBD), the UNESCO's Convention concerning the Protection of the World Cultural and Natural Heritage and the UNESCO's Man and Biosphere Program (Gaudin, 2006).

Fauna in mangrove ecosystems are important components of local biodiversity and may include birds, fishes, invertabrates, reptiles and mammals.

The very common monitor lezard.

Birds

Birds are one of the most well-known groups of animals and are arguably one of the most relevant assemblages to use in order to monitor ecological change. Additionally, birds are more easily observed, monitored, and identified than reptiles or mammals. Several inventory techniques can generate an overview of the bird populations in large areas at a low cost and with minimal human investment (Blondel, 1975; Bibby et al., 1992; Borchers and Buckland, 2002).

Fishes and invertebrates

Fishes and aquatic invertebrates are also important components of fauna. The submerged mangrove roots provide shelter for young fishes and shrimps from larger predators. Some species constitute a food source for humans. Also, communities of macroinvertebrates play a crucial ecological role in the mangrove forests. Their occurrence and biodiversity can be easily assessed using fishing gear and identification in the laboratory.

Reptiles and mammals

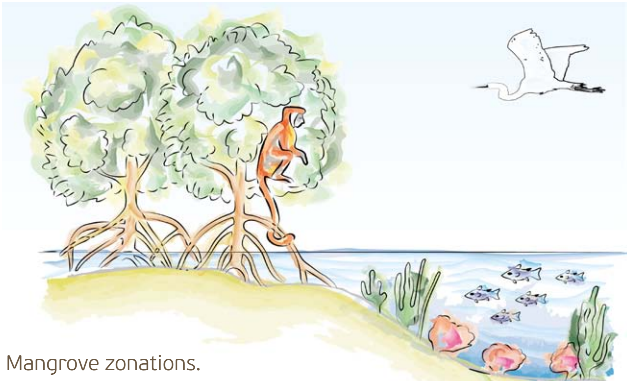
Some species of mammals and reptiles also live in the mangrove habitat. In the Mahakam delta, it includes monkeys such as the proboscis monkey (*Nasalis larvatus*, endangered species), the estuarine crocodile (*Crocodylus porosus*) and monitor lizards (*Varanus salvator*).

The comprehensive inventory of these mammals and reptiles requires an important work and investment; it is recommended to conduct observations on a regular basis concurrently with others field surveys.

A proboscis monkey with her young.

A purple heron.

A periophtalm.



Mangrove zonations.

A fiddler crab (*Uca tetragonon*).

A striated heron.

Egrets, mainly little egret.

A saltwater crocodile (*Crocodylus porosus*).

Bird inventory

In the Mahakam delta bird population dynamics were examined by comparing studies done in 1987 and 2013. A baseline assessment of bird populations (primarily water birds) was done in 1987 (Eve and Guigue, 1989) before the delta was altered by aquaculture.

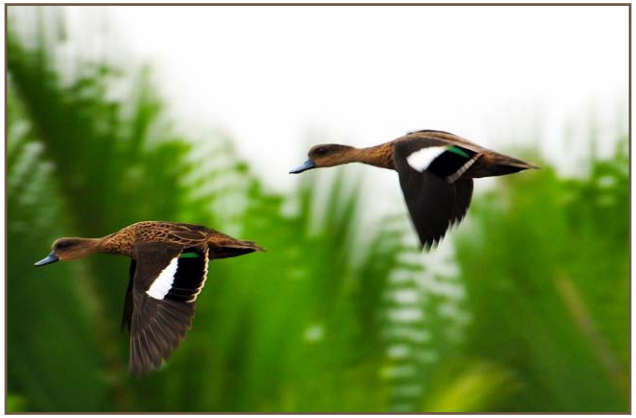
In 2013, observations were made from boat transects. Daily survey tracks and locations, where observations were made, were recorded using GPS. However, this surveying technique only allowed observation of birds in flight, living on the banks or in trees along the edge of the river.

At the same time, the position of ponds and locations where monkeys and reptiles had been observed were opportunistically recorded.

Most of the time, the edges of the Nypa prevented the observation of birds living in the shrimp ponds. Yet, when the birds were observed in these habitats, it was possible to record and georeference the GPS location of the observation point. At each observation point the abundance of each species was recorded in a standardized way following state of the art methodologies (Reynolds et al., 1980; Goldsmith, 1991; Braun, 2005).

Birds were identified and counted. Pictures were taken to illustrate reports and help with further identification. When possible, the behavior data (reproduction, feeding, transit) were noted as well as age categories (juvenile, immature, subadult and adult).

Specific areas were targeted to be overflown by helicopter in order to take more pictures and make observations on the evolving mangrove cover. Considering the speed of flight of the helicopter (about 100 km/h) and the altitude (50 m), it was only possible to detect the largest or most easily detectable species (such as the Javan pond-heron).



A pair of Sunda Teal in flight.

Birds: an indicator of vegetation changes

The evolution of bird biodiversity in the Mahakam Delta could correspond to a widely known effect of fragmentation: a lower species richness of habitat specialist species and a high relative abundance of generalist species (i.e. species able to live in a wide range of habitats) (Harrison and Bruna, 1999). However, there are very few mangrove forests specialists, most of the birds living in mangroves can also live in adjacent ecosystems (Nagelkerken et al., 2008). The ruddy kingfisher (*Halcyon coromanda*), or greater goldenback (*Chrysocolaptes lucidus*) recognized as mangrove specialists in Malaysia were not observed in 2013. Others are still observed such as the mangrove blue flycatcher (*Cyornis rufigastra*) or the copper-throated sunbird.

Tips

Bird inventories are mainly based on direct observations from land but also by the identification of the bird songs. For most abundant species living in large groups, aerial observations can be very usefull.

Bird observation.

A litle Egret (*Egretta garzetta*).

A Brahminy Kite.

Fish and invertebrate inventories

Sampling method

To collect fish and invertebrates demersal trawl surveys can be used (Sparre and Venema, 1992). In our case, the bottom trawl used was a conical net bag with a mouth fitted with weights on the ground-rope and floats on the head-rope. When the vessel is under way, the net is kept open by two otter boards (Sparre and Venema, 1992). GPS tracking is used to determine the length of the area swept by trawl. The swept area is the product of the length by the width of mouth of the trawl.

Identification in the laboratory

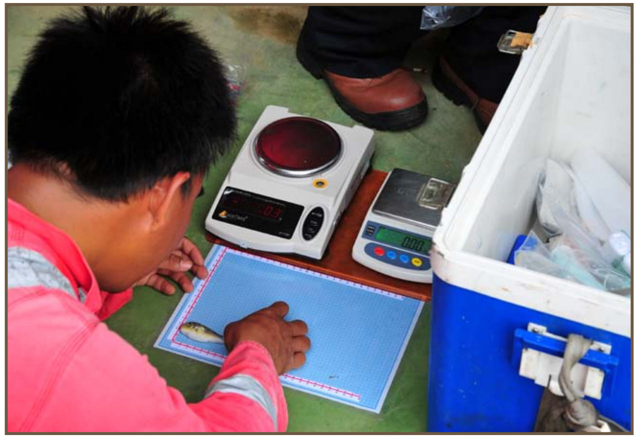
Samples should be roughly sorted by species, photographed, counted, measured, and weighed in the field. Then they need to be packaged in separate plastic bags with diluted formalin at 10%, and sent to the laboratory. Identification is then conducted by experts.

Location of sampling stations

Sampling stations should be located according to the knowledge of the area and hydrological circulation. There were three main zones: two distributary channel zones in the North and in the South, and one inter-distributary zone in the center of the delta. Sampling stations were also determined according to the different bodies of water of the delta, including marine waters and brackish waters. Last consideration, the sampling stations were located at the fishing grounds of local fishermen.

Hauling.

Recovering of the net.



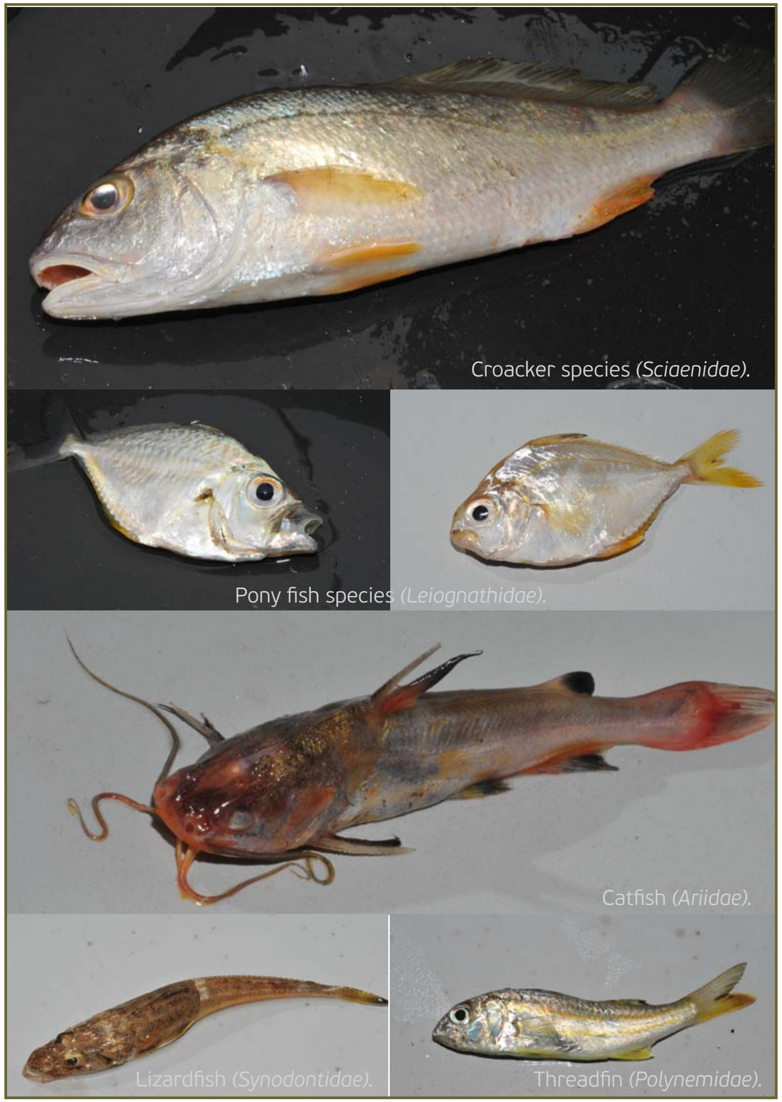
Sorting, counting, measuring and weighing samples.

Operating a CTD for water quality measurment.

Tips

Local fishing vessels should be used to ensure a good efficiency. However safety equipment as well as a geographical positioning system should be provided.

Fish species commonly found in a mangrove channel



Croacker species (*Sciaenidae*).

Pony fish species (*Leiognathidae*).

Catfish (*Ariidae*).

Lizardfish (*Synodontidae*).

Threadfin (*Polynemidae*).

Less abundant fish species

Gobies (*Gobidae*).

Ray (*Dasyatidae*).

Lionfish (*Scopionidae*).

Harpadon (*Synodontidae*).

Frogfish (*Atennariidae*).

Pufferfish (*Tetraodontidae*).

Some common invertebrates in brackish waters


Portunus sanguinolentus.


Matuta planipes.


Scylla serrata.


Penaeus monodon.


Sea cucumber.


Squid.


Sepia.

Charybdis feriatus.



Amusium pleuronectes.

Starfish.


IMPORTANCE OF VEGETATION DYNAMICS

- ✓ Changes in vegetation cover (Mahakam delta case study)
- ✓ Evidence of a widespread natural regeneration
- ✓ Understanding the natural regeneration processes of a resilient ecosystem

IMPORTANCE OF VEGETATION DYNAMICS

CHANGES IN VEGETATION COVER (MAHAKAM DELTA CASE STUDY)

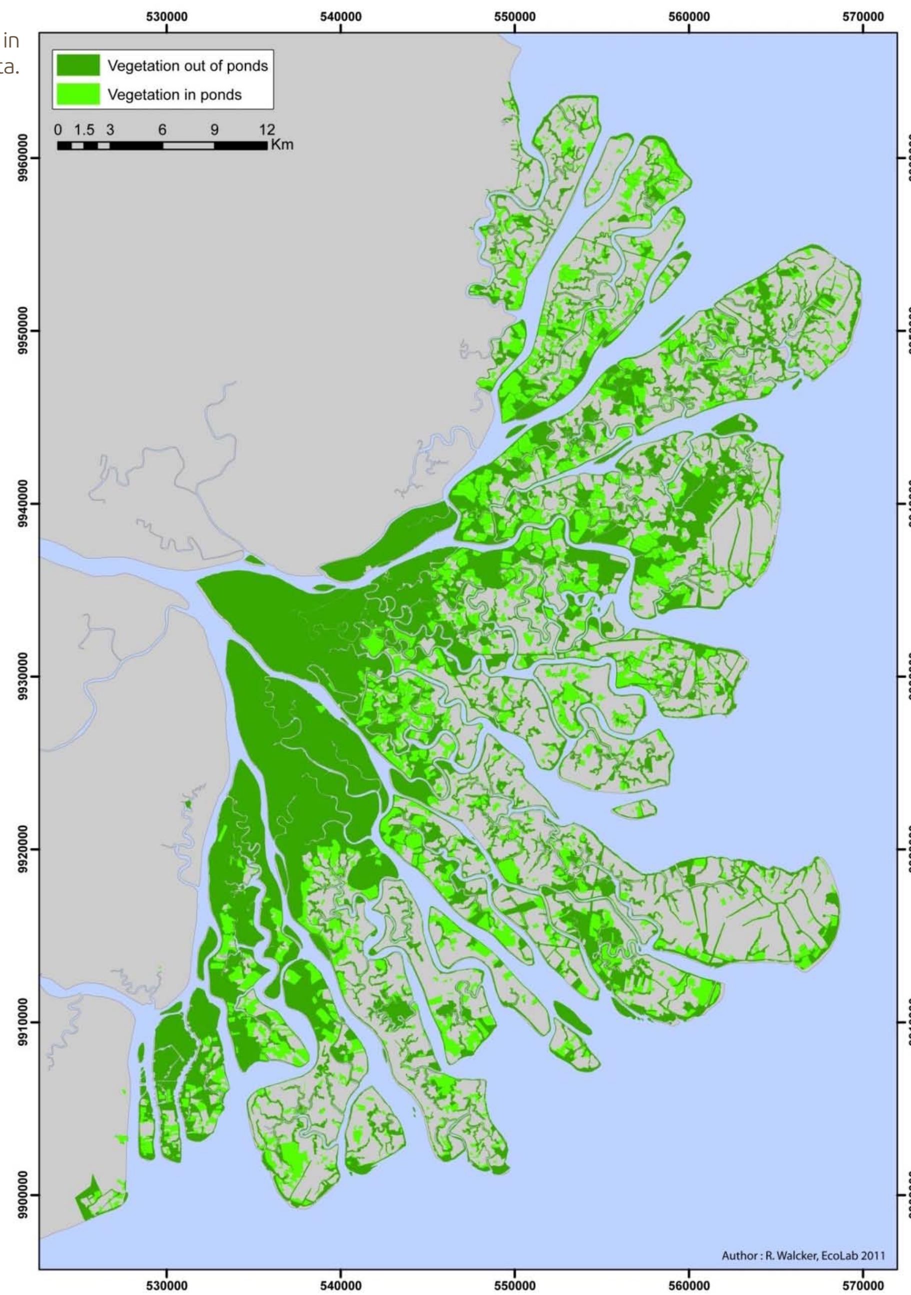
By using both optical and radar datasets, vegetation and mangrove distribution was mapped at a 1/10000 scale over the entire delta and compared through the time.

It was found that 45000 ha were occupied in 2010 either by original or secondary vegetation, while in 2001 only a 27000 ha of vegetated areas were observed. Hence, despite the localized deforestation that had been observed, many areas were subject to reforestation over time.

This reforestation concerned all types of vegetation, with the exception of the mixed freshwater forest which was probably in the process of being deforested.

The shrimp ponds were individually identified by digitizing the berms. In 2010, the total cover of shrimp ponds was 63000 ha. The vegetation cover within the ponds was about 18000 ha including 7000 ha of original vegetation (not yet deforested) and 11000 ha of secondary vegetation (newly colonized or planted areas).

Spatial distribution of vegetation in 2010 in the Mahakam Delta.



EVIDENCE OF A WIDESPREAD NATURAL REGENERATION

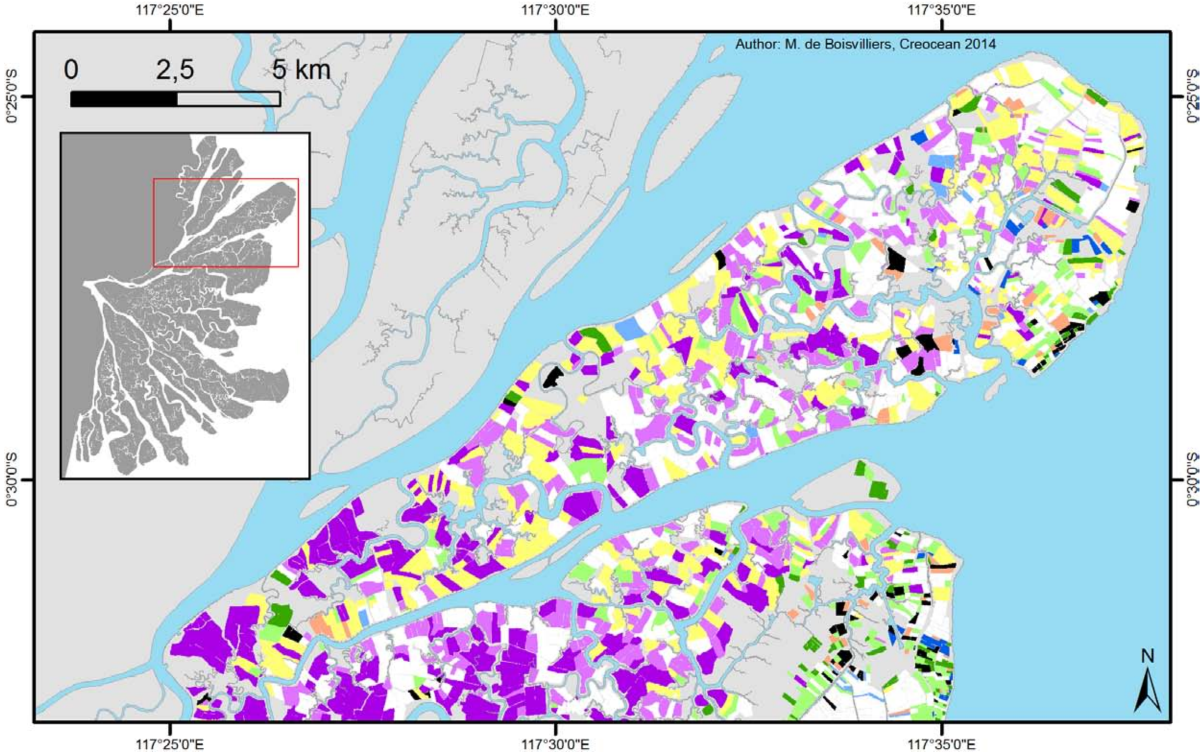
During the Mahakam delta study, we used a very high resolution aerial photography mosaic to assess the vegetation cover. Vegetation was observed in a selection of some 6649 shrimp ponds (corresponding to 32391 ha). They were described one by one, thus representing more than 50% of the 12406 shrimp ponds counted throughout the delta. Vegetation (with no distinction of the categories natural mangrove, *Nypa*, and plantation) was present in 63% of the study area.

Nypa community was the most dominant vegetation cover, as it occurred in 53% of the study area. This type of cover was mainly observed in the upper and central part of the delta. Natural mangrove (non *Nypa*) regeneration occurred in 32% of the study area. Open and closed canopy areas occured in 5% of the study area. Dispersed mangrove trees occurred in 27% of the study area. Mangrove plantations done by Total E&P Indonésie and local villagers covered less than 3% of the study area, and represented about 12 million living trees.

Tips

Regular aerial surveys are very useful to assess vegetation trends using chronological photographic sequences.

Example of detailed vegetation cartography



Spatial distribution of the main vegetation communities within aquaculture ponds, in the Mahakam Delta

- Mangrove dominated
- Mangrove only - dispersed trees
- *Nypa* dominated
- *Nypa* only - dispersed trees
- *Nypa* and natural mangrove
- Plantation dominated
- Plantation only - dispersed trees
- Mix planted and natural communities
- No vegetation
- Not classified

UNDERSTANDING THE NATURAL REGENERATION PROCESSES OF A RESILIENT ECOSYSTEM

A green belt (trees) are protecting the areas against sea generated erosion. Vegetation recolonization is then active in this area.

Natural regeneration can be a rapid process in terms of covered areas

The qualitative analysis of chronological sequences of helicopter-based pictures revealed that some areas without human influence with apparently no vegetation could become covered with mangroves trees (from about 60% up to 100% of the area) in a 3-year period provided that natural supply of seeds and water pathways exist.

The speed of regeneration cannot be estimated since the date of pond abandonment is unknown. Estimates of regeneration are based on the assumption that areas were abandoned "before 2011" as observed in helicopter-based photographs taken in 2011.

Natural regeneration is conditioned by hydrological processes

In abandoned areas, breaches in dykes appeared to be essential for mangrove regeneration. The establishment and development of mangroves depends on flooding depth, duration, and frequency (Lewis, 2005). Ponds are designed to control these parameters. Opening the dykes allows the water to flow in and out of the pond.

Moreover, most mangrove seeds are waterborne and the seed supply is likely to be higher if the water can enter a pond.

Places exposed to strong hydrodynamics may not be favorable to natural mangrove regeneration

Movements of water can be strong near the shore and can cause the removal or seeds and young seedlings. This hypothesis is supported by the results of Balke et al. (2011), who showed that hydrodynamics conditioned the establishment of *Avicennia* seedlings.

Moreover it was observed that some of the non-colonized areas on the seaward shoreline were subject to erosion. The sediment removal may prevent the development of seedlings. Balke et al. (2011) identified this as a limiting factor for the establishment of *Avicennia*.

Tips

Flyovers at low tide generate more efficient observations.

Tips

- ✓ An area sheltered from strong water movement is probably more favorable to the natural establihment of vegetation.
- ✓ In exposed areas, planting mangroves is probably the best option.
- ✓ A physical protection of the shoreline could be beneficial to limit erosion.

The ecological succession process

A forest is a dynamic system: the structure and the species composition evolve over time. This consideration is essential to study regeneration, and consequently for restoration planning. Indeed, the secondary colonization may start with one or a small number of species in very high densities. Following this, a few new species colonize the stand and then may or may not replace the pioneer species. However, as the trees grow, competition for resources (such as light, space, and nutrients) increases and the weakest individuals may die, thereby decreasing density.

Evolution of mangrove natural regeneration in an abandoned shrimp pond in the Mahakam delta. The colonization seems to “spread” from the opening (tip of the arrow) showing that the motor of the colonization is the dissemination of the seeds.

Absence of mangrove regeneration at an exposed site on the seaward shoreline in the Mahakam Delta. (evidence of vegetation losses).

RECOMMENDATIONS WHEN OPERATING IN OR NEAR A MANGROVE ECOSYSTEM

- ✓ Assess biodiversity with environmental baseline studies
- ✓ Monitor biodiversity over time
- ✓ Protect biodiversity by implementing the mitigation hierarchy

RECOMMENDATIONS WHEN OPERATING IN OR NEAR A MANGROVE ECOSYSTEM

Recommendations for a good environmental management of a mangrove ecosystem area are usually included in a Biodiversity Action Plan (BAP) and often result from the environmental impact assessment study. Some parts in this section refer to the mangrove specificity in the Mahakam delta context.

There is an essential need to make sure that methods used for the baseline studies are reproducible and precisely described, in order to pursue monitoring efforts as per GS EP ENV 111 and per GS EP ENV 112 recommendations.

ASSESS BIODIVERSITY WITH ENVIRONMENTAL BASELINE STUDIES

Since vegetation is a structuring element of a mangrove ecosystem, vegetation cover analysis should be given high priority. Vegetation communities can be precisely mapped with very high resolution imagery.

Forest inventories (i.e. measuring and identifying trees in a specific plot) are essential to assess the composition and physiognomy of the forest and to complement photo-interpretation. Assessing the structure of the original vegetation communities will be useful for restoration planning in case of degradation. Monitoring plots should be implemented at the onset of the inventories.

The identification of hydrological and tidal characteristics will also be beneficial for preservation and restoration planning, since mangrove establishment and growth are strongly dependent of these factors.

Tips

Baseline studies are the main tool to assess biodiversity. They should be performed at the earliest stage of any oil and gas activity, and should cover a wide area.

The baseline study

The first requisite is to highlight the baseline characteristics of the mangrove ecosystem at the studied area and to identify any potential human-induced threats in order to prevent them. A baseline study is essential in that it provides a reference status against which restoration can be planned and monitored. There is an essential need to make sure that methods used for the baseline studies are reproducible and precisely described, in order to pursue monitoring efforts.

Aerial imagery: first step of data acquisition

High definition aerial imagery can be acquired with satellite as in the Mahakam Delta, and with an aerial survey with an embarked camera. The advantage of the acquiring images from an equipped plane or helicopter is the near absence of clouds. As mangrove regions are often cloudy, it may be difficult to find cloud-free satellite images for a vast study area such as the Mahakam Delta.
The use of an infrared camera for the aerial data acquisition would be very useful considering that it may allow observers to identify some of the mangrove tree genera.

Share findings with the scientific community

The baseline and monitoring studies should be carried out in partnership with research centers, in order to contribute to the scientific knowledge and to add value to the technical biodiversity report. Results published in peer-reviewed journals are more widely recognized since they are validated by independent scientific specialists.

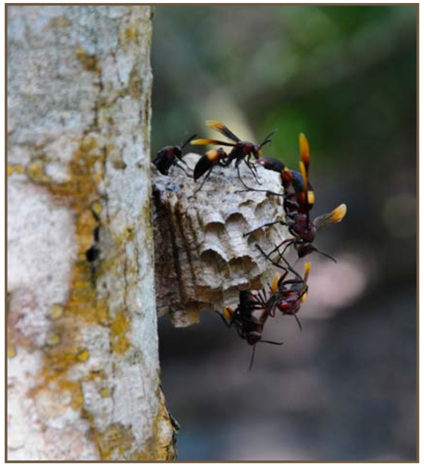
Researchers at work.

Health, Safety and Environment aspects for a field survey

Conducting mangrove forest studies involves entering the mangrove, an environment which is rather hot, wet, muddy and often swarming with mosquitoes. Additionally, working in the mangrove sometimes requires progressing through thigh-high mud or water. Therefore clothing, equipment, and behavior need to be adapted. Here are safety measures recommended for a field survey in mangrove forests.

✓ Field work needs to be performed during daylight hours only, when possible at low tide, and postponed in case of bad weather conditions.

✓ Proper PPE, including cotton clothing with long sleeves and trousers and/or coveralls, should be used during work to avoid scratches and prevent mosquito bites.



✓ Field participants need to be physically and psychologically fit.

✓ A first aid kit was available and communication was established with the boat team by walkie-talkie.

Tips

Early detection of dangerous animals by using drones equipped with a camera can prevent exposure of the field crew to probable hazards.

✓ Prior to entering the mangrove, the area needs deemed free of any potential danger, such as the presence of crocodiles. Seek the participation of a animal behaviour expert. While in the forest there is a need for constant vigilance for dangers associated with wildlife such as stinging caterpillars, bees, wasps, ants, snakes and crocodiles.

MONITOR BIODIVERSITY DURING THE COURSE OF AN OIL AND GAS PROJECT

Monitor the environment

The evolution of the vegetation extent (structuring element) can be monitored through the comparison of satellite or aerial imagery over time. It is essential to compare images that have the same spatial resolution, and to map the vegetation at the same scale.

Monitoring the evolution of vegetation structure and diversity through forest inventories is necessary in order to qualify the natural evolution of the forest, and to maintain it as a reference for potential restoration activities. The number of monitoring plots and frequency of monitoring will depend on the site. The monitoring plan should be established with support from local and international experts.

To monitor fauna indicators, the same protocols as those used for baseline studies should be applied and they should be carried out as close as possible to the baseline sampling locations or observation points. Note that bird inventories will need to be conducted during the same month as the baseline to avoid biases associated with migrating species.

The monitoring frequency should be adapted to the type of fauna and events of significant environmental changes.

All results should be incorporated into a dedicated Biodiversity Action Plan (BAP).

Monitor human activity

Migrants may be attracted to the settlement of an oil and gas exploration and production activity. Since population increases may lead to environmental degradation, the monitoring of human activity is relevant to the sustainable management of the resource. Human activity can be monitored using simple indicators such as:

- ✓ Main economic activity
- ✓ Location of aquaculture and agriculture fields
- ✓ Number of fishermen, locations of fishing grounds

Environmental sensitization programs may also contribute to preventing excessive impacts.

Forest inventories.

Traditional trawling activity is tolerated in the Mahakam delta.

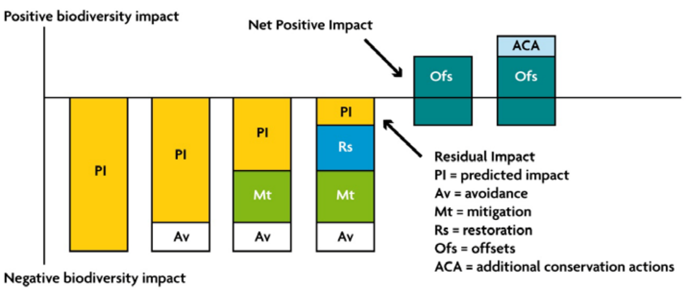
Shrimps are fished and carried to the refrigeration compagny upstream.

PROTECT BIODIVERSITY BY IMPLEMENTING THE MITIGATION HIERARCHY

Mitigation hierarchy

The mitigation policy implementation (i.e. avoidance, reduction, restoration and offsetting measures) for coastal and marine development projects is designed to ensure the respect of the “no net loss” principle and preferably a net gain in biodiversity. The intent is to protect species composition, habitat structure, ecosystem function, and the people’s use and cultural values associated with biodiversity.

Most of the effort must be first to avoid and minimize the impact of a development project and then to restore biodiversity on-site. Biodiversity offsets should only be applied as a ‘last resort’ to the residual adverse impacts of a project.



Preserve the natural hydrology

To reduce the impacts of Exploration and Production activities on mangrove areas, one of the major considerations is to maintain the natural hydrology, since mangroves strongly depend on flooding periods and frequency to settle and grow. The disturbance of hydrology may lead to rapid plant mortality, and prevent natural colonization, while cleared areas can be naturally recolonized if hydrology is preserved. Maintaining preserved forest areas is essential to maintain a large enough supply of seeds. A newly colonized stand may not furnish the same ecological function (e.g. habitat) as a mature forest.

Operations close to mangroves (new trench ROW full of water at high tide).

Protect important species

Protective measures for important species should be put in place such as exclusion areas for activities, specific management plans to preserve habitats, and preservation of connectivity.

Great egret.

SPECIAL FOCUS ON DEGRADED AREA RESTORATION

- ✓ From natural recolonization to replanting operations
- ✓ Long-term regeneration monitoring and protection
- ✓ Involvment of the local populations in the entire restoration project

Restoring a degraded area is part of the mitigation hierarchy described in the previous section. However, as it plays a very important role in mangrove managment, we have dedicated this section to restoration.

FROM NATURAL RECOLONIZATION TO REPLANTING OPERATIONS

Step 1: Understand the ecology of mangrove species potentially impacted by operations (dredging, construction, pipelaying, etc.)

The natural settlement of a mangrove species depends on two conditions: propagules reaching a given the site (propagule availability), and propagules germinating and growing at the same location (ability to settle). Consequently, to favor the natural regeneration of mangroves at a given location, it is crucial to determine if the propagules are able to reach this location and to determine the favorable conditions for the establishment of each species.

To assess propagule availability, essential activities are :

- ✓ Identification of sources of propagules (nearby mother trees)
- ✓ Inventory of propagule stranded in the vicinity of the area in a period of 3-12 months before expected recolonization time

For example, in the Mahakam Delta case, there are likely mother trees in the vicinity of most areas, especially the pioneer type species such as *Avicennia* and *Sonneratia*. Therefore, propagule availability, in most cases is not an issue in ecological mangrove restoration. Naturally, each species has its own strategy to settle at a new site. The ability to settle depends on environmental conditions including flooding depth, duration, frequency of tidal inundation, and soil salinity (Nitto et al., 2013).

Some fruits like these *Sonneratia* fruits can be eaten by monkeys. The very small seeds are then disseminated with the monkey's feces.

On the left side of the channel bank, *Rhizophora* roots are close to the low level of the water while on the right side *Avicennia* roots are in the upper level.

Natural recruitment of *Avicennia* trees. Most of these young seedlings will die before becoming adults.

Step 2: Understand the natural hydrology of the site to be restored: flooding duration, height and frequency.

Once favorable conditions for species establishment are assessed, it is necessary to assess what the natural conditions of the site are, especially hydrology. Main hydrological features that affect natural recolonization are: (1) duration of tidal inundation, (2) height of water level, and (3) frequency of inundation (Lewis, 2005).

For example, in the Mahakam Delta tidal pattern is mixed semi-diurnal with different high and low tide elevation around 2 meters (Widyastuti et al., 2008). At least three inundation types are encountered in the Mahakam mangrove forest.

1. Fully inundated area

These areas are rarely occupied by mangrove trees. All the mangrove trees need at least a small period of aerial exposure to breath.

2. Partly inundated

This is the most common type of inundation in Mahakam Delta mangroves. Various species are able to grow at sites where duration and frequency of tidal inundation allow for sufficient daily aerial exposure, especially if the water movement is relatively calm.

At low tide it is obvious that mangroves do not colonize lower tide levels. Young recruits colonize the sand banks only when they reach a suitable level.

Unfortunately, studies about the survivability of mangroves (trees and saplings) mostly refer to frequency and duration of inundation on an annual basis, not on a daily basis. However the authors found that disruption of hydrological movement could kill mangroves, especially *Avicennia*, within a few days/weeks.

3. Not inundated

Some areas of the Mahakam Delta such as riverbanks, pond dykes, and settlements are typically not flooded by tidal water. These areas are normally occupied by species that are also found inland, far from the coast. These species are not considered as true mangroves, but as mangrove associates.

Restoration of these sites is important to maintain the integrity of ecosystems, including providing corridors for wildlife movements, maintaining soil quality, and providing a source of construction materials, food, and medicine for communities. As the site is not inundated by tidal water, the site should likely be rehabilitated manually through planting activities.

Rhizophora roots along a tidal channel.

Avicennia pneumatophores and some other species must be exposed to air during a few hours every day.

Disruption of natural water exchange caused the mortality of trees (*Avicennia* and *Sonneratia*) located inside ponds.

Step 3: Identify the obstacles to natural regeneration

Look for disturbance of natural hydrology

The disturbance of environmental conditions, especially hydrological conditions, may prevent natural colonization by mangrove species, more than the propagule availability. Comparing the initial and the current situation of the restoration site is essential to determine potential obstructions to natural revegetation.

For example, the Mahakam Delta mangroves have been heavily impacted due to development of aquaculture ponds. The main physical constraints that were identified was the pond structure, especially the dykes and peripheral ditch which disturb tidal flooding frequency and duration. The central part of the pond may also have been leveled during its construction which modifies water height.

Secondary factors may be biological, such as heavy attack of crabs, barnacles, and competition with shrubs including acanthus and derris. In some cases, the lack of natural recolonization was seemingly caused by the loss of topsoil due to erosion and left only peat layers that were not appropriate for any type of mangrove growth. This was probably the worst type of landscape change, as the damage of mangroves in this case is likely to be irreversible.

In case of excessive erosion and low sediment thickness, consider re-establishing the original soil level and protect against erosion.

Soil characteristics can also put a brake on the recolonisation process (such as excessive acidity due to acid sulfate soils) but in this case no action is possible to improve the situation.

Along the seaward shoreline, excessive wave energy and erosion may also be obstacles to regeneration.

Previous natural flow can be identified from satellite imagery. The red squares show locations where artificial barriers can be opened to enable the natural flow of tidal waters.

Step 4: Design the restoration program

Understanding soil pedology and its characteristics is important as soil supports the establishment of mangrove plant species. Measuring soil pH along a profile enables to ascertain the soil conditions.

Depending on the soil structure and composition, when pyrite is exposed to oxygen, soil pH drastically drops (pH<3) and vegetation cannot grow until soil pH returns to background level. Any attempts to restore the impacted area will fail. It is then necessary to reinstate the soil profile as it was before the activities.

Increase soil thickness to restore water height during tidal flooding

Increasing soil thickness is necessary in the areas where substrate/ground level is very low, possibly due to heavy erosion to a point where small propagules find it difficult to settle. This situation can be found in abandoned ponds with relatively deep and flat substrates causing the duration of inundation in the area to exceed 30% of the time in a day. Large propagules such as *Rhizophora*, *Ceriops*, and *Bruguiera* will likely settle in these areas. However, if this was not the case, encouraging other species to settle by increasing the soil thickness may be needed to help small trees to survive during the high tide. In other cases, the raised substrate will have to endure a longer aerial exposure and will develop mud cracks that will trap small propagules.

Remove the obstacles identified in **step 3**, and the vegetation should come back naturally.

Local hydrology may be the most important issue in ecological mangrove restoration. Therefore, natural restoration is sometimes called, "hydrological restoration". Indeed, the natural flow of saline water into the restoration site is precondition to allow propagules to establish and maintain their normal growth. Therefore, restoring hydrology to mimic natural flow is a must, either to encourage natural mangrove recolonization or in an attempt to rehabilitate the area through replanting activities.

Selecting specific locations for the removal of physical obstacles such as dykes is a challenging task and there is no simple method. Di Nitto et al. (2013) suggest considering placing the water inflow opening based on the location of sources of propagules combined with suitable hydrodynamic flows.

In most cases, small natural flows of water (creeks, channels, tributaries) that are disrupted by the development of shrimp farm and dikes, can still be traced through aerial photographs or satellite images and could be restored to their initial conditions.

The other advantage in restoring hydrology is the access for aquatic biota (fish, crabs, shrimp) and other wildlife animals to move in and out of the restoration sites. This will avoid them from being stranded in the restoration area as tidal water may only flood the site for a few hours a day (Lewis et Gilmore, 2007).

Permeable dam to reduce wave energy

A permeable dam is a type of barrier used to reduce the energy of waves or tidal current and to increase substrate accretion behind the dam. Water and sediments will be able to flow through the porous barrier thanks to the energy of waves or current. As wave and tidal current energy is relatively low after passing the dam, most of the sediment will settled behind the dam. The calmer conditions and continuous supply of sediments will gradually provide suitable conditions for mangrove propagules to naturally settle and grow.

When the shrimp pond doors are not maintained, mud dykes are quickly destroyed. Water can then easily penetrate the pond and the tidal cycle is restored.

Step 5: Consider plantation in case of adverse conditions to natural recolonization

Manual planting of propagules to rehabilitate mangrove ecosystems should only be undertaken once the appropriate hydrological and environmental conditions have been restored, and only in the rare places where the natural seedlings supply is not sufficient to colonize a given area.

In the Mahakam Delta, plantations were successful in terms of survival rate (> 90%); however they appeared to be limited in terms of structure and biodiversity. The following are options for the improvement of planting techniques.

When the propagule supply is limited at the restoration site, seeds of different species can be collected from a nearby forest and the tide can be used to broadcast the seeds into the restoration site, so they can "float and find their own suitable location for germination" (MAP-Indonesia, 2006).

If seedlings planting is necessary, it is better to favor random distribution than planting rows and to make sure that they are spaced by at least 2 meters to reduce competition.

Note that for both tidal-planting and manual planting, the planted species need to be selected according to their own ecology (assessed in step one) and to the characteristics of sites (assessed in step two). Additionally, there is an essential need to plant more than one or two species to favor biodiversity.

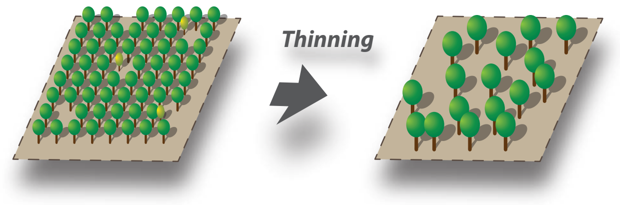
Restoring biodiversity in dense mangrove plantations through thinning activities

When dense planting activities have already been conducted, it would be interesting to consider thinning activities. Thinning consists of reducing the density by cutting some trees in order to reduce competition for light and nutrients. The gaps created in the canopy may facilitate the natural colonization by other species and increase biodiversity (Bosire, 2006).

Thinning activities should be directed at the stunted trees, and the smallest stems of the multi-stemmed trees. As a result, a space of 2 meters between trees should substantially reduce competition for resources.

Planting or not planting

Given that mangroves provide many ecosystem services, the restoration of the degraded ecosystems is essential. Replanting is not a new technique as it is widely implemented by governments, private sectors, NGOs and communities, and it can yield good survival rates. However, the findings of this study revealed that the natural recovery of mangrove forests exceeds by far man-made replanting activities. Additionally, plantations do not result in genuine forests in terms of structure and biodiversity. Consequently, it is important to introduce an integrated method to encourage natural regeneration, which is known as ecological mangrove restoration or EMR (Lewis, 2005).



Thinning in dense a plantation should reduce the competition between the trees for light and nutrients.

Mangrove and soil conditions monitoring.

Structure and composition of plantations

Forest inventories revealed that plantations exhibited a strong survival rate and growth.

Rhizophora is the most used genus for planting in the Mahakam Delta. Two species are used: *Rhizophora apiculata* and *Rhizophora mucronata*, mixed or not. The use of *R. mucronata* is of concern because it does not naturally occur in the Mahakam Delta. In pre-adult and adult plantations, the planted species tend to dominate in terms of density and basal area. However, the original vegetation map shows more than just *Rhizophora*-dominated communities.

Additionally, density in adult plantations is much higher than in adult natural stands. Yet, a too high density increases the competition between trees for surrounding resources. Trees may not have access to enough light or nutrients and their structure and function are likely to be disturbed.

Regarding density, and species composition, *Rhizophora* plantations may more closely resemble a transformation into a new managed forest rather than a restoration to an original state. Moreover, the nearly mono-specific status of plantations is risky for their sustainability, since trees from same species may require the same resources and be affected by the same diseases.

Ceriops fruits.

Rhizophora planted propagules are here mixed with *Nypa* and *Avicennia* seedlings. This diversity is a good option.

Avicennia seeds.

Tips

Recommendations for planting

✓ Use the tide to disperse seedlings collected in natural stands.

✓ determine as early as possible period(s) of seeds availability and maturity for collection and plantation.

✓ Plant various species (according to step 1).

✓ Space the seedlings by 4 meters.

✓ Favor random planting.

Tips

Rhizophora sp. is the most commonly planted species because its propagules are very easy to plant. However, more suitable species can be used. For most species, consider harvesting and nurseries.

LONG-TERM MONITORING AND PROTECTION OF RESTORED AREAS

Monitoring the progress of restoration sites is a crucial activity. Ideally, monitoring should cover all aspects of ecosystems: biology (flora and fauna); physicochemistry (hydrology, water quality); and socioeconomics (livelihoods, awareness, ecosystem services, conflict).

As the comprehensive monitoring of biophysical and socio-economic conditions of the restoration areas is beyond the objective of this REX, we focused on the biological monitoring hereafter.

The objective of monitoring is to assess the effectiveness of restoration activities. Mangrove forests are dynamic and their structure and composition evolve over time. This also will contribute to the quantification of the colonization speed, which will be useful in adjusting the restoration programs.

The main activity is the trees monitoring, which includes:

1. Photographing the site to provide general condition information, **2.** Identifying the species, **3.** Counting the number of individuals for each species, **4.** Measuring DBH and the height, **5.** Recording occurrence of associated species.

Photography of each species.

Four main phases:

Phase 1- During the first year following the hydrological restoration, frequent monitoring is recommended at a frequency of 3, 6 and 12 months. This early inventory is crucial to identify if the hydrological restoration is sufficient. If there is no seedlings establishment and if many mother trees have been identified in the site vicinity, there may still be an environmental obstacle which has to be identified and removed. If there is no seedlings establishment and/or no mother trees nearby, planting may need to be the next step.

Phase 2- If a sufficient density of young trees and seedlings has been recorded at the one year monitoring, it is then possible to monitor at two years and at three years after the hydrological restoration.

Phase 3- Regenerating forest stands may be more diverse only after 5 years. To confirm this trend, a forest inventory 5 years after the hydrological restoration is required. Since the growth rate of mangrove trees decreases as the trees age, the frequency of monitoring efforts can be reduced 5 years after the restoration. Forest inventories can be conducted 10 years, 15 years and 20 years after the hydrological restoration.

Phase 4- According to the scientific community, mangrove forests can undergo natural succession within 50 years. This study recommends monitoring every decade starting 20 years following the restoration and up to 50 years post restoration, knowing that mangrove trees can live more than 100 years.

Forest inventories.

Tips

Learning lessons from mistakes:

In mangrove restoration projects, it is essential to record and explain failures in order to prevent repeated mistakes and improve mangrove restoration methods.

INVOLVE THE LOCAL POPULATION IN THE ENTIRE RESTORATION PROJECT

It is essential to involve the communities which live nearby mangrove areas in all steps of the restoration and not only during planting. Community members could contribute to most of the field activities: inventorying the mother trees and seed availability, assessing hydrological conditions, breaching dykes, and monitoring natural regeneration. Moreover local knowledge of the site history will be precious to obtain a more comprehensive insight on the original conditions.

Regarding the long-term impact of the Total plantation program on local environmental awareness, the integration of local communities in the Ecological Mangrove Restoration will have a positive impact on planted and naturally-recovering areas.

Benefits of mangrove planting on local community environmental awareness

Interviews with local community members of the Mahakam Delta revealed that manual planting activities have a positive impact on the community's perception of mangroves.

Involving them in the planting activities increased their awareness of the importance of mangrove ecosystems. They also tend to protect plantations rather than naturally colonized areas. Moreover, the homogeneous composition and the structure of straight rows are perceived as evidence that the site is not abandoned and thus will avoid land claims and occupation by community members.

Despite of its ecological limitation, manual replanting may still be considered as part of the environmental sensitization program, but not as the main focus of the restoration program.

Involvement of local communities in the whole restoration process and not only during planting is essential in having local inhabitants value in plantations but also in self-regenerating areas.

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